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كلمة العدد

يسرُّنا في مجلة قورينا العلمية (QSJ) – إحدى منصات النشر العلمي بجامعة قورينا الدولية – أن نُصدر هذا العدد الخاص، تزامناً مع انعقاد "المؤتمر الأول للهندسة الطبية الحيوية – بنغازي" (FBBEC 2025) ، الذي تنظمه كلية التقنية الطبية – بنغازي خلال الفترة: (6-8) ديسمبر 2025 ، تحت شعار: "نحو تكامل هندسي–طبي لخدمة الإنسان"
.(Engineering Health for a Better Life)

يأتي هذا العدد ليجسد رؤية المجلة في دعم البحث العلمي الرصين، وتعزيز الشراكة الأكاديمية بين المؤسسات العلمية، لا سيما في المجالات البينية كالهندسة الطبية الحيوية التي تمثل جسراً استراتيجياً بين العلوم الهندسية والطبية. وقد حرصت المجلة على رعاية أبحاث المؤتمر ونشرها، انطلاقاً من دورها الريادي في توفير منصة علمية محكمة تجمع الباحثين والأكاديميين والمختصين، وتسهم في إثراء المحتوى العلمي العربي والدولي.

ويأتي انعقاد هذا المؤتمر في توقيت مهم، يتزايد فيه الاهتمام العالمي بتوظيف التكنولوجيا والذكاء الاصطناعي في تطوير الرعاية الصحية، وتحسين دقة التشخيص، ورفع كفاءة الأجهزة الطبية، وضمان سلامة المرضى. كما أن المؤتمر يُعنى بمناقشة قضايا محورية، أبرزها: الابتكار في الهندسة الطبية، تقنيات التشخيص الحديثة، السلامة الطبية وإدارة المخاطر، ودور التعليم التقني في النهوض بالقطاع الصحي.

وإيماناً من مجلة قورينا العلمية بأهمية التكامل بين المؤسسات الأكاديمية والبحثية، فقد ارتأت أن تخصص هذا العدد لنشر الأبحاث المشاركة في المؤتمر، بعد تحكيمها علمياً واستيفائها لمعايير النشر المعتمدة. ويأتي ذلك في سياق جهود المجلة لدعم الباحثين وطلبة الدراسات العليا، وتحفيز الدراسات التطبيقية التي تقدم حلولاً مبتكرة تلبي احتياجات القطاع الطبي محلياً وإقليمياً.

ولا يسعنا في هذا المقام إلا أن نتقدم بالشكر والتقدير للجنة العلمية للمؤتمر، وجميع الباحثين والمحكمين والشركاء الذين ساهموا في إخراج هذا العدد. كما نخص بالشكر كلية التقنية الطبية – بنغازي على استضافتها ورعايتها لهذا الحدث العلمي المتميز، سائلين المولى عز وجل أن يحقق هذا العدد الأهداف المرجوة، وأن يكون إضافة نوعية للمكتبة العلمية، وخطوة مباركة على طريق التميز والابتكار.

رئيس تحرير مجلة قورينا العلمية (QSJ)

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نبذة عن المؤتمر الأول للهندسة الطبية الحيوية – بنغازي (FBBEC 2025)

انعقد **المؤتمر الأول للهندسة الطبية الحيوية – بنغازي (FBBEC 2025)** خلال الفترة **6–8 ديسمبر 2025** في مدينة **بنغازي، ليبيا**، بتنظيم من **كلية التقنية الطبية – بنغازي.** و أُقيم المؤتمر تحت شعار" :نحو تكامل هندسي–طبي لخدمة الإنسان(Engineering Health for a Better Life) "، ليشكل منصة علمية رائدة تجمع الأكاديميين، الباحثين، الأطباء، المهندسين، والمختصين في المجال الطبي والهندسي.

رؤية المؤتمر: أن يكون منصة رائدة محليًا وإقليميًا في مجالات الهندسة الطبية والتقنيات المصاحبة، تسعى لتعزيز البحث والابتكار ودعم التكامل بين التخصصات بما يسهم في تطوير الرعاية الصحية وتحقيق التنمية المستدامة وجودة الحياة.

رسالة المؤتمر: تهدف رسالة المؤتمر إلى تفعيل الدور التكاملي بين العلوم الهندسية والطبية من خلال تشجيع البحوث التطبيقية، وتبادل الخبرات بين المختصين، وعرض أحدث الابتكارات في مجالات الأجهزة الطبية والتقنيات الصحية. كما يسعى المؤتمر إلى تقديم حلول هندسية مبتكرة للتحديات الصحية المحلية والعالمية، ودعم التعليم والتدريب في التخصصات البينية، والمساهمة في رفع جودة الرعاية الصحية وسلامة المرضى.

أهداف المؤتمر:

- تعزيز التكامل بين المجالين الطبي والهندسي عبر البحوث التطبيقية والتقنيات الحديثة.
- دعم البحث العلمي وتشجيع الدراسات التطبيقية في مجالات الأجهزة الطبية والتقنيات الصحية.
- مناقشة التحديات الصحية العالمية والمحلية وتقديم حلول هندسية مبتكرة.
- المساهمة في تطوير التعليم الطبي والهندسي بما يخدم التنمية المستدامة وجودة الحياة.
- تعزيز الجودة والسلامة في الرعاية الصحية.

محاور المؤتمر:

- الأجهزة الطبية وتقنيات التشخيص الحديثة.
- الهندسة الحيوية والتقنيات الترميمية.
- الذكاء الاصطناعي وتكنولوجيا المعلومات في الرعاية الصحية.
- السلامة الطبية وإدارة المخاطر.
- الابتكار وريادة الأعمال .

- التعليم والتدريب ودور التعليم التقني العالي في تطوير الرعاية الصحية.

الفئة المستهدفة:

- أعضاء هيئة التدريس بالكليات الطبية والهندسية.
- المهندسون والأطباء في المستشفيات والمراكز الصحية.
- الباحثون وطلاب الدراسات العليا.
- الشركات والمؤسسات العامة في مجال الأجهزة الطبية.
- المهتمون بالابتكارات والتقنيات الطبية الحديثة.

تواريخ مهمة:

- إعلان المؤتمر: 15 سبتمبر 2025م.
- آخر موعد لتقديم الملخصات: 10 أكتوبر 2025م.
- إشعار بقبول الملخصات: 20 أكتوبر 2025م.
- آخر موعد لتسليم الأوراق كاملة: 10 نوفمبر 2025م.
- إعلان نتائج التحكيم النهائي: 20 نوفمبر 2025م.
- آخر موعد لتسليم عروض الباوربوينت: 30 نوفمبر 2025م.
- موعد انعقاد المؤتمر: 6–8 ديسمبر 2025م – بنغازي، ليبيا.

النشر في مجلة قورينا العلمية:

في إطار التعاون الأكاديمي، تشارك **جامعة قورينا الدولية** بكونها راعياً علمياً للمؤتمر عبر **مجلة قورينا العلمية (QSJ)** ، حيث سيتم نشر الأبحاث المشاركة والمستوفية لمعايير التحكيم في عدد خاص من المجلة، تأكيداً على دعم البحث العلمي وتعزيز الشراكات بين المؤسسات الأكاديمية. لمزيد من المعلومات حول شروط النشر، يرجى زيارة الموقع الإلكتروني للمجلة. https://qsj.qiu.edu.ly

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يد رابتور الاصطناعية: تصميم وتطوير طرف علوي ميكانيكي منخفض التكلفة

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Abstract:
This study presents the design and testing of a low-cost, 3D-printed prosthetic hand based on the Raptor Hand model developed by the e-NABLE community. The goal was to create a functional upper-limb prosthesis using accessible materials and fabrication methods. We utilized CAD software to adapt the open-source Raptor design for a pediatric user, printed the components on an FDM 3D printer using PLA filament, and assembled them with conventional cables and springs to enable movement by wrist flexion. The hand's performance was evaluated through simple tasks and mechanical tests, measuring finger range-of-motion and grip strength. Results showed that the prototype achieved approximately 90° finger closure and demonstrated a grip force on the order of 10–15 N, which is comparable to values reported for similar 3D-printed designs. These results, while below those of high-end commercial prostheses, were sufficient for basic gripping tasks. Notable observations included slight loosening of elastic components after repeated use, echoing issues noted in the literature (Cuellar *et al.*, 2021). Overall, the study confirms the viability of a community-driven prosthetic solution: the printed Raptor Hand can perform basic functions effectively, offering a promising low-cost option. This work highlights the importance of material selection and design refinements for future improvements of open-source prostheses.

Keywords: 3D Printing; Assistive Technology; Biomedical Engineering; e-NABLE; Prosthetic Hands.

ملخص البحث:

يسعى هذا البحث إلى إنشاء وتطبيق طرف اصطناعي علوي بتكلفة منخفضة مستند على نموذج اليد الرابتور الذي ابتكرته مجموعة e-NABLE التطوعية. اعتمدنا على تقنية الطباعة ثلاثية الأبعاد (FDM) لإنتاج مكونات اليد باستخدام مادة PLA، ثم قمنا بتجميعها مع نظام شد تقليدي يعتمد على الأسلاك والزنبركات. تضمنت الطريقة استخدام نماذج ثلاثية الأبعاد مفتوحة المصدر، مع قياس الأداء الميكانيكي للنموذج المطبوع (اختبار قوة القبضة، زاوية الحركة). أظهرت النتائج أن النموذج المعروف برابتور يمكنه إغلاق الأصابع والإمساك بالأشياء البسيطة بأداء مقبول ضمن الحدود المتوقعة، حيث كان متوسط قوة القبضة حوالي 10 إلى 15 نيوتن، وهي أرقام مشابهة لتصاميم سابقة (Cuellar *et al.*, 2021). كما أظهرت بعض العيوب مثل تآكل الأربطة السلكية مع الاستخدام المستمر. بناءً على ذلك، يمكن اعتبار اليد الاصطناعية التي تم تطويرها خيارًا فعّالًا لتوفير أطراف صناعية للأطفال ذوي الاحتياجات الخاصة، مع ضرورة اتباع التوصيات لتحسين المواد وعناصر الشد.

الكلمات المفتاحية: الأطراف الاصطناعية، التصميم، الطباعة ثلاثية الأبعاد، الهندسة الطبية الحيوية، يد اصطناعية.

المقدمة:

تعتبر الأطراف الاصطناعية العلوية عنصرًا رئيسيًا في تحسين حياة الأشخاص الذين فقدوا أطرافهم، خاصة في الدول ذات الدخل المنخفض، حيث تظل تكاليفها مرتفعة للغاية. يسعى مشروع e-NABLE العالمي لتقديم نماذج بتكلفة منخفضة من خلال تقنية الطباعة الثلاثية الأبعاد. وقد تمكن هذا المشروع من استقطاب حوالي 7000 متطوع، مما أسفر عن توفير ما يقرب من 2000 طرف صناعي لأشخاص في 45 دولة. من

بين هذه النماذج، برز تصميم يد الرابتور (Raptor Hand) كتصميم حديث يضم مفاصل متعددة، يهدف إلى دمج أفضل الأفكار من التصاميم السابقة في يد اصطناعية بسيطة وسهلة الطباعة .(Simon, 2023) يتميز هذا التصميم بقدرة الطباعة دون الحاجة إلى دعم أو مسامير معدنية، بالإضافة إلى نظام شد مُحسّن يتيح تطويره في المستقبل.

في هذا البحث، نقدم شرحًا دقيقًا حول عملية تطوير نموذج مطابق ليد رابتور، ونسعى لتقييم أدائها في مهام الإطباق والقبضة مقارنة بالنتائج المتاحة في المراجع. سنبدأ بمناقشة الخلفية النظرية والأنظمة المشابهة للأطراف الاصطناعية، ثم نحدد مشكلة الدراسة وأهدافها، ونبرز أهمية هذه الدراسة في مجال الهندسة الطبية الحيوية. بعد ذلك، نستعرض الأبحاث السابقة المتعلقة بتصاميم الأطراف الصناعية بتكلفة منخفضة ونتائجها. وأخيرًا، نقوم بتوضيح المنهجية المتبعة والإطار النظري الذي يدعم هذه الأطراف، قبل عرض نتائجنا ومناقشته.

الشكل رقم 1: (Hand Raptor).

1.الاختبار الوظيفي: شمل قياس نطاق حركة الأصابع في حالتي الفتح والإغلاق باستخدام حاسبة بسيطة (مثلا" الزوايا المحصلة). كما قُيّمت قوة القبضة بقياس الوزن الأقصى الذي يمكن حمله بثبات (مثلا" إمساك كأس مملوء بالماء أو كتلة ثقيلة). استُخدِمت أدوات يدوية بسيطة مثل ديناميومتر لقياس القوة المرجعية عند الإمساك.

2. تحليل البيانات : تمت مقارنة البيانات المقاسة مع نتائج سابقة في الأدبيات .(Cuellar *et al.*, 2021) وقد اعتمدنا في التحليل على الأساليب الوصفية (مثل رسم منحنيات القوة مقابل الشد) لتحليل كفاءة اليد. كذلك طُبق تقييم نوعي من حيث سهولة التركيب والراحة النسبية للمستخدم.

الإطار النظري:

تقوم فكرة اليد الاصطناعية المدعومة بحركة الجسم على استخدام حركة المعصم أو الكتف لتحريك الأسلاك التي تجعل الأصابع تتقارب. في هذا البحث، تم تفعيل اليد عن طريق الأسلاك والنوابض، بحيث يؤدي انحناء المعصم إلى إغلاق اليد من خلال تقارب الأصابع. يختلف تصميم الأطراف العلوية حسب مستوى البتر، ولكن معظم هذه التصاميم تستخدم نظام غلق بسيط يعتمد على خيط موجه أو شجرة وير (Whiffle) لضمان توزيع الشد بالتساوي على الأصابع. في نموذج اليد الميكانيكية، يعد اختيار نقاط الارتكاز (محاور المفاصل) وزاوية الحركة الحاسمة مهمين لتمكين الإطباق الكامل (بزاوية 90º) وتجنب الامتداد الزائد (hyperextension) .

يهدف التصميم إلى إنتاج كفاءة جيدة في نقل القوة حتى يتوفر جهد كافٍ في طرف الأصابع) على سبيل المثال، بعض التصميمات تصل إلى حوالي 16 نيوتن .(Cuellar *et al.*, 2021) وهو أقل من الأطراف عالية التقنية ولكنه كافٍ لأداء المهام الأساسية.

يجب أن تؤخذ بعين الاعتبار عوامل مثل سهولة الإنتاج والموثوقية؛ حيث أظهرت الدراسات أن المطاط التقليدي قد يفقد مرونته مع مرور الوقت .(Ferreira *et al.*, 2017) لذلك، كان التركيز على استعمال مواد بلاستيكية مرنة وعالية الجودة لتأخير تدهورها. علاوة على ذلك، يجب أن يكون التصميم مريحاً ومقبول الشكل من الناحية التشريحية. رغم أن اليد المنتجة بتقنية الطباعة ثلاثية الأبعاد غالباً ما تكون أقل تكلفة بكثير من الأطراف التقليدية، مع إمكانية تخصيصها بسهولة وفقاً لمقاسات الفرد.

النتائج والمناقشة:

تمكنت من إنتاج النموذج المحسن بنجاح وتركيبه وفقاً للطريقة السابقة. أظهرت الاختبارات المتعلقة بالزوايا أن اليد تغلق بزاوية قريبة من 90 درجة في الأصابع الأربعة، مما يسهل القبض على الأجسام الدائرية. بالنسبة لقوة القبضة، لاحظنا أن اليد كانت قادرة على حمل أوزان خفيفة، مثل الإمساك بكأس مليء بالماء وزنه حوالي نصف كيلو جرام دون أن ينزلق. تراوحت قيم قوة القبضة التي قمنا بتقديرها بين 10 و15 نيوتن، وهو ما يتماشى مع القيم الموجودة في دراسات مشابهة .(Cuellar *et al.*, 2021) هذه القوة كافية لأداء مهام بسيطة مثل حمل كوب أو لعبة خفيفة، لكنها تظل أقل من الأطراف الصناعية المتطورة التي يمكن أن تتجاوز قوة 40 نيوتن في بعض النماذج. وفقاً للتحليل النظري، تبين أن اليد المعاد تصنيعها أدت الوظيفة المتوقعة لكن مع وجود بعض القيود: حيث لوحظت تآكلات متزايدة في سلك الشد بعد الاستخدام المتكرر، وهو ما أشار إليه الباحثون سابقاً: (Cuellar *et al.*, 2021) ، مما جعل الإغلاق الكامل سريعاً أمراً صعباً. كما أظهرنا أن الجسم البلاستيكي لليد قد يتعرض لتمزقات بسيطة في أطراف المفصل عند زيادة القوة خلال الاستخدام الطويل الأمد. بالمقارنة مع الأبحاث السابقة، تبقى النتائج متوافقة مع ما أورده كويلار وآخرون(Cuellar *et al.*, 2021) ، حيث وجدت قوتهم في الإطباق حوالي 16 نيوتن باستخدام مواد .PLA يتفوق تصميمنا على النتائج الأولية لليد الرابتور من حيث كفاءة التجميع وسهولة التصنيع، لكن لم نتمكن من تجاوز الحدود الخاصة بسرعة الأداء الميكانيكي التقليدية. تناقش هذه النتائج أهمية المتانة والدقة في أي تحسينات مستقبلية؛ مثل تحسين نظام الشد عبر استخدام نوابض ذات جودة أفضل، أو استخدام مواد مرنة أكثر تطوراً للرابط. في الختام، تؤكد الدراسة أن يد الرابتور تعتبر قابلة للاستخدام العملي كوحدة اختبار، مع ضرورة الاستمرار في العمل من أجل تحسين عيوب التصميم كما هو موضح في الأدبيات.

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الشكل رقم 2: مقارنة (Hand Raptor).

التوصيات:

- استخدام مواد أكثر مرونة وقوة في الأربطة والأسلاك (مثل الأوتاد النابضة أو خيوط Kevlar) لمنع فقدان المرونة مبكرا.
- تحسين تصميم محور مفاصل الأصابع لضمان غلق أكثر انسيابية ودون اهتزازات.
- إجراء دراسات ميدانية إضافية مع مستخدمين فعليين (نماذج أولية للاختبارات البشرية) لتقييم الراحة والوظيفة على المدى الطويل.
- تدريب الطلاب والمتطوعين على عملية التصنيع والتركيب بالشكل الموصى به لزيادة فرص توزيع النموذج واستخدامه في مشاريع تطوعية ومؤتمرات مستقبلية.
- النظر في إضافة حساسات بسيطة (مثل مستشعرات قوة في المستقبل) لتقييم الأداء بشكل أكثر دقة خلال الاستخدام.
- يوصى بتوسيع نطاق نشر مشروع Hand Raptor لما يملكه من أثر إيجابي كبير، إذ يمكن لاعتماده على نطاق واسع أن يسهم في تحسين جودة حياة المستخدمين ودعم فئات عديدة بطريقة عملية وفعّالة.

الشكر وتقدير:

يتقدم الباحث بخالص الشكر والتقدير إلى فريق e-NABLE والمصمم Owen Ivan على إتاحة التصاميم المفتوحة المصدر، كما نشكر أساتذة قسم الهندسة الطبية الحيوية الذين دعموا هذا المشروع وإدراج نموذج اليد في فعاليات المؤتمر.

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اتجاهات المرضى ومرافقيهم نحو الأخطاء الطبية في مصحة بن سينا ـمدينة بنغازي (دراسة مقطعية وصفية)

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ABSTRACT:
Medical errors pose major health and legal challenges. This study assessed patients' attitudes toward medical errors at Ibn Sina Hospital and examined their relationship with gender and educational level.
A cross-sectional study was conducted on 1000 participants using a structured questionnaire. Statistical analysis was performed using the Chi-square test ($p < 0.05$).
Results showed that 63.3% did not report medical errors, while 36.7% reported them sometimes or frequently. Significant associations were found between educational level and reporting ($p < 0.001$), and between gender and expected reaction ($p < 0.05$) The study highlights the need to strengthen patient safety and improve clear. reporting mechanisms.

Keywords: Medical errors, patient safety, patient attitudes, quality of healthcare, patient acceptance, reaction.

ملخص البحث:
الخلفية: تُعد الأخطاء الطبية من أبرز التحديات التي تواجه الأنظمة الصحية، لما لها من آثار صحية ونفسية وقانونية، وكذا يُعد فهم مواقف المرضى تجاه هذه الأخطاء وردود أفعالهم، من الأمور الأساسية التي تؤدي دورًا مهمًا في صياغة سياسات الإبلاغ والمساءلة، وتحسين الأداء المؤسسي وجودة الرعاية، وتعزيز ثقافة سلامة المرضى.
الهدف: هدفت الدراسة هذه إلى تقييم اتجاهات المرضى ومرافقيهم نحو الأخطاء الطبية، وقياس مدى تقبلهم لها، وتحديد ردود الفعل المتوقعة عند حدوثها، في مصحة ابن سينا، ودراسة العلاقة بينهما مع كل من الجنس والمستوى التعليمي.
المنهجية: أُجريت دراسة عن طريق دراسة مقطعية وصفية شملت 1000 مشارك من المرضى ومرافقيهم. جمع البيانات باستخدام استبيان منظم تضمن الخصائص الديموغرافية، تقبل الأخطاء الطبية، وردود الفعل المتوقعة، ثم حُللت البيانات باستخدام الإحصاء، واختبار مربع كاي لدراسة العلاقة بين المتغيرات، مع اعتماد مستوى دلالة $p < 0.05$.
النتائج: أظهرت النتائج أن 63.3% من المشاركين لا يتقبلون الأخطاء الطبية، بينما أبدى 36.7% تقبلًا كليًا أو نسبيًا لها. لُوحظ وجود علاقة ذات دلالة إحصائية بين المستوى التعليمي وتقبّل الأخطاء الطبية($p < 0.001$) . وكذلك علاقة ذات دلالة إحصائية بين الجنس وردة الفعل تجاه الخطأ الطبي.($p < 0.05$)
الاستنتاج: تشير نتائج الدراسة إلى انخفاض مستوى تقبل الأخطاء الطبية بين المستفيدين من الخدمات الصحية، مما يؤكد الحاجة إلى تعزيز ثقافة سلامة المرضى، وتطوير آليات مؤسسية واضحة وشفافة؛ للتعامل مع الأخطاء الطبية. وتؤكد الدراسة أن الخصائص الديموغرافية، ولا سيما الجنس والمستوى التعليمي، تؤثر بشكل واضح في مواقف المرضى تجاه الأخطاء الطبية، مما يستدعي تطوير سياسات إفصاح وتواصل تراعي هذه الفروق.

الكلمات المفتاحية: الأخطاء الطبية، سلامة المرضى، اتجاهات المرضى، جودة الرعاية الصحية، تقبّل المرضى، ردة الفعل.

المقدمة:

تُعد سلامة المرضى أحد المرتكزات الأساسية لجودة الرعاية الصحية، وتشير التقارير الدولية إلى أن الأخطاء الطبية تمثل سببًا مهمًا للضرر الصحي الذي يمكن الوقاية - بنسبة كبيرة- منه .(WHO, 2019) ولا تقتصر آثار الأخطاء الطبية على الجوانب السريرية فقط، بل تمتد لتشمل الجوانب النفسية والاجتماعية والقانونية، سواء للمرضى أو لمقدمي الرعاية الصحية .(Gallagher *et al.*, 2003) وقد ازداد الاهتمام خلال السنوات الأخيرة

بدراسة تصورات المرضى ومرافقيهم تجاه الأخطاء الطبية، لما لذلك من دور في تعزيز الشفافية، وتطوير نظم الإبلاغ، وبناء الثقة بين المؤسسات الصحية والمجتمع.(WHO, 2020)
وعلى الرغم من هذا الاهتمام العالمي، لا تزال الدراسات المحلية في السياق الليبي محدودة، خاصة في المؤسسات الصحية الخاصة، مما يبرز الحاجة إلى دراسات ميدانية تسهم في معالجة هذه المشكلة.

مشكلة الدراسة:

على الرغم من الاهتمام العالمي المتزايد بدراسة الأخطاء الطبية، إلا أن الدراسات المحلية في ليبيا، وبخاصة في المؤسسات الخاصة، لا تزال محدودة، مما يقلل من فهم تصورات المرضى ومرافقيهم تجاه هذه الأخطاء.

أسئلة البحث:

1. ما مدى تقبل المرضى ومرافقيهم للأخطاء الطبية؟
2. ما ردود الفعل المتوقعة عند حدوث خطأ طبي؟
3. هل توجد علاقة بين الخصائص الديموغرافية وتقبل الأخطاء الطبية؟

الفرضيات:

- هناك علاقة ذات دلالة إحصائية بين المستوى التعليمي للمشارك وتقبله للأخطاء الطبية.
- تختلف ردود الفعل المتوقعة تجاه الأخطاء الطبية حسب صفة المشارك (مريض/مرافق).
- تختلف ردود الفعل المتوقعة تجاه الأخطاء الطبية حسب جنس المشارك.

أهمية الدراسة:

- تعزيز فهم اتجاهات المرضى ومرافقيهم تجاه الأخطاء الطبية في السياق الليبي.
- دعم تطوير سياسات مؤسسية واضحة للتعامل مع الأخطاء الطبية.
- الإسهام في تحسين ثقافة سلامة المرضى وجودة الرعاية الصحية.

أهداف الدراسة:

1.تقييم اتجاهات المرضى ومرافقيهم نحو الأخطاء الطبية.
2.قياس مدى تقبل المرضى والمرافقين للأخطاء الطبية.
3.تحديد ردود الفعل المتوقعة عند حدوث الأخطاء الطبية.
4.دراسة العلاقة بين كلٍ من الجنس والمستوى التعليمي.

المنهجية: إجراءات الدراسة والأدوات:

- **تصميم الدراسة :**دراسة مقطعية وصفية.
- **مكان الدراسة :**مصحة ابن سينا، مدينة بنغازي، ليبيا.
- **عينة الدراسة** 1000 **:**مشارك من المرضى ومرافقيهم المترددين على المصحة خلال فترة جمع البيانات.
- **أداة جمع البيانات :**استبيان منظم شمل:
  - البيانات الديموغرافية.
  - مدى تقبل الأخطاء الطبية.
  - ردود الفعل المتوقعة عند حدوث الخطأ الطبي.

حدود الدراسة:

المكانية: مدينة بنغازي – نوعية المؤسسة: القطاع الخاص.

الدراسات السابقة ذات الصلة:

أظهرت الدراسات العربية والعالمية أن غالبية المرضى لا يتقبلون الأخطاء الطبية، ويميلون إلى المطالبة بالعقاب أو التعويض، خاصة عند حدوث ضرر صحي مباشر. في دراسة لـ El-Nagar & Ahmed (2020) في مصر، بينت النتائج أن المرضى يتوقعون الإفصاح الصريح عن الأخطاء، مع الاعتذار وتقديم التعويض عند الضرر الفعلي. أما دراسة Al-Shammari & Al-Kandari (2021) في السعودية، فقد أكدت أن الوعي الصحي والمستوى التعليمي يؤثران على قبول المرضى للأخطاء الطبية وعلى ردود أفعالهم تجاهها.

الإطار النظري:

الأخطاء الطبية هي أي فعل أو قرار أو إجراء طبي غير صحيح، أو الامتناع عن إجراء مناسب، يحدث أثناء تقديم الرعاية الصحية، ويؤدي أو قد يؤدي إلى إلحاق ضرر بالمريض، سواء كان الضرر فعليًا أو محتملًا نتيجة خلل بشري أو تنظيمي أو تقني في النظام الصحي. (WHO, 2019) تشير منظمة الصحة العالمية إلى أن الأخطاء الطبية تمثل واحدًا من أهم التحديات التي تواجه نظم الرعاية الصحية لما لها من آثار صحية ونفسية وقانونية (WHO, 2019).وتعتمد سلامة المرضى على مجموعة السياسات والممارسات والإجراءات التي تهدف إلى تقليل مخاطر الضرر غير الضروري المرتبط بتقديم الرعاية الصحية، من خلال منع الأخطاء الطبية والكشف المبكر عنها والتعامل معها بفعالية ضمن إطار مؤسسي قائم على التحسين المستمر. (WHO, 2020) كما يوضح تقرير *To Err is Human*، أن الأخطاء الطبية مشكلة نظامية تتطلب حلولًا مؤسسية قائمة على التعلم والتحسين بدلًا من الاقتصار على العقاب.(Kohn *et al.*, 2000)

النتائج والمناقشة:

النتائج:

النتائج المتحصل عليها كانت حسب الجداول الثلاثة التالية والاشكال البيانية الموضحة لها

المتغير	الفئة	العدد (n)	النسبة (%)
صفة المتردد	مريض	789	78.9
	مرافق	211	21.1
الجنس	أنثى	648	64.8
	ذكر	352	35.2
المستوى العلمي	متوسط	407	40.7
	جامعي	341	34.1
	أساسي	180	18
	لا يوجد	43	4.3
	أعلى	29	2.9

الجدول 1: الخصائص الديموغرافية للمشاركين

مدى التقبل	العدد (n)	النسبة (%)
لا	633	63.3
نعم	202	20.2
نسبيًا	165	16.5

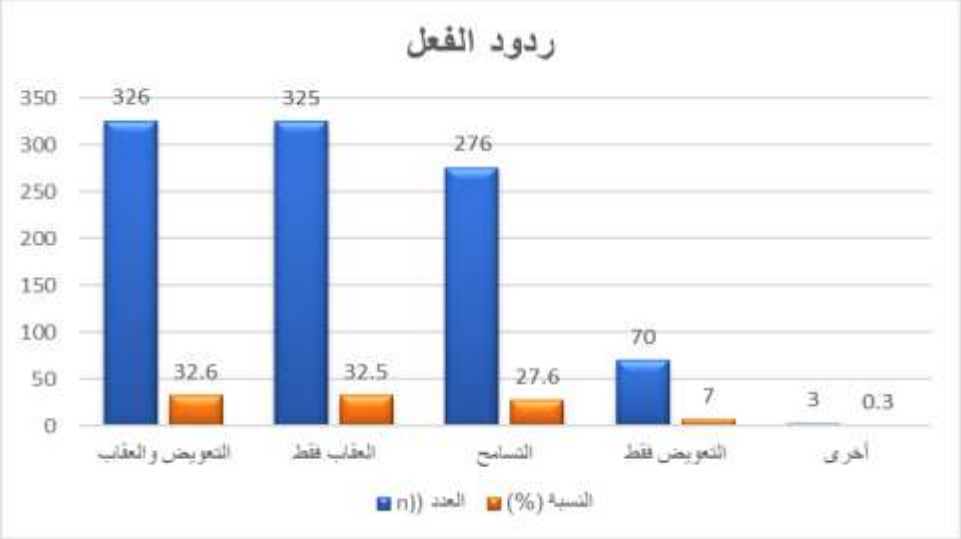
الجدول 2: مدى تقبل الأخطاء الطبية

ردة الفعل	العدد (n)	النسبة (%)
التعويض والعقاب	326	32.6
العقاب فقط	325	32.5
التسامح	276	27.6
التعويض فقط	70	7
أخرى	3	0.3

الجدول 3: ردود الفعل المتوقعة تجاه الخطأ الطبي

الشكل رقم 1: الخصائص الديموغرافية للمشاركين.

الشكل 2: مدى تقبل الأخطاء الطبية.



الشكل رقم 3: ردود الفعل المتوقعة تجاه الخطأ الطبي.

التحليل الإحصائي:

- علاقة ذات دلالة إحصائية بين المستوى التعليمي وتقبل الأخطاء الطبية ($p < 0.05$) .
- علاقة ذات دلالة إحصائية بين صفة المشارك وردة الفعل تجاه الخطأ الطب ($p < 0.05$) .
- علاقة ذات دلالة إحصائية بين جنس المشارك وردة الفعل تجاه الخطأ الطبي ($p < 0.05$) .

المناقشة:

تنسجم نتائج الدراسة الحالية مع ما ورد في الأدبيات الدولية التي تؤكد أن إدراك المرضى للأخطاء الطبية غالبًا ما يرتبط بمفهوم الإهمال المهني وفقدان الثقة بمقدمي الرعاية الصحية. (AbuAlRub & Abu Alhijaa, 2014; WHO, 2019; WHO, 2020). كما تتوافق العلاقة بين المستوى التعليمي وتقبّل الأخطاء الطبية مع دراسات سابقة أشارت إلى أن ارتفاع الوعي الصحي يسهم في فهم أفضل لطبيعة المخاطر الطبية وحدود الممارسة السريرية (Makary & Daniel, 2016; Reason, 2000).

- أظهرت نتائج الدراسة أن غالبية المشاركين لا يتقبلون الأخطاء الطبية، وهو ما يعكس حساسية مرتفعة تجاه هذا الموضوع في المجتمع محل الدراسة. وتنسجم هذه النتيجة مع تقارير منظمة الصحة العالمية التي تشير إلى أن المرضى غالبًا ما يربطون الخطأ الطبي بالإهمال المهني وهو ما يتوافق والدراسات العربية السابقة.
- كما أظهرت النتائج علاقة قوية بين المستوى التعليمي وتقبّل الأخطاء الطبية، حيث كان ذوو التعليم الجامعي والدراسات العليا أكثر تفهمًا للأخطاء الطبية مقارنة بذوي التعليم الأساسي، ويُعزى ذلك إلى ارتفاع مستوى الوعي الصحي والإدراك بطبيعة المخاطر الطبية.
- ردود الفعل تميل إلى المطالبة بالعقاب أو التعويض، خاصة بين المرضى مقارنة بالمرافقين، مما يوضح تأثير الضرر المباشر على صحة المريض الجسدية والنفسية.
- وفيما يتعلق بالجنس، أظهرت الدراسة وجود فروق ذات دلالة إحصائية في ردة الفعل تجاه الخطأ الطبي، حيث مالت الإناث بدرجة أكبر إلى ردود الفعل العقابية، بينما أظهر الذكور نسبًا أعلى من التسامح أو الاكتفاء بالمطالبة بالتعويض. ويمكن تفسير ذلك بعوامل نفسية واجتماعية تتعلق بدرجة القلق الصحي والمسؤولية الأسرية.

التوصيات:

1. تعزيز ثقافة سلامة المرضى داخل المؤسسات الصحية.
2. وضع سياسات واضحة للتعامل مع الأخطاء الطبية تشمل الإبلاغ والتحقيق والتعويض.
3. تحسين التواصل والإفصاح الصريح مع المرضى عند وقوع الخطأ الطبي.
4. إشراك المرضى ومرافقيهم في برامج تحسين الجودة.
5. إدماج مفاهيم سلامة المرضى والأخطاء الطبية في المناهج الصحية.
6. تعزيز الأطر القانونية والتنظيمية بما يحقق التوازن بين حقوق المرضى والعاملين الصحيين.
7. إنشاء وحدات متخصصة لسلامة المرضى داخل المؤسسات الصحية.
8. إجراء دراسات وطنية موسعة تشمل مؤسسات صحية متعددة.
9. الاستفادة من نتائج الدراسة في دعم السياسات الصحية المحلية.
10. تعزيز برامج التثقيف الصحي المجتمعي.

الشكر والتقدير:

نتوجه بالشكر إلى الأخوات الممرضات واللواتي ساعدنا في عملية توزيع الاستبيانات وتجميعها.

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Spatial and Temporal Constraints for Acquisition in FMRI

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الملخص:

يُعدّ التصوير بالرنين المغناطيسي الوظيفي (fMRI) تقنية تصوير عصبي غير جراحية تُستخدم لقياس نشاط الدماغ من خلال رصد التغيرات في تدفق الدم ونسبة الأكسجة المرتبطة بالنشاط العصبي. ويُمكّن الباحثين من دراسة وظائف الدماغ أثناء أداء مهام معرفية أو حسية محددة. وتتكوّن البيانات المكتسبة عادةً من سلاسل صور ثلاثية الأبعاد مقسّمة إلى عناصر حجمية تُسمّى «فوكسلات»، يمثّل كلٌّ منها مكعّبًا صغيرًا من نسيج الدماغ.

يمكن لجلسة واحدة من التصوير الوظيفي إنتاج مئات إلى آلاف الصور ثلاثية الأبعاد، حيث يضمّ كل حجم قرابة 100,000 فوكسل. وتعكس شدة كل فوكسل كثافة اللفّ النووي المحلي وترتبط بالتغيرات الديناميكية في تدفق الدم والأكسجة. ونظرًا لتعقيد البنية الدماغية وانخفاض نسبة الإشارة إلى الضوضاء، تظهر تحديات تتعلق بالقيود المكانية والزمانية أثناء جمع البيانات وتفسيرها.

وتهدف هذه الدراسة إلى تقديم مراجعة شاملة لمعاملات اكتساب بياناتfMRI ، مع التركيز على تحديات الدقة المكانية (حجم الفوكسل وتغطية الدماغ) والدقة الزمنية (زمن التكرار وديناميكيات الإشارة). كما أن ضخامة البيانات وارتفاع أبعادها يفرضان تحديات إحصائية وحاسوبية تستلزم تعاونًا بين تخصصات علم الأعصاب والهندسة الطبية الحيوية والفيزياء والإحصاء. وتسلّط المقالة الضوء على التطورات المنهجية الحديثة بهدف توفير إطار متكامل يساعد الباحثين على فهم مبادئ اكتساب بيانات fMRI وتطبيقها بدقة لضمان تفسيرات علمية موثوقة لنشاط الدماغ.

الكلمات المفتاحية: التصوير بالرنين المغناطيسي الوظيفي (fMRI)، قياس نشاط الدماغ، الدقة المكانية في التصوير بالرنين المغناطيسي الوظيفي، تحديات الدقة الزمنية، الحصول على بيانات التصوير بالرنين المغناطيسي الوظيفي وتفسيرها.

Abstract: Functional Magnetic Resonance Imaging (fMRI) is a non-intrusive neuroimaging method that measures brain activity via measurement of changes in blood oxygenation and flow that occur in response to neural activity. This facilitates the ability of researchers to study brain function in response to specific cognitive or sensory tasks. The acquired data typically comprise sequences of three-dimensional MR images, partitioned into three-dimensional elements referred to as voxels, with each voxel representing a small, uniformly-sized cube of brain tissue. A single fMRI session can produce hundreds to thousands of 3D images, each volume encompassing nearly 100,000 discrete voxels. The intensity value of each voxel reflects the local nuclear spin density and is associated with hemodynamic fluctuations, such as variations in blood flow and oxygenation. As a result of the brain's structural intricacy and the relatively low signal-to-noise ratio of fMRI data, the influence of spatial and temporal limitations on data acquisition and interpretation. This study seeks to offer a comprehensive review of the acquisition parameters in fMRI, with a particular focus on the challenges posed by spatial resolution (voxel size, brain coverage) and temporal resolution (repetition time, signal dynamics). The immense data quantity and its high dimensionality present statistical and computational challenges, demanding collaborative efforts across neuroscience fields, biomedical engineering, physics, and statistics. This article also highlights the methodological developments fueled by the rising number of fMRI studies and the escalating demand for robust analytical methodologies. The primary objective is to provide a detailed framework for researchers across diverse disciplines to understand and apply fMRI acquisition principles effectively, ensuring accurate and meaningful interpretations of brain activity.

Keywords: Functional Magnetic Resonance Imaging (fMRI), Brain activity measurement, Spatial resolution in fMRI, Temporal resolution challenges, fMRI data acquisition and interpretation.

INTRODUCTION

In FMRI technology, a standard for MRI is used to form a series of brain sizes and study dynamic changes, which requires focusing on FMRI data, and three-dimensional acquisition. To understand this process, one must review the techniques of collecting stereotypes of the brain (Adolescent risk taking, 2011; Nurse home visitation, 2010; Andersen & Teicher, 2009).

FMRI study data, depending on MR physics and signaling signal, description and accurate discussion for each stage (Anokhin *et al*., 2011; Arsalidou & Taylor, 2011; Barnett *et al*., 2008) and thus get to know the basis of MR scanner and clarify how to use the signal, form images, and discuss issues related to FMRI technology. The MR scanner is a group of devices; the main part is an extremely connected electrical magnet with a fixed magnetic field, usually ranging from 1.5–7.0 Tesla in brain research, and interacts with the Earth's magnetic field and its value is 0.0000005 tesla, which makes it strong enough to withdraw magnetic bodies to its core (Beauchaine *et al*., 2008; Beauregard, 2009; Bechara, 2005)

The second critical component of the scanner is the radio frequency coils, where the coils of devices near the object that is photographed, and its function generating and receiving energy on the resonance frequency in the size that is photographed (Bechara, 2005; Benoit *et al*., 2011). The gradient coils are the third component, which are electromagnetic coils that create a spatial contrast in the magnetic field, and they encode spatial information in the necessary signal to create images. This makes MR signals effective tools to study both the structure and function of the brain and the creation of types of images to confirm the contrast related to the characteristics of tissue, studying directional patterns to spread water—or diffusion-weighted imaging (DWI)—to measure the areas of white matter, and set the flexible characteristics of the brain tissue, and the flow of cerebral fluid, and others (Berkman *et al*., 2011; Berman *et al*., 2011).

The same scanner for MRI, fMRI functional imaging (DTI) from white matter spaces also works with the goal of obtaining several types of images, so that MR images are part of the standard fMRI survey session, as a pre-data process. All MR technologies depend on a basic set of physical rules, and their understanding we start by examining one atomic nucleus and studying its effect on the MR signal, and focusing on hydrogen atoms that consist of one proton, because it is the most common nucleus in MRI because of both its properties and abundance in the human body. Protons are positive particles that revolve around their axis, which leads to a clear magnetic moment along the direction of the rotation axis, which is the source of the signal that we seek to measure. However, because it is impossible to measure one proton magnetization, we measure the net magnetization of the nucleus within a specific volume. This can be represented as a two-part vector: the first is a longitudinal component parallel to the magnetic field, and the second is transverse perpendicular to the field (Bierman *et al*., 2008; Bryant *et al*., 2008).

DISCUSSIONS

This paper aims to provide a comprehensive framework for understanding the principles and challenges of functional magnetic resonance imaging (fMRI), focusing on acquisition parameters, spatio-temporal resolution, and complexities in signal modeling and data analysis. Although fMRI is a powerful, non-invasive tool for mapping brain activity, interpreting its data requires a deep understanding of basic physics, neurophysiology, and computational statistics. The fundamental challenges in fMRI relate to the balance between spatial resolution (voxel size, brain coverage) and temporal resolution (repetition time TR, signal dynamics) (Chua *et al*., 2011; Dannlowski *et al*., 2012).

Improving one often comes at the expense of the other due to the physical limitations of acquisition time. While high-resolution structural recordings (e.g., T1 images) allow precise anatomical discrimination, studies of function require rapid and repeatable acquisition, which limits the voxel size to about 3 × 3 × 5 mm in conventional studies (Dannlowski *et al*., 2012). With technical advances such as higher magnetic fields (7 Tesla), parallel acquisition techniques, and simultaneous multiple slices, it has become possible to achieve higher spatial (≈2 mm^3) and better temporal (TR < 1 s) resolution (Carter *et al*., 2011; Decharms, 2008). However, these improvements increase the volume and analytical complexity of the data.

The signal measured in fMRI, known as the blood oxygen level dependent (BOLD) response, is an indirect indicator of neural activity, relying on changes in oxy-/deoxyhemoglobin ratios resulting from neuronal metabolism and vascular response (Deco *et al*., 2011; Caria *et al*., 2007). This response is modeled by the hemodynamic response function (HRF), which is delayed and temporally spread relative to the actual neural activity (Beauchaine *et al*., 2008; Falk *et al*., 2012). This delay, combined with differences in the form and timing of HRF between different brain regions and between individuals (Adolescent risk taking, 2011; Dosch *et al*., 2010; Eisenberger *et al*., 2007b), poses a fundamental challenge in analysis. The linear time-invariant (LTI) model is often assumed to describe the relationship between stimulus and BOLD response (Barnett *et al*., 2008), although there is evidence for nonlinearity of this relationship in cases of rapidly successive stimuli (Andersen & Teicher, 2009; Falk *et al*., 2012). To address the variation in HRF, flexible models based on a set of basis functions (time derivatives, gamma functions, principal components) can be used instead of adopting a fixed canonical form (Adolescent risk taking, 2011; Bierman *et al*., 2008; Casey *et al*., 2011; Fenton *et al*., 2009).

Experimental design is crucial to the success of an fMRI study. The design conflicts between block design (more statistical power of detection, less sensitivity to HRF shape) and event-related design (flexibility in estimating HRF parameters, linking to specific cognitive processes) (Berkman *et al*., 2011; Berman *et al*., 2011). The optimal choice depends on the primary goal of the study: identifying areas of activity versus understanding the precise temporal sequence of brain processes. The design must also balance statistical efficiency with randomness to prevent expectation and adaptation effects.

Functional data contain complex noise and artifacts from multiple sources including: head movement (which is partially corrected by realignment but whose effects remain (Cacioppo *et al*., 2003; Crowe & Blair, 2008)), slow signal drift resulting from scanner instability, and periodic physiological fluctuations from heartbeat and respiration (Bechara, 2005; Eckenrode *et al*., 2010; Filiou & Turck, 2011). Since the typical acquisition rate (TR) (≈2 s) is lower than the frequencies of these physiological processes, aliasing occurs leading to temporal autocorrelation in the noise (Cheung, 2009). This noise is often modeled using AR(p) or ARMA(1,1) operations to improve statistical inference (Diamond *et al*., 2007). Preprocessing constitutes a vital step to mitigate these problems and includes: slice time correction, motion realignment, co-registration with anatomical images, and normalization to standard space (e.g., MNI) (Eisenberger *et al*., 2007a). Normalization, especially nonlinear, is a potential source of error in group analyses and requires careful quality checking (Critchley, 2009). Basic statistical analysis is often done using a voxel-by-voxel general linear model (GLM) (Filiou & Turck, 2011). However, the high-dimensional nature of the data (tens of thousands of voxels and thousands of time points) requires strict correction for multiple comparisons, often using Gaussian Random Field Theory. Current developments are moving towards functional and structural network analyses, understanding resting-state functional states (Bierman *et al*., 2008; Decharms, 2008), and integrating fMRI data with other methods such as electroencephalography (EEG) or transcranial magnetic stimulation (TMS) within the framework of multimodal analysis.

Open initiatives and data sharing, such as the Human Connectome Project and the Open fMRI and NeuroVault repositories, facilitate progress in this field (Bierman et al., 2008; Eisenberger *et al*., 2007a). Free analysis software such as SPM, FSL, and AFNI provide standard tools for researchers (Benoit *et al*., 2011; Bryant *et al*., 2008; Development of cognitive control, 2006). It is believed that the biggest challenge in the near future is to transform the huge amount of data into a true understanding of brain function. This requires interdisciplinary collaboration between neuroscientists, engineers, physicists, statisticians, and machine learning experts (Beauchaine *et al*., 2008; Davidson, 2004).

Through this study we expect the development of rapid, high-resolution acquisition techniques, precise physiological modeling, and complex network analysis to continue to push the boundaries of what can be detected and inferred using fMRI, contributing to a deeper understanding of the healthy and diseased brain.

CONCLUSIONS

In neuroscience, an understanding of the human brain has become among the most complex, important and difficult issues, and more neural substrates are needed to understand the huge amounts of data created. With this rapid development, new research questions open every day. The exciting fields of research that we feel will be of increasing importance in the coming years are renewed every day with the progress of scientific research. However, there is no doubt that there is a need to continue studying in this field. For the use and creation of imaging databases, these endeavors were implemented both at the base level (e.g., the CONNECTONES project 1000) and institutional level (e.g., the Human Connectome project), and databases that consist of more than 1000 subjects are increasingly available. Consequently, multimodal analysis allows opportunities and creates restrictions for all methods used in human neuroscience, and fMRI is of course no exception. Therefore, the current trend is towards multidisciplinary methods that increasingly use multiple methodologies to overcome some of the restrictions of each method used in isolation.

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Comparative Dosimetry and Risk Coefficient Calculation for ^{99m}Tc and ^{123}I in SPECT using the Radiological Toolbox and Federal Guidance Report No.13 Databases

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الملخص:

تتناول هذه الدراسة مبادئ الطب الإشعاعي في مجال الطب النووي، من خلال مقارنة النظيرين المشعين تكنيشيوم-99م واليود-123 المستخدمين في تصوير SPECT. وتحلل الدراسة خصائصهما الفيزيائية مثل نصف العمر وطاقة الانبعاث، وتأثير ذلك في الجرعة الإشعاعية والمخاطر المرتبطة بها، بالاعتماد على أدوات تحليل وقاعدة بيانات الجرعات. وتهدف النتائج إلى دعم اتخاذ القرار في اختيار الدواء الإشعاعي الأنسب للإجراء التشخيصي، بما يسهم في تقليل التعرض غير الضروري للإشعاع وتحسين كفاءة التشخيص وسلامة المرضى.

الكلمات المفتاحية: معامل المخاطر؛ قياس الجرعات المقارن؛mTc99 و I123.

Abstract: This research paper addresses the understanding of radiological principles, more specifically in the context of nuclear medicine diagnostics. The study revolves around two radionuclides, Technetium-99m (^99m^Tc) and Iodine-123 (^123^I), which are both widely applied. They each possess distinctive physical and nuclear properties that have direct and significant influences on both the resulting radiological dose delivered to the patient and risk levels involved. The main methodology of this paper involves an in-depth comparative study of ^99m^Tc and ^123^I used in Single-Photon Emission Computed Tomography (SPECT) imaging. This is achieved using the Radiological Toolbox to analyze in-depth and understand their physical properties, such as half-life and photon emission energies. The Federal Guidance Report data base (FGR13-DB) is employed for estimating the absorbed dose and the risk coefficients of every radionuclide administration appropriately. Finally, this study aims to offer the necessary scientific basis for making informed and logical decisions in selecting the optimal radiopharmaceutical for a specific diagnostic procedure. The resultant data is intended to optimize patient outcomes by mitigating superfluous radiation exposure, consequently minimizing the potential for long-term health compromise, and concurrently improve diagnostic efficacy.

Keywords: Risk Coefficient; Comparative Dosimetry; ^{99m}Tc and ^{123}I.

INTRODUCTION

A medical imaging method called single photon emission computed tomography (SPECT) is based on tomographic reconstruction techniques and standard nuclear medicine imaging. The pictures show functional details about the patients, much like positron emission tomography (PET) does. In contrast to PET, which uses radiopharmaceuticals that emit positrons followed by the generation of two 511-keV annihilation photons, SPECT uses radiopharmaceuticals that are frequently found in nuclear medicine clinics. Radiopharmaceutical amount that can be administered as restricted by the permitted radiation dose to the patient. Although the amount of dose is small, periodic studies of these pharmaceutical drugs are necessary to ensure compliance with public health safety standards and to achieve better outcomes by minimizing radiation exposure (National Research Council, 1996). The ability to accurately calculate the absorbed dose in

the body's organs and tissues for individuals exposed to external radiation sources and radiation from internally distributed radionuclides is crucial for radiological protection. Due to the difficulty of measuring the absorbed dose to organs and tissues, computer programs are required. In the case of occupational and environmental exposures involving radionuclides that enter the body through ingestion and inhalation, the Dose and Risk Calculation (Andersson *et al*., 2017).

This study aims to enhance understanding of radionuclides used in nuclear medicine by comparing the dose coefficients and risk coefficients of ^99m^Tc and ^123^I, which are commonly used in SPECT, using the Toolbox for studying physical properties and FGR13_DB for calculating dose and risk coefficients as shown in Fig.1 and 2.

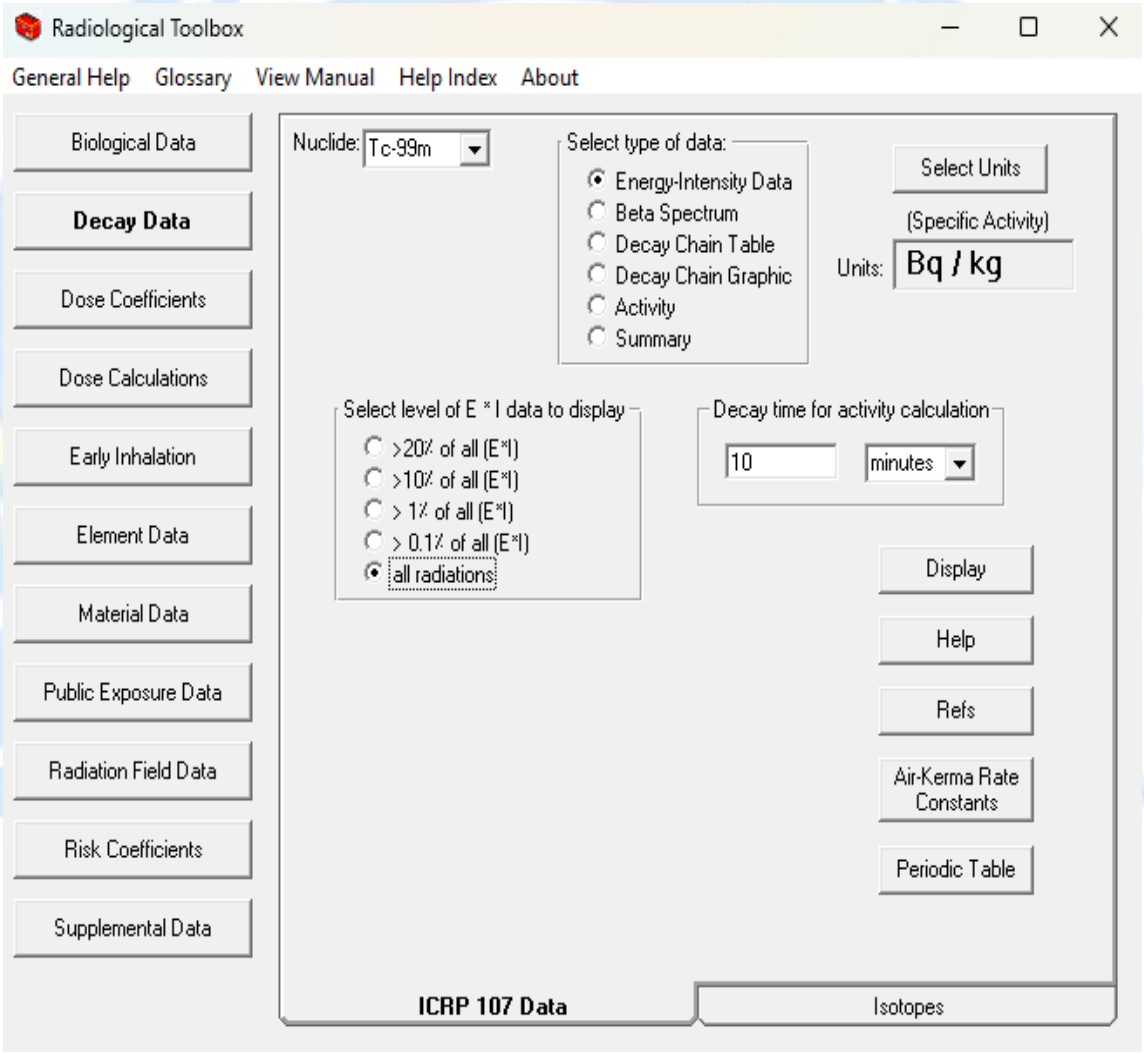

Fig 1: Radiology Toolbox Database.

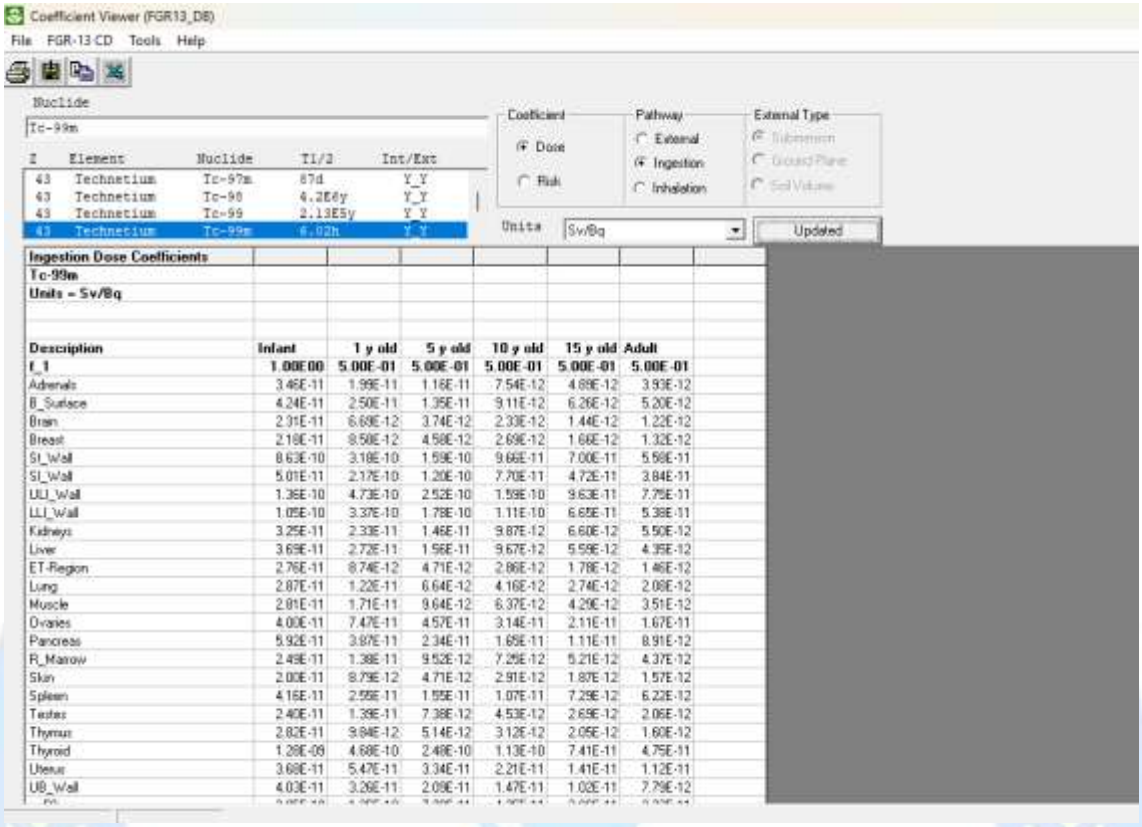

Fig 2: The Federal Guidance Report data base (FGR13_DB).

METHODOLOGY

Utilizing data from International Commission on Radiological Protection (ICRP) Publication 107, the radiology Toolbox software will be used. The extensive radionuclide decay data within the toolbox covers detailed information on the energy and intensity of radiation emitted during nuclear transformations (decays), types of emitted radiation, and radioactivity/time-integrated radioactivity calculations over different time intervals (Eckerman *et al*., 2013).

Activity (A) and Integrated Activity (A_I):

Radioactivity is a natural and spontaneous property possessed by the nuclei of unstable atoms (radionuclides). These nuclei strive to reach a more stable state through decay, and this decay process is accompanied by the emission of various types of radiation and energy. This phenomenon is expressed by the following equation:

$$A(t) = A_0 e^{-\lambda t} \quad (1)$$

Where $A(t)$ is the remaining activity at time t, A_0 is the initial activity, λ is the decay constant.

The integrated activity is defined as the total number of nuclear transformations that occur in a source over a specified time period. The calculation involves integrating the source's activity (A) over the duration of the exposure (t), and the result is typically expressed in units of Becquerel-seconds (Bq.s):

$$A_I = At \quad (2)$$

Or

$$A_I = \int_0^t A(\acute{t})\, d\acute{t} \quad (3)$$

Specific Activity (S_A):

Specific activity is undoubtedly one of the most critical factors in the production of radiopharmaceuticals. When administering low doses of radiotracers, it is important to note that the mass of the supplied compound is often less than the amount required to elicit a biological response. This observation forms the core of the radiotracer concept. In nuclear medicine, specific activity for both therapeutic and diagnostic radiopharmaceuticals is defined as the substance's radioactivity per unit mass or per mole, typically expressed in Bq. mol^{-1} or Bq. Kg^{-1}:

$$S_A = \frac{\lambda N_a}{M} \qquad (4)$$

where M is radionuclides molar mass, and Na is the Avogadro number (Lapi & Welch, 2012)

Dose Coefficient:

Dose coefficients are applied to measured or anticipated concentrations of radionuclides in the environment or workplace to determine the equivalent dose and effective dose values for radiation protection. These coefficients are derived from anatomical and physiological data for Reference Individuals (e.g., Reference Adult Male). The radiation protection community has a shared foundation thanks to these reference data (ICRP, 2007).

Internal exposure to ionizing radiation happens when a radionuclide is inhaled, eaten, or enters the bloodstream in any other way (for instance, through an injection or a wound). The end of internal exposure occurs when the radionuclide is eliminated from the body, either spontaneously (for instance, through faeces) or as a result of medical treatment. For internal exposure, the dosage coefficients for ingestion and inhalation will be estimated. Age-specific biokinetic models will be used to determine the time-dependent actions of the radionuclides after they enter the body.

The following calculations will be conducted for six age groups: infants, 1year, 5 years, 10 years, 15 years, and adults. There are two kinds of body regions are considered in dosimetric models for internal emitters: source regions and target regions. "Source regions" identify the areas of the body where radioactivity is found. "Target regions" are the tissues and organs that can be used to calculate the radiation dosage. These organs and tissues will be evaluated: Adrenals, Bone surface (B_Surface), Brain, Breast, Stomach wall (St_Wall), Small intestine wall (SI_Wall), Upper large intestine wall (ULI_Wall), Lower large intestine wall (LLI_Wall), Kidneys, Liver, Extra-Thoracic airway (ET-Region), Lung, Muscle, Ovaries, Pancreas, R_Marrow, Skin, Spleen, Testes, Thymus, Thyroid, Uterus, Urine Bladder wall (UB_Wall) (Bellamy *et al*., 2017; U.S. EPA, 1999). The dose coefficient takes into account factors such as the specific organs or tissues that are exposed to radiation and the particle size of the material that is consumed.

The absorption of radionuclides into the blood is defined by values of fractional absorption from the small intestine, or "f_1 value," which indicate the portion of the element's ingested quantity that is absorbed to blood (Melo *et al*., 2022). For the purpose to calculate inhalation dose coefficients, the ICRP defined numerical values for model parameters and classified absorption into three categories: slow (Type S), medium (Type M), and fast (Type F). According to the particle deposition model, smaller particles are mostly found in the extra-thoracic airways, whereas larger particles are more likely to be deposited in the upper respiratory tract. Although larger particles may result in higher expulsion rates and less deposition in alveolar regions, larger particles tend to deposit more in bronchial, bronchiolar, and alveolar areas (Melo *et al*., 2022).

Risk Coefficient:

The risk coefficient allows quantification of the average risk per unit exposure to radionuclides over a lifetime or a short period. According to FGR 13 (U.S. EPA, 1999), the coefficient refers to the general public, which is based on age and gender distributions from a hypothetical population, drawing cancer death rates from recent data (Kim *et al*., 2016). The risk coefficients for morbidity and mortality from cancer resulting from indoor exposure to radionuclides will be calculated for the 0–110-year age group, and the results for both radionuclides will be compared.

RESULT AND DISCUSSION

A. Activity (Bq) and Integrated Activity (Bq.s):

The activity was calculated using Eq 1. and the toolbox software. Fig.3 shows the instantaneous

activity of the radionuclides ^{99m}Tc and ^{123}I during a short period of time, up to around 7 days. At first (3 hours), the activity of ^{123}I was a little greater (about 0.85 Bq) than that of ^{99m}Tc (about 0.7 Bq). Both isotopes decay rapidly in an exponential manner, but ^{99m}Tc reaches near-zero activity (≈ 0.05 Bq) after 864000 seconds (1 day), whereas the ^{123}I continues to persist.

This fast initial drop of ^{99m}Tc is in line with its much shorter physical half-life as opposed to that of ^{123}I. The accumulation of total decays (in Bq.s) over an extended period of time is shown in Fig.4. The amount of radiation delivered to the tissue is directly proportional to this value. This figure clearly demonstrates the critical role of the half-life in determining the cumulative dose: the integrated activity curve for ^{99m}Tc rapidly stabilizes (plateaus) at approximately 31240 Bq·s by 345600 s (4 days), confirming the near completion of all decay events. On the other hand, the combined activity for ^{123}I continues to increase steeply for a longer period, reaching a significantly higher final plateau of around 68920 Bq.s by 1209600 s (2 weeks). Even though the initial instantaneous activities are similar, the total integrated activity of the ^{123}I nuclide is almost 2.3-fold higher than ^{99m}Tc. This means that the cumulative radiation dose delivered to the patient per unit of administered activity is significantly higher than ^{99m}Tc.

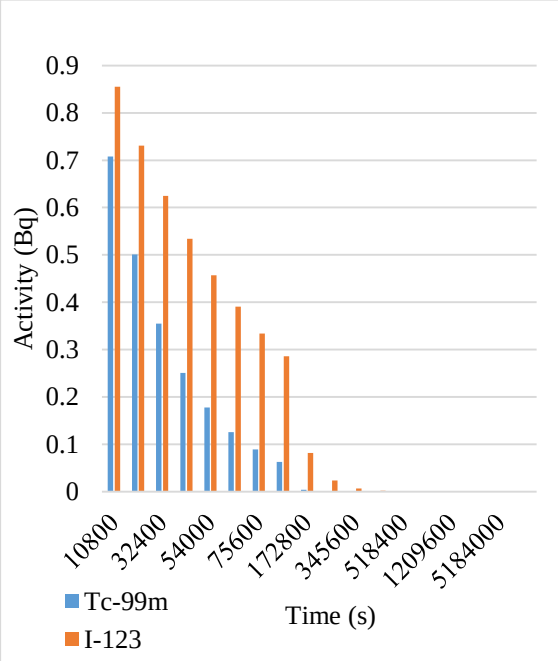

Fig 3: Comparison of the activity of ^{99m}Tc and ^{123}I isotopes as a function of time.

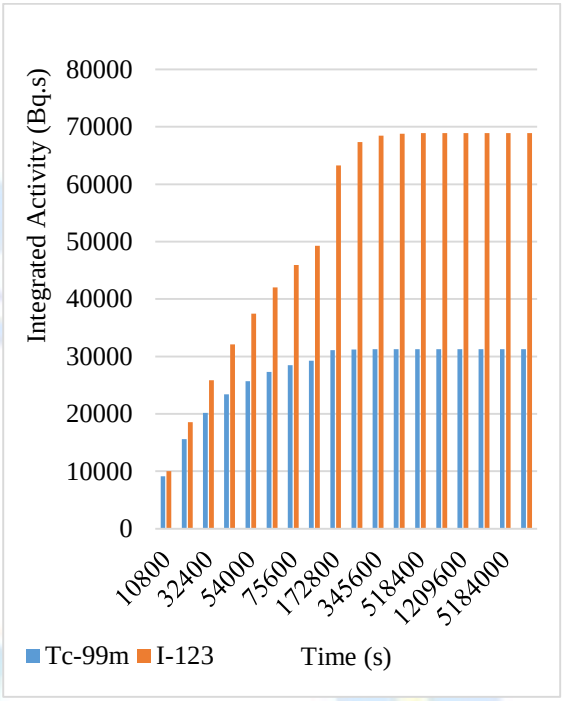

Fig 4: Integrated activity of ^{99m}Tc and ^{123}I.

B. Specific activity (Bq.s):

As previously mentioned, specific activity is defined as the activity per unit mass. We can calculate this value either using the general Eq.4 or by obtaining it from a database (Toolbox). The data indicates that the specific activity of ^{99m}Tc is higher than that of ^{123}I due to the inverse relationship with the radionuclide's half-life. TABLE I presents the specific activity values and their corresponding half-lives for both radionuclides.

Table I: Specific Activity and Half-Lives of the 99mtc and 123i.

Radionuclide	Half-life (h)	S_A (Bq/kg)
^{99m}Tc	6.02	7.11×10^{19}
^{123}I	13.2	1.949×10^{20}

C. Comparative analysis of Ingested Dose Coefficients:

The organ sensitivity to radiation exposure is shown in Fig. 5 and 6 for $^{99\ m}$Tc and ^{123}I for different age groups (ranging from infants to adults). The dose coefficient represents the equivalent dose delivered to a particular organ per unit of administered activity. The dose coefficients for $^{99\ m}$Tc are usually lower than those of ^{123}I. It has been shown that the Thyroid is the organ receiving the highest dose coefficient for infants, while the ULI_Wall was the most exposed organ to these coefficients in other age groups. These coefficients generally range between 7.75×10^{-11} and 4.73×10^{-10} Sv/Bq for most of the age categories included in the study. The results show an inverse relationship with age, which is consistent with radiological principles: dose coefficients are typically highest for infants and decrease with patient age, with the adult receiving the lowest dose per Becquerel. In addition to other biological factors, the main cause of this increase is children's smaller organ mass, which concentrates the administered activity in a smaller volume and results in a higher absorbed dose. The ^{123}I dose coefficients exhibit a very different pattern, which is mostly explained by iodine's strong biological affinity for the Thyroid. The Thyroid is the organ with the overwhelmingly highest dose coefficient. The Thyroid dose coefficient for infants is close to 1.00×10^{-08} Sv/Bq. In terms of quantitative comparison, the Thyroid dose coefficient for ^{123}I ($\approx10^{-08}$ Sv/Bq) is two orders of magnitude higher than the highest dose coefficient found for $^{99\ m}$Tc ($\approx10^{-10}$ Sv/Bq). The high dose disparity for the Thyroid is significant across all age groups, even though the coefficients decrease with age. In conclusion, the Thyroid receives a substantially greater dose from ^{123}I for the same administered activity than any other organ would from ^{99m}Tc. This important distinction emphasizes how important it is to carefully plan doses when using iodine isotopes, particularly in pediatric populations. Table II. shows a comparison between these two radioactive isotopes and their effect on diagnostic nuclear medicine.

Table II: Comparison And Impact on Nuclear Medicine.

Feature	^{99m}Tc	^{123}I
Organ with the Highest Dose	St_ Wall / ULI_Wall	Thyroid
Maximum Value	$\approx2\times10^{-10}$ Sv/Bq	$\approx10^{-08}$ Sv/Bq
Main Conclusion	The dose is mainly affected by the excretion pathway of radiopharmaceutical.	The dose is mainly affected by the excretion pathway of the radiopharmaceutical.

D. Analysis of Inhaled Dose Coefficients for ^{99m}Tc.:

A rigorous examination of Fig.7, 8, and 9 reveals that the spatial distribution of the absorbed dose is fundamentally dictated by the kinetics of the radionuclide's transfer from the pulmonary system to the systemic circulation, a process critically dependent upon its inherent solubility characteristic. In all three solubility types F, M, and S, the ET region (trachea and upper respiratory tract) and the Liver receive the highest dose coefficients. The highest values in the ET-Region range from approximately 1.79×10^{-10} Sv/Bq for adults up to 1.52×10^{-09} Sv/Bq for infants. Type F exhibits the highest dose in non-pulmonary organs such as the Liver, Thyroid, and St_Wall. This reflects the rapid absorption of the radionuclide from the lung into the bloodstream, followed by systemic distribution. Analysis of the Type S data confirms substantial dose deposition in both the ET region and the Lung, indicative of extended residence time and sluggish clearance from the respiratory tract. Furthermore, the Type M behavior is clearly delineated as an intermediate state, bridging the differences observed between Type F and Type S particulates.

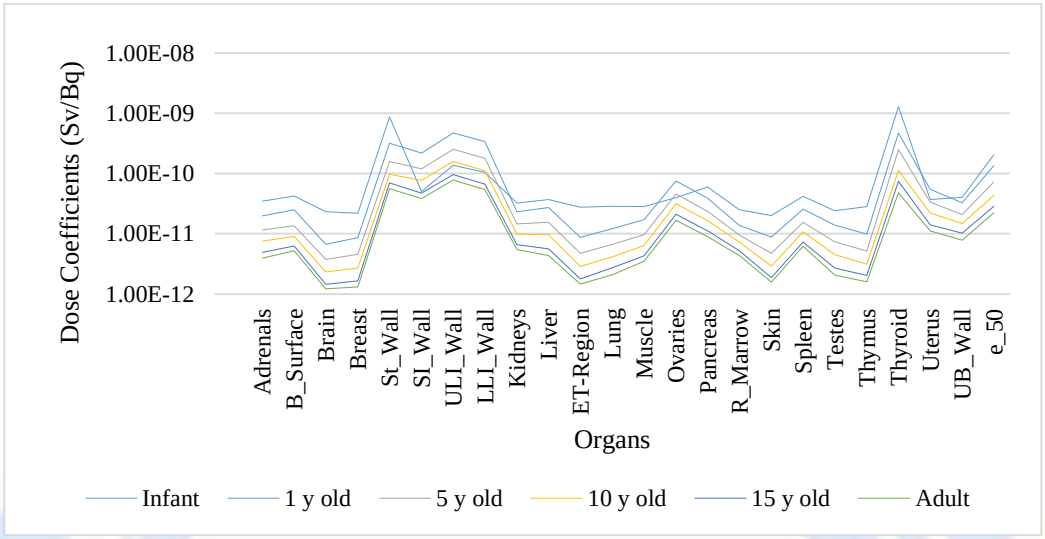

Fig 5: Variation in Organ Dose Coefficients (Sv/Bq) for ^{99m}Tc.

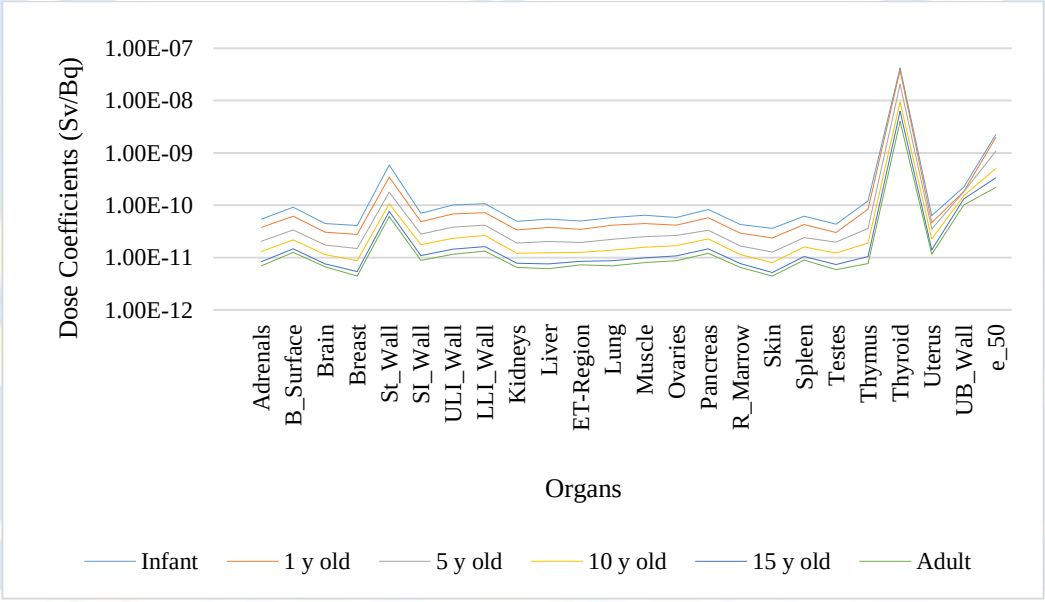

Fig 6: Variation in Organ Dose Coefficients (Sv/Bq) for ^{123}I.

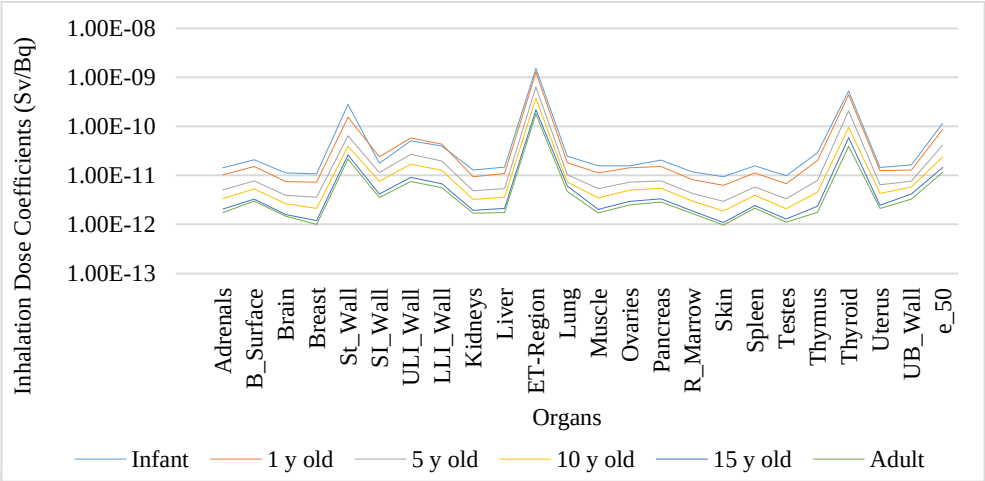

Fig 7: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type F Particulates.

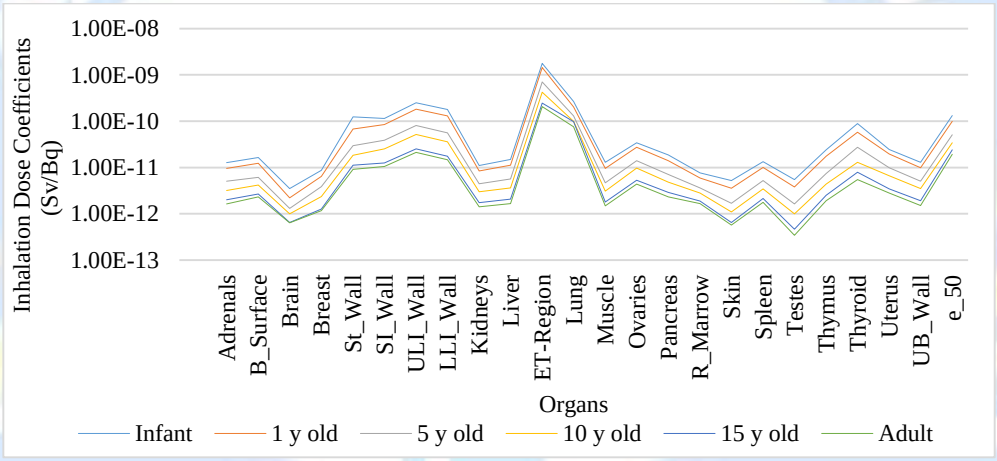

Fig 8: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type M Particulates.

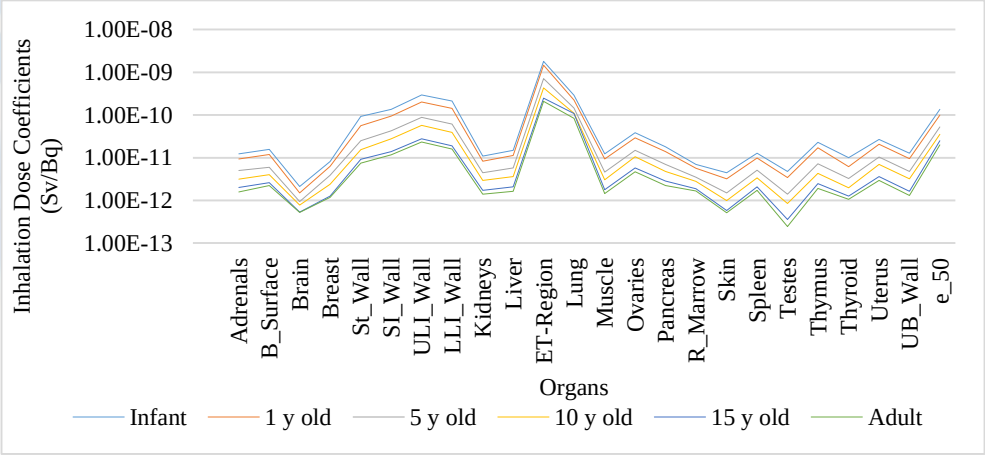

Fig 9: Inhalation Dose Coefficients (Sv/Bq) for ^{99m}Tc Type S Particulates.

E. Analysis of Inhaled Dose Coefficients for ^{123}I.:

A focused analysis of Fig. 10, 11, and 12 reveals a distinct and consistent pattern characterized by a highly concentrated absorbed dose. Specifically, the Thyroid Gland unequivocally emerges as the critical organ, receiving the maximal dose coefficient for the Type F particulate. This is attributable to the rapid absorption of iodine from the lung into the blood, followed by extremely fast biological uptake by the thyroid. The dose in the Thyroid peaks at 1.68×10^{-08} Sv/Bq for infa-nts and 1.39×10^{-09} Sv/Bq. Types M and S show slightly lower thyroid doses compared to Type F, due to partial retention in the ET_Region which delays its arrival into the bloodstream. With values ranging from 5.85×10^{-10} to 4.97×10^{-09} Sv/Bq for particles of type M and from 5.90×10^{-10} to 5.02×10^{-09} Sv/Bq for particles of type S. TABLE III. shows a comparison between these two radioactive isotopes and their effect on diagnostic nuclear medicine.

Table III: Comparison Between the Two Radionuclides and Clinical Effects.

Feature	^{123}I	^{99m}Tc
Maximum Dose Limit	$\approx10^{-09}$ Sv/Bq (In Liver / ET-Region)	$\approx10^{-07}$ Sv/Bq (In Thyroid)
Dose Difference	Approximately 100 times less than ^{123} I	Approximately 100 times higher than ^{99m} Tc
Crucial Dose Coefficient	Pulmonary/Intestinal Clearance and Chemical Compound Distribution	Biologically Determined Thyroid Binding Sites

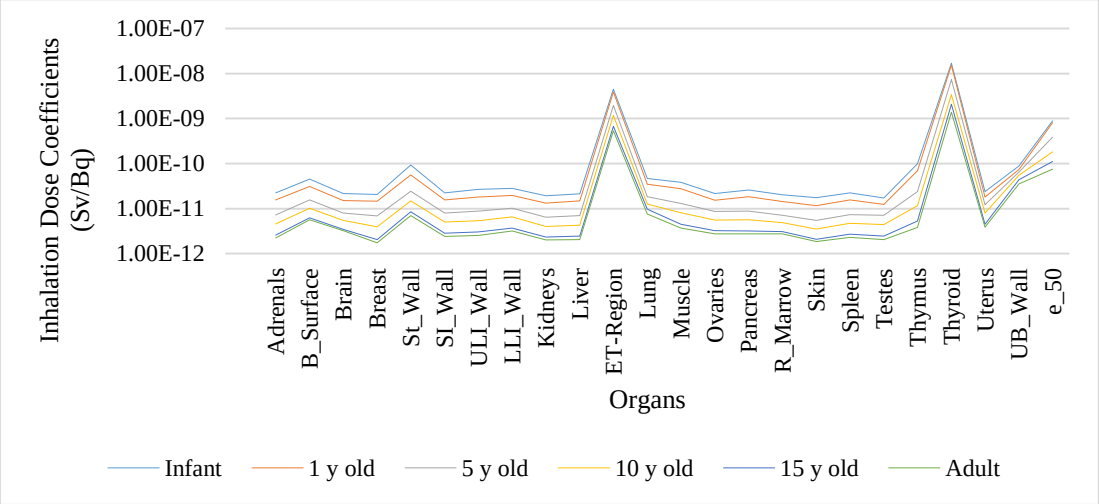

Fig 10: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type F Particulates.

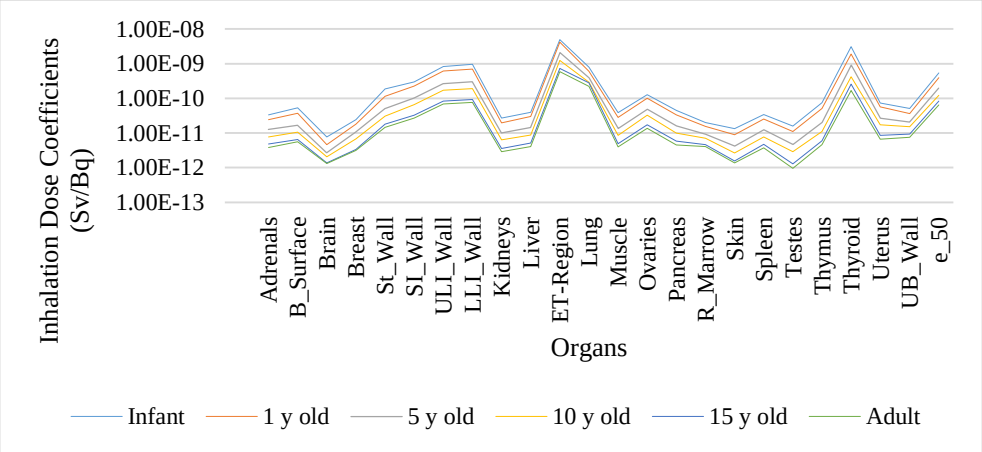

Fig 11: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type M Particulates.

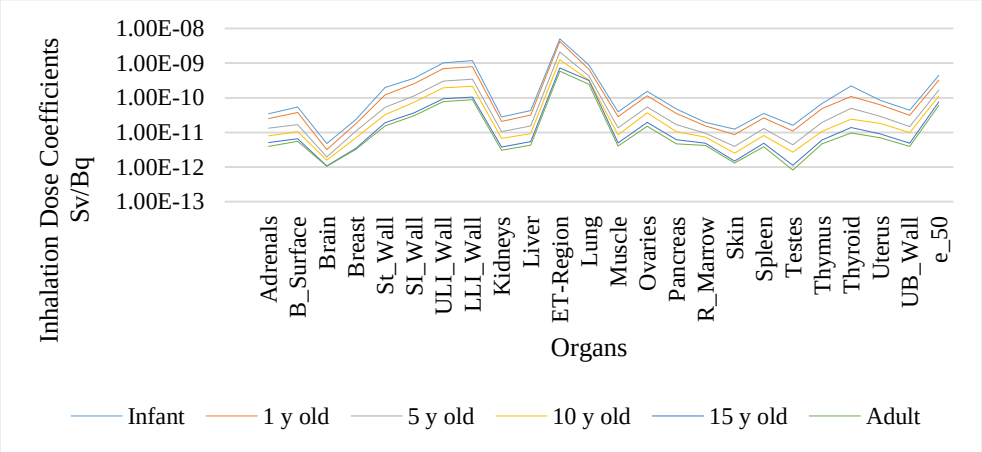

Fig 12: Inhalation Dose Coefficients (Sv/Bq) for ^{123} I Type S Particulates.

F. Risk Coefficient (Bq^{-1}):

1. Comparative Analysis of Ingestion Risk Coefficients (^{123}I and ^{99m} Tc):

The data clearly shows the risk coefficients for different organs resulting from the consumption of ^{123}I and ^{99m} Tc through two routes: drinking water (D Water) and food consumption, as shown in detail in Fig. 13 to 16.

Iodine-123: Exhibits a highly concentrated dose distribution pattern. The organ that unequivocally receives the highest risk coefficient is the Thyroid, with ingestion risk coefficients of 1.74×10^{-12} Bq^{-1} for mortality and 1.74×10^{-11} Bq^{-1} for morbidity for the 0-110 years age group.

Table IV: General Behavior and Maximum Risk Coefficients.

Radionuclide	Organ Receiving the Highest Risk Dose	Approximate Maximum Risk Value
^{123}I	Thyroid	Ranges between 10^{-10} - 10^{-09} Bq^{-1}
^{99m} Tc	Colon	Ranges between 10^{-11} - 10^{-10} Bq^{-1}

This is due to the high biological specificity of iodine towards this organ (rapid and vital uptake).

Technetium-99m: Shows a less concentrated dose distribution pattern. The organ that receives the highest risk coefficient is the Colon (and, to a

lesser extent, the Stomach), with ingestion risk coefficients of 7.78×10^{-13} and 2.28×10^{-13} Bq^{-1}, respectively for mortality and 7.78×10^{-13}, 2.53×10^{-13} $Bq^{-1}$for morbidity, for the 0-110 years age group. This indicates that the crucial dose factor is the excretion pathway and the passage of the radionuclide through the gastrointestinal tract before it is eliminated or partially absorbed.

For both radionuclides, there is no significant difference in risk coefficients between the drinking water and dietary intake pathways, indicating that the absorption and biological distribution mechanisms are key in determining final doses. Total risk values are higher for ^{123}I compared to ^{99m}Tc, primarily due to the larger dose received by the Thyroid ^{123}I.

All graphs demonstrate that younger age groups (specifically 0-5 years and 5-15 years) generally receive the highest risk coefficients compared to older age groups (25-70 years and 0-110 years).

2. Impact on Morbidity and Mortality Rates:

The final health risks are represented by the Total values, which include the subsequent cancer risks (morbidity and mortality).

Iodine-123: The Total risk is very high, driven mainly by the risk of Thyroid cancer.

Technetium-99m: The Total risk is much lower than that of ^{123}I. The organs that contribute most to the overall risk are those receiving the highest dose (the Colon and Stomach).

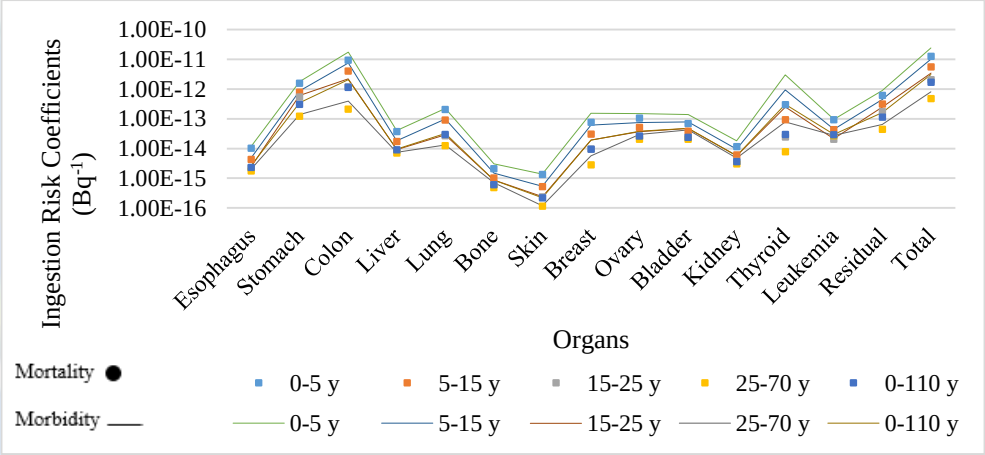

Fig 13: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{99m}Tc via Dietary.

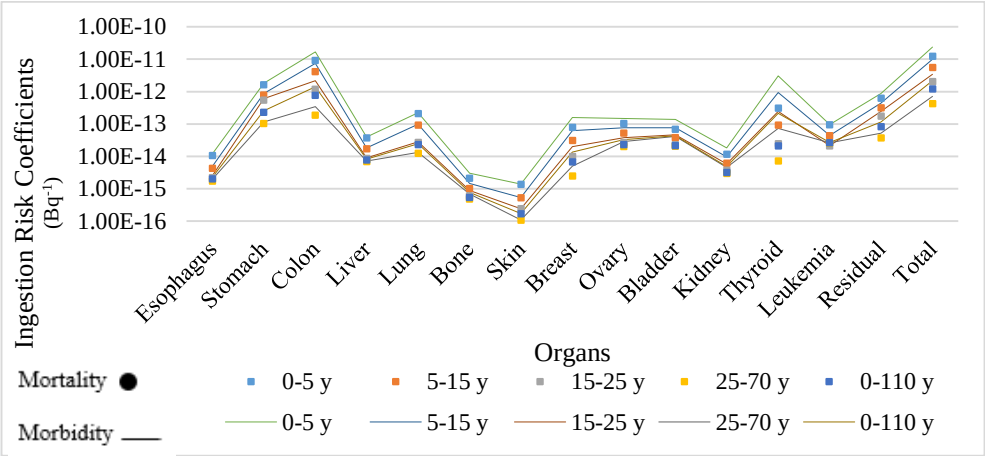

Fig 14: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{99m}Tc via Water Pathways.

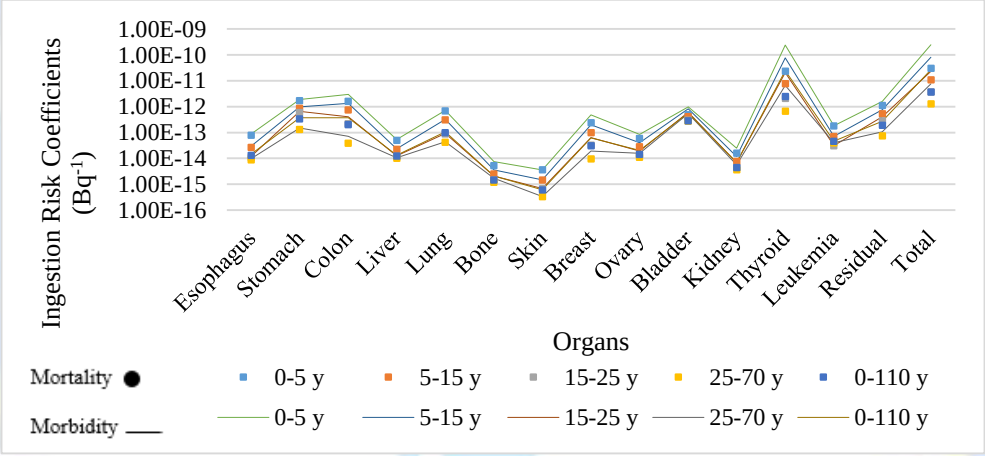

Fig15: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{123}I via Dietary.

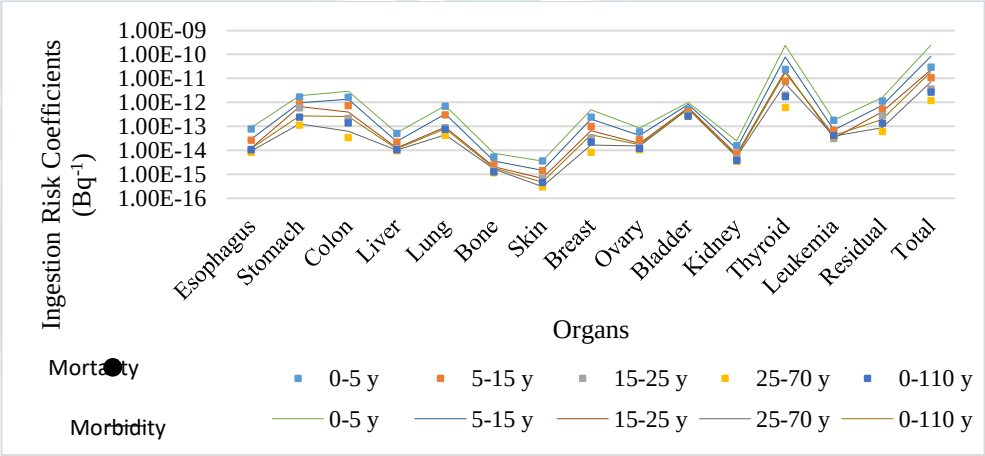

Fig 16: Comparison of Age-Dependent Ingestion Risk Coefficients (Bq^{-1}) for ^{123}I via Water Pathways.

3. Comparative Analysis of Inhaled Radiation Risk Coefficients (Bq^{-1}):

A comprehensive dosimetry assessment, depicted across Fig. 17 to 19 for Particulate

Types F, M, and S, precisely quantifies the organ-specific and total-body inhalation risk coefficients over the lifetime (0-110 years). These derived coefficients inherently reflect the estimated probability of both cancer incidence (morbidity) and subsequent mortality per unit of inhaled activity.

- **Fast Absorption Particulates (Type F):** Type F particulates generally show a concentrated risk in organs where the radionuclide accumulates rapidly after reaching the bloodstream. For ^{123}I, the Thyroid stands out as the organ with the significantly highest risk across all types. This is particularly evident in Type F (especially for morbidity) because Iodine is rapidly absorbed by the thyroid. For ^{99m}Tc, which does not undergo organification in the thyroid like ^{123}I, the risk concentration in the thyroid is relatively lower compared to ^{123}I, although it still shows elevated risk in some other organs.

- **Particulates with Moderate and Slow Absorption (Type M & S):** As solubility decreases (from M to S), the residence time of the particulates in the respiratory tract (lungs and airways) increases, leading to a higher local radiation dose in the Lung. Slower absorption also reduces the activity reaching distant organs (such as the bladder, kidneys, and spleen) during the early stages, thereby altering the dose distribution.

In all cases, the risk coefficients for morbidity (cancer incidence) are higher than the risk coefficients for mortality for the same organ and for the total risk. This reflects the fact that the probability of developing cancer (morbidity) is greater than the probability of that cancer being fatal (mortality), a fundamental principle in radiation risk assessment models. TABLE. V illustrates the highest mortality and morbidity risk coefficients for the two radionuclides across all particulate types.

Table V: The Highest Mortality and Morbidity Risk Coefficients for the Two Radionuclides Across All Particulate Types.

		Type F					
^{99m}Tc				**^{123}I**			
Mortality		**Morbidity**		**Mortality**		**Morbidity**	
Organs	Value	organs	Value	organs	Value	organs	Value
Stomach	1.08×10^{-13}	Thyroid	2.15×10^{-13}	Thyroid	7.64×10^{-13}	Thyroid	7.64×10^{-12}
Colon	1.04×10^{-13}	Colon	1.89×10^{-13}	Bladder	9.39×10^{-14}	Bladder	1.88×10^{-13}
Lung	5.21×10^{-14}	Lung	5.49×10^{-14}	Lung	8.71×10^{-14}	Lung	9.17×10^{-14}
Type M							
Mortality		Morbidity		Mortality		Morbidity	
Organs	Value	organs	Value	organs	Value	organs	Value
Lung	7.78×10^{-13}	Lung	8.19×10^{-13}	Lung	2.27×10^{-12}	Lung	2.39×10^{-12}
Colon	2.96×10^{-13}	Colon	5.38×10^{-13}	Colon	1.18×10^{-12}	Colon	2.15×10^{-12}
Stomach	4.73×10^{-14}	Stomach	5.26×10^{-14}	Thyroid	9.30×10^{-14}	Thyroid	9.30×10^{-13}
Type S							

Mortality		Morbidity		Mortality		Morbidity	
Organs	Value	organs	Value	organs	Value	organs	Value
Lung	8.59×10^{-13}	Lung	9.04×10^{-13}	Lung	2.51×10^{-12}	Lung	2.65×10^{-12}
Colon	3.25×10^{-13}	Colon	5.91×10^{-13}	Colon	1.35×10^{-12}	Colon	2.45×10^{-12}
Stomach	3.91×10^{-14}	Stomach	4.35×10^{-14}	Stomach	8.20×10^{-14}	Stomach	9.11×10^{-14}

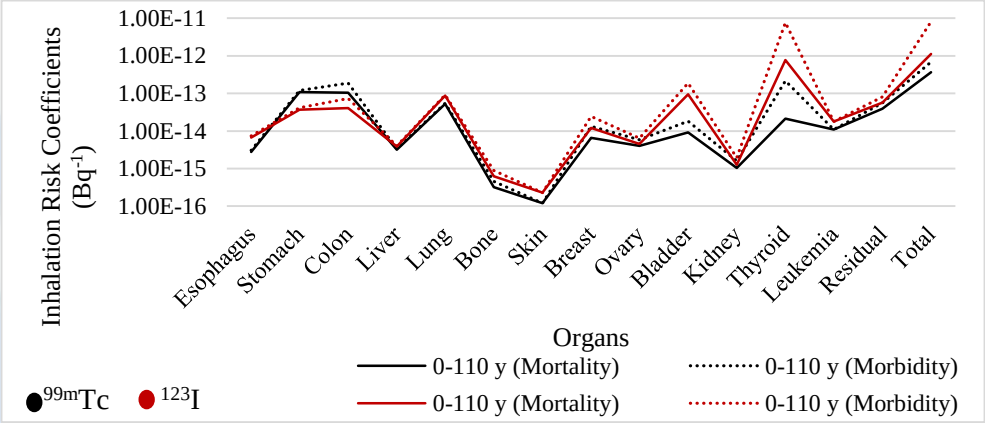

Fig 17: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type F Solubility.

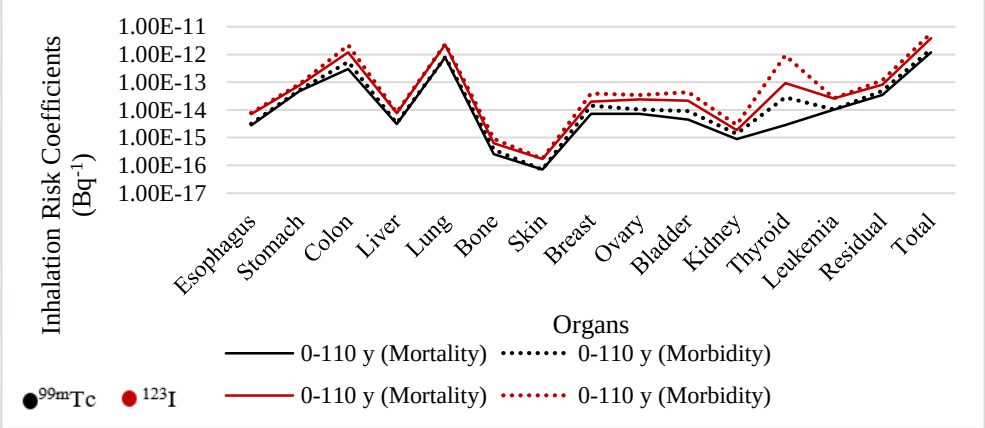

Fig 18: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type M Solubility.

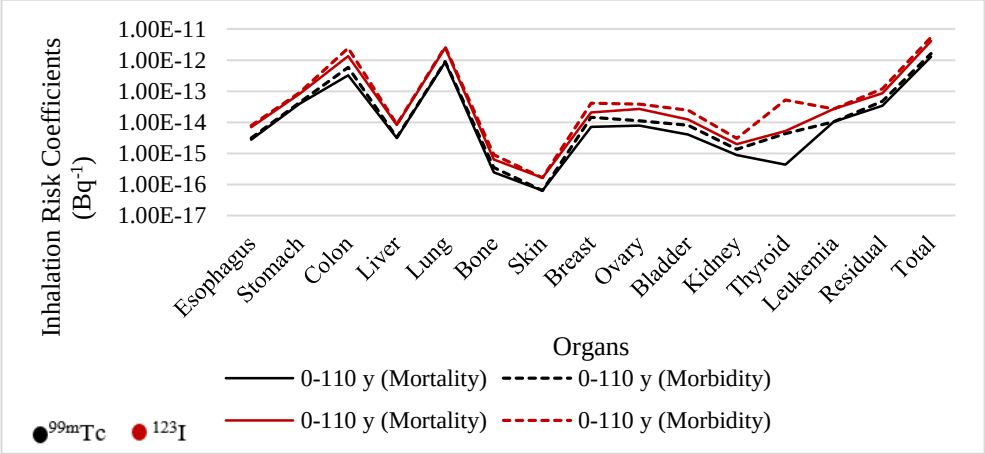

Fig 19: Comparative Inhalation Risk Coefficients (Mortality and Morbidity) for ^{99m}Tc and ^{123}I of Type S Solubility.

CONCLUSION

Based on the study of the physical behavior of ^99m^Tc and ^123^I, a comparative analysis of dose and hazard parameters according to biological behavior and properties of radionuclides reveals several points, namely:

- The short half-life of ^99m^Tc has the following advantages: Over a very brief time (one day), it produces a concentrated burst of radioactivity. In many medical imaging applications where the lowest radiation dose while maintaining image quality is required, this is the recommended option because it drastically lowers the cumulative radiation dose to which the patient is exposed (about 2.3 times less than iodine).

- An advantage of ^123^I is its comparatively longer half-life. The persistence of its integrated activity over a longer period of time (up to two weeks) may make it appropriate for studies requiring extended biological tracing or when the time required for the radiotracer's absorption and distribution within the body is longer, despite the fact that its decay is slower and its cumulative dose is higher. As a result, choosing a radionuclide in nuclear medicine involves carefully weighing the patient's cumulative radiation dose, which should ideally be kept to a minimum, against the amount of time needed to gather the required clinical data.

- Upon comparing the specific activities, ^99m^Tc exhibited a higher specific activity compared to Iodine, which is attributed to its shorter half-life. A higher specific activity is associated with superior image quality for a very small quantity of the radiopharmaceutical.

- Iodine-123 exhibits a highly specific biological mechanism resulting in an extremely concentrated dose to the Thyroid, leading to a very high localized risk, especially for Thyroid cancer (morbidity). Technetium-99m, by contrast, has a less concentrated distribution, mainly affecting the colon and stomach wall upon intake. In all evaluated scenarios, the overall health risk (including morbidity and mortality) for ^123^I is consistently and significantly higher than that of ^99m^Tc.

- According to a universal principle, the risk coefficients for morbidity (or cancer incidence) are always higher than those for mortality for both radionuclides. This is because there is a greater chance of developing cancer than of it turning out to be lethal. The general principle is that age has an inverse relationship with dose coefficients. Accordingly, the dose received

per administered becquerel is lowest for adults and highest for infants.

RECOMMENDATIONS

- Conducting research in the field of dose reduction and the development of radiopharmaceuticals.
- Verification of the clinical implications of the higher overall risks associated with ^{123}I.
- Establish optimized and standardized (or generalized) dosing protocols based on age.

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Enhancing Libya's Healthcare System Through Technical and Vocational Education in Medical Engineering

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الملخص:

يواجه النظام الصحي في ليبيا تحديات مزمنة، منها تقادم البنية التحتية وضعف صيانة الأجهزة الطبية ونقص المهندسين الطبيين المؤهلين، مما يؤثر في جودة الرعاية وسلامة المرضى. وتشير التقارير إلى أن أكثر من 40٪ من الأجهزة الطبية في بعض المستشفيات خارج الخدمة بسبب نقص الدعم الفني المتخصص.

تبحث الدراسة في دور تطوير تعليم وتدريب الهندسة الطبية في تعزيز القطاع الصحي، من خلال تحديث المناهج، وإنشاء مراكز تدريب عملي، وتعزيز التعاون بين الجامعات والمستشفيات. كما توصي بالاستثمار في هذا المجال لتقليل الاعتماد على الخبرات الأجنبية وتحسين كفاءة وجودة الخدمات الصحية في ليبيا.

الكلمات المفتاحية: الهندسة الطبية، الرعاية الصحية في ليبيا، التدريب المهني، المعدات الطبية، تطوير التعليم.

ABSTRACT: Libya's healthcare system faces longstanding challenges, including outdated hospital buildings, poorly maintained medical equipment, and a shortage of qualified medical engineers. These issues compromise patient safety and care quality. Medical engineering, which integrates medicine, technology, and engineering, is essential to ensure medical devices function correctly and safely. However, education and training in this field in Libya remain limited, creating a gap between the demand for skilled professionals and their availability. This study explores how developing medical engineering education and technical training can strengthen healthcare in Libya. By reviewing international practices and comparing them with local conditions, it highlights the need to update university curricula, establish hands-on training centers, and foster collaboration between hospitals and academic institutions. Reports indicate that over 40% of medical equipment in Libyan hospitals is out of service, mainly due to insufficient specialist support, increasing costs and posing risks to patients. Recent initiatives, including the First International Conference on Medical Engineering Sciences and Technologies in Tripoli, and efforts by institutions such as the Higher Institute of Medical Sciences and Technology in Hon and the Arab Medical and Technical University in Benghazi, reflect growing recognition of this field. Reconstruction projects in Benghazi also provide opportunities to integrate medical education with facility development.

The study recommends renewing academic programs, opening specialized training centers, and building international collaborations. Investing in medical engineering education will reduce dependence on foreign expertise and contribute to safer, more reliable, and cost-effective healthcare, ultimately supporting a healthier future for Libya's population.

Keywords: Medical Engineering, Healthcare in Libya, Vocational Training, Medical Equipment, Education Development.

I. INTRODUCTION

The healthcare system is the foundation of sustainable development in any society. As Libya's health sector faces many growing challenges, it is important to find new solutions that can improve the quality of healthcare services and increase the efficiency of workers. One way to strengthen Libya's healthcare system is through technical and vocational education in medical engineering. This field plays an important role in supporting health facilities, maintaining modern medical equipment, and ensuring their proper use. Investing in this type of education by developing curricula and training qualified staff for maintenance work can help reduce the gap between healthcare needs and human resources. It

is also a key step toward building a strong and modern healthcare system that keeps up with technological progress in medicine and reducing dependency on foreign technical support.

As part of the efforts to evaluate the healthcare system, our team conducted field visits to a number of healthcare institutions to examine the current situation and the level of collaboration between Libyan technical competencies and hospitals. Despite the limited cooperation in some institutions, these visits provided a realistic picture of the Libyan healthcare sector from technical and administrative perspectives. A survey was also conducted, involving a group of healthcare workers as well as graduates and professors of biomedical engineering, aiming to gather their opinions and evaluate the status of technical education and its relevance to the labor market and the requirements for developing the healthcare system.

The results of this study serve as a fundamental basis for proposing improvements to the healthcare system in Libya through the enhancement of technical and vocational education in the field of biomedical engineering, contributing to improving the quality of healthcare services and raising the efficiency of the workforce. This paper is divided into the following sections:

- Section Two: Reviews previous studies related to the role of technical and vocational education in developing healthcare systems.
- Section Three: Presents the research methodology and the field procedures followed.
- Section Four: Shows the results of the visits and surveys conducted.
- Section Five: Discusses the results and proposes ways to develop the Libyan healthcare system.
- Section Six: Provides the conclusion and future recommendations.

II. LITERATURE REVIEWS

Biomedical engineering plays a crucial role in linking technology and healthcare delivery, yet education and practice in this field remain underdeveloped in many low- and middle-income countries. Lustick and Zaman (2011) pointed out that most developing countries face serious shortages in biomedical engineering education and innovation, which directly limits their ability to address healthcare challenges effectively. They argued that the lack of institutional support and structured academic programs prevents the development of sustainable healthcare technologies.

De Maria *et al.* (2022) analyzed the state of biomedical engineering in low- and middle-income settings and found that medical devices are often unsuited for local environments. They studied the main weaknesses and strengths of biomedical engineering in low-income countries and noted that many devices do not work well in difficult environments because maintenance is limited. Devices tend to fail in harsh or remote conditions where maintenance capacity is weak. This mismatch between technology and context results in a high percentage of equipment being out of service, which echoes the current situation in Libya, where more than 40% of hospital devices are reportedly nonfunctional.

Similarly, Oden *et al.* (2010) introduced a new approach in bioengineering education that engages undergraduate students in solving real global health problems, beginning with freshman design projects and continuing through senior capstone experiences. Such hands-on curricula are considered effective for fostering innovation and preparing graduates for the technical realities of healthcare systems in developing regions.

Nkuma-Udah *et al.* (n.d.) have noted the importance of collaboration between institutions in developed and developing countries to strengthen biomedical engineering capacity. They argued that partnerships, such as the Engineering World Health program, can help transfer both technical expertise and educational methodologies, creating a more self-reliant engineering workforce.

Recent literature has also highlighted the opportunities that come with targeted investment in biomedical education. Raxworthy *et al.* (2022) reported that in East Africa, initiatives connecting universities, hospitals, and international partners have started to improve healthcare delivery by

strengthening engineering support systems. Such models demonstrate that collaboration, contextualized training, and policy alignment are critical to making biomedical engineering a sustainable driver of healthcare improvement.

Monzon (n.d.) observed that biomedical engineering education globally must evolve to reflect the dynamic and interdisciplinary nature of the profession. Likewise, Douglas (n.d.) proposed that programs in developing countries should prioritize local innovation and adaptability rather than merely replicating Western models. These perspectives suggest that for countries like Libya, national strategies should combine theoretical education with locally relevant applications and continuous technical training.

Abdulhay *et al.* (2017) identified weaknesses in the curriculum by tracking shortcomings in the achievement level of each outcome. Subsequently, actions were then taken to address these gaps, and these actions were also mapped to the students' medical-related outcomes.

In summary, previous research consistently shows that strengthening biomedical engineering education in developing countries is essential for ensuring the functionality, safety, and affordability of medical technologies. The evidence indicates that educational reform, hands-on training, and international cooperation can significantly enhance healthcare outcomes. In Libya, aligning these global lessons with national healthcare reconstruction could help build a stronger, more resilient health system supported by skilled biomedical professionals.

III. METHODOLOGY

This study adopts a methodology based on data collection through a survey to explore the current status of medical engineering education and its relation to the labor market in Libya.

3.1 Data Collection:

- The survey was conducted both on paper and online using an electronic form to facilitate participation and efficiently gather data.
- The survey link was sent to participants who voluntarily completed it, enabling the collection of quantitative data from healthcare workers and medical engineering graduates. The survey aimed to gather quantitative information regarding the development of technical and vocational education in medical engineering to strengthen Libya's healthcare system.
- In addition, interviews were conducted with hospital technicians, medical engineers, and academic faculty members. These interviews provided qualitative insights into the challenges, training needs, and potential strategies to improve healthcare support.

3.2 Sample Selection:

Participants were randomly selected from within the relevant field to ensure that all groups related to healthcare were represented, including medical engineering graduates as well as hospital staff with various roles and levels of experience. This approach ensured a diverse and representative sample for both the survey and interviews.

3.3 Data Analysis:

Quantitative survey data were analyzed using descriptive statistics to identify trends, gaps, and priorities. Qualitative interview data were coded and analyzed thematically to extract key patterns and recommendations.

3.4 Comparative Review:

The study also included a review of international practices in medical engineering education and hospital maintenance. These findings were compared with the Libyan context to identify applicable strategies and best practices. This methodology allows for a comprehensive understanding of the technical and educational challenges in Libya's healthcare system and provides a solid foundation for making practical recommendations to enhance medical engineering capabilities.

IV. RESULTS

Table 1: Participant Characteristics of Participants (Percentages):

As shown in Table 1, the majority of participants were female (56.1%), and most were healthcare professionals (61%). The sample included a diverse range of educational qualifications, job

positions, and years of experience, ensuring representativeness of the relevant population.

Table 1: Participant Profile (Percentages):

Category	Sub C.	Percentage (%)
Gender	Male	43.9
	Female	56.1
Educational Qualification	Diploma	22.0
	Bachelor's Degree	24.4
	Master's Degree	29.3
	PhD	24.4

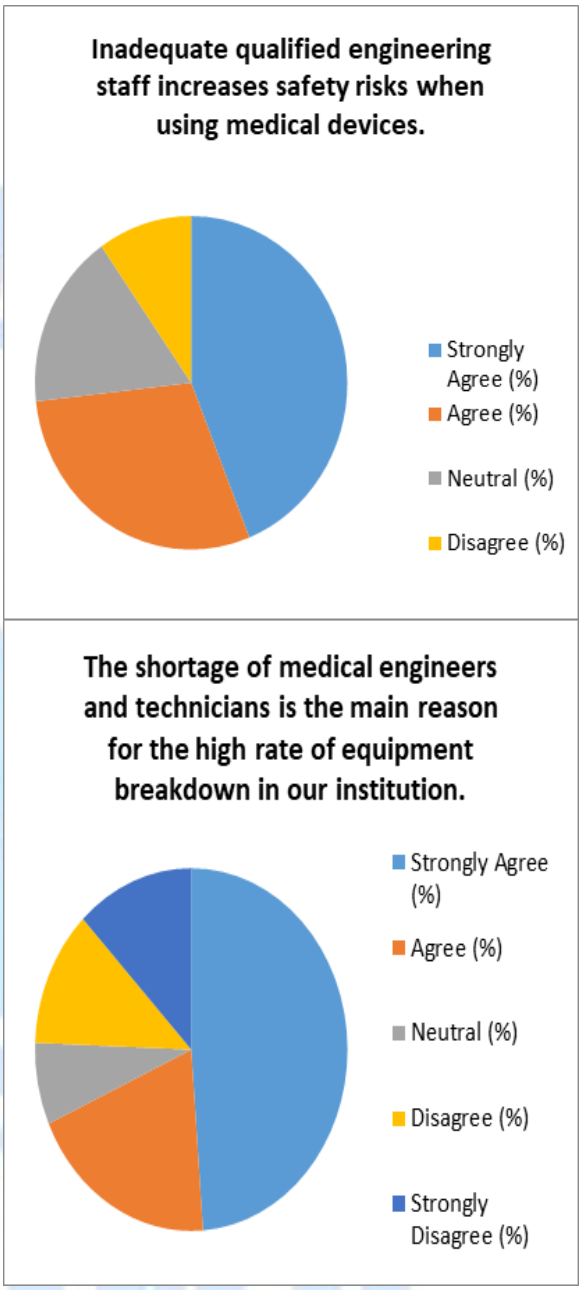
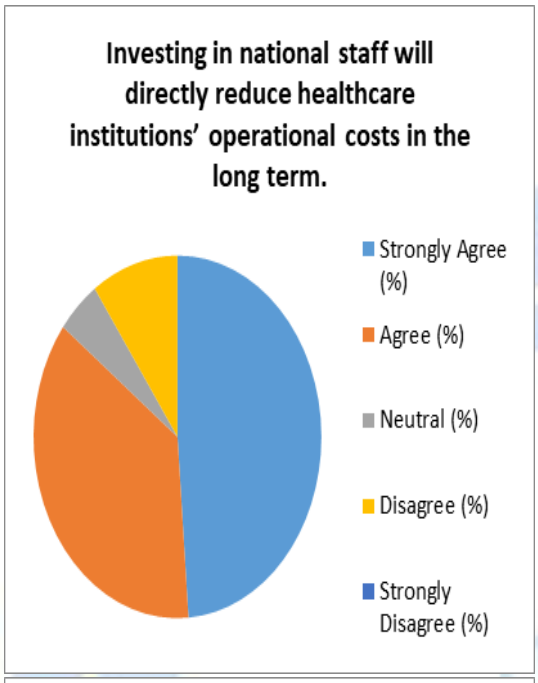
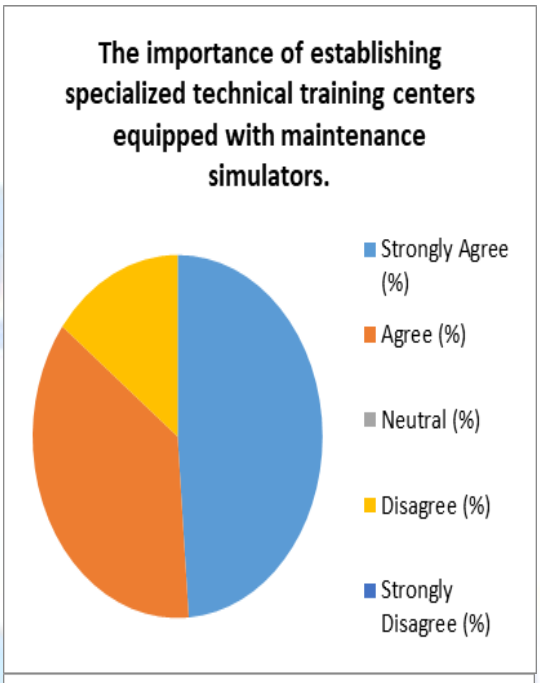
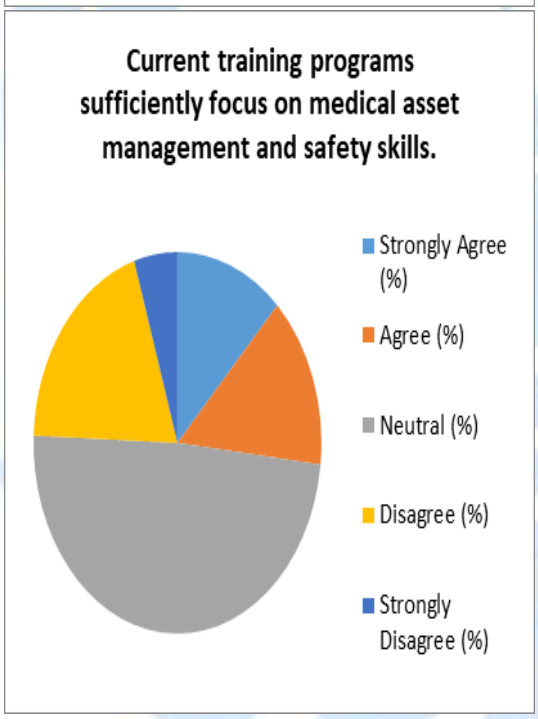


Fig. 1: Participants' Perceptions of the Effect of Inadequate Medical Engineering Staff on Medical Device Safety.







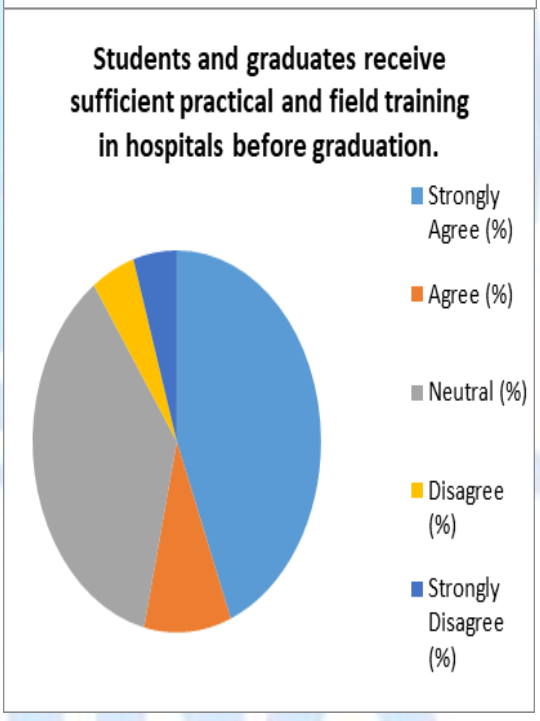
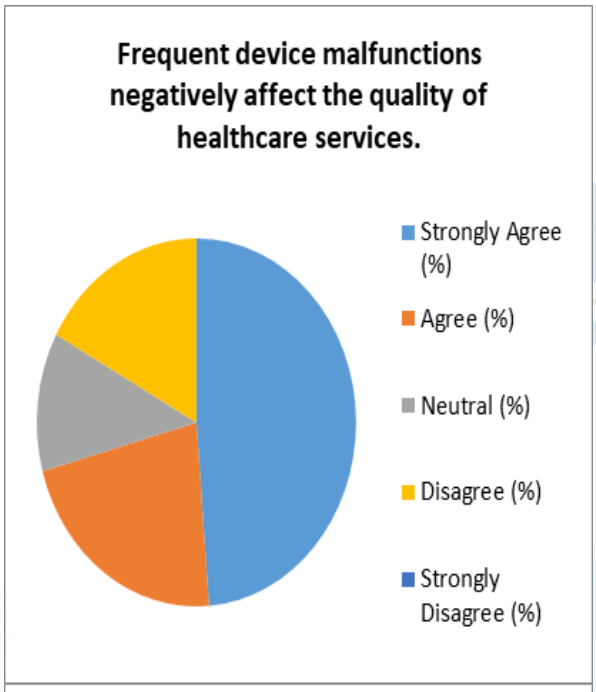
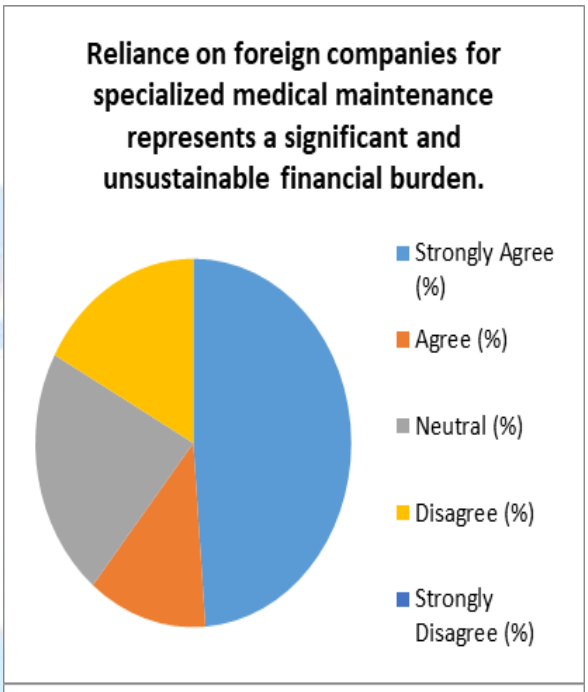
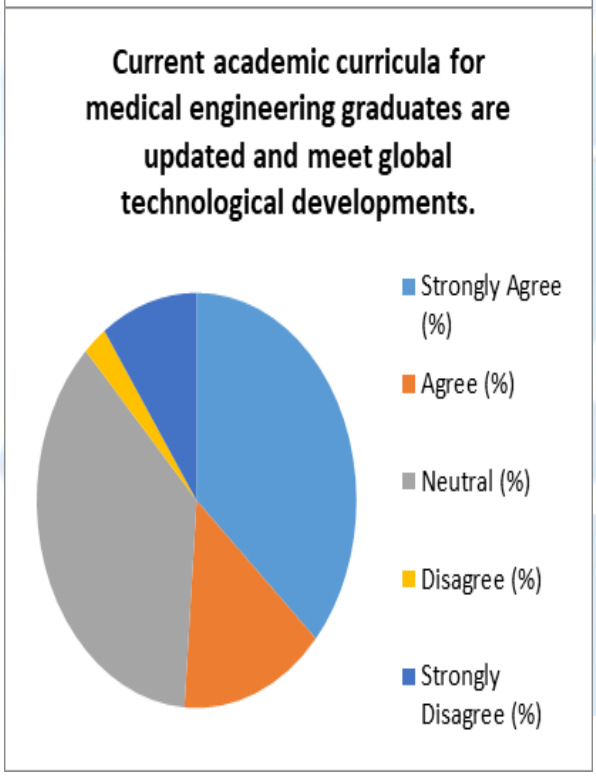


Fig. 2: Investment in National Staff and Cost Reduction and Need for Specialized Technical Training Centers.

Fig. 3: Effectiveness of Current Training Programs And Adequacy of Practical Training Before Graduation.







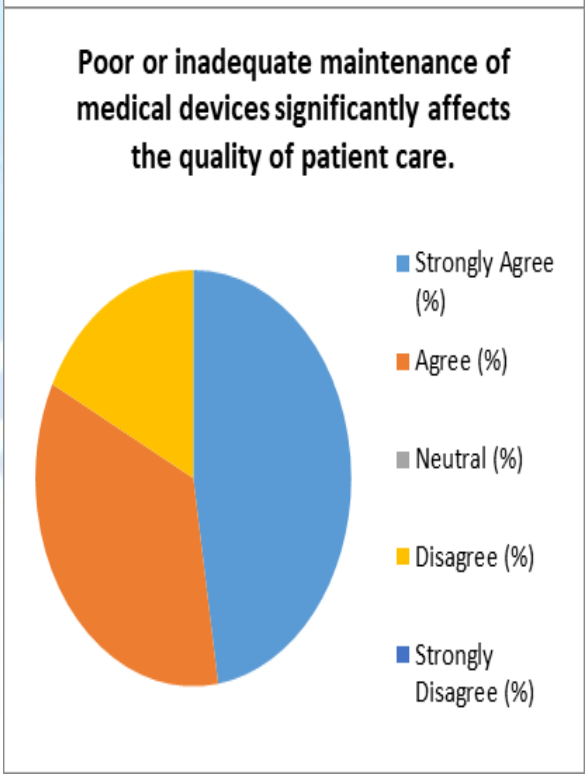


Fig.4: Frequent device malfunction and current academia curricula.

Fig.5: Relying on foreign companies, and maintenance of medical devices.

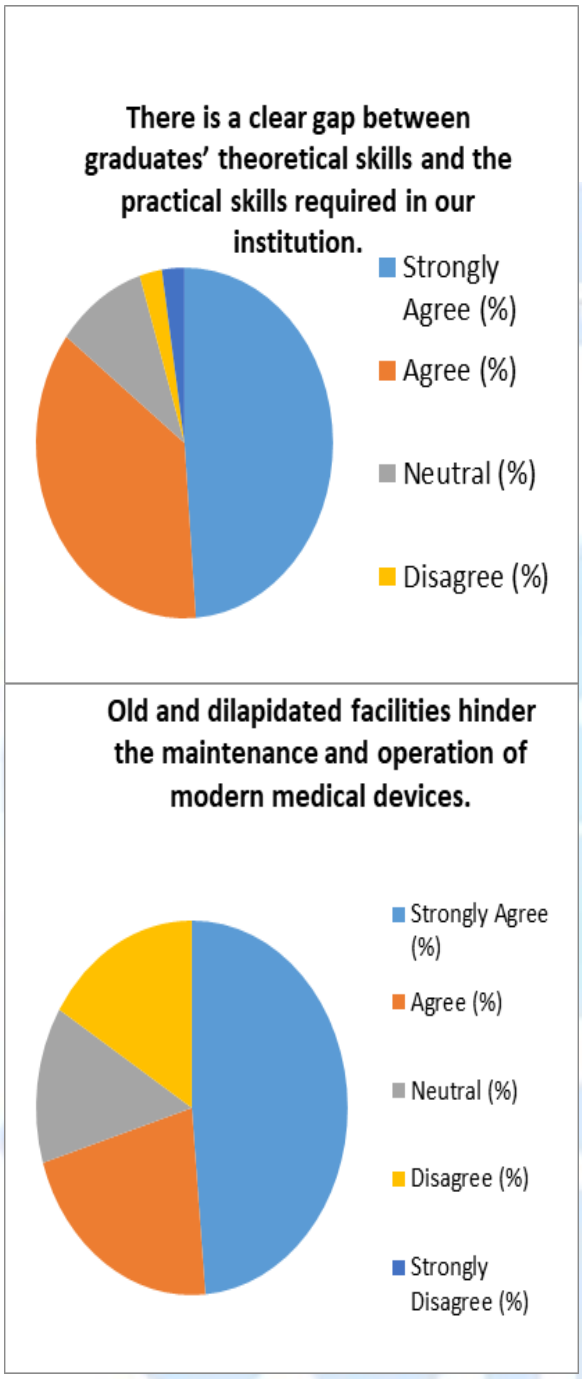
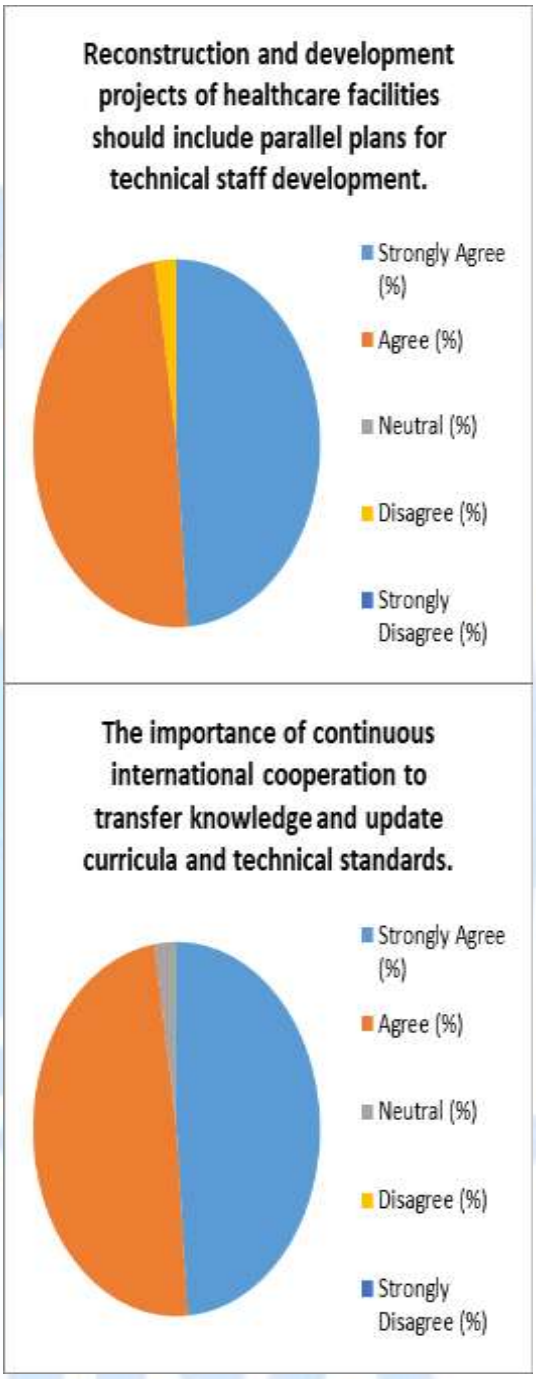


Fig. 6: Gap between graduates and theoretical and practical skills, and old with the dilapidated facilities hinders.



Fig, 7: Recon-instruction and development of HCF, and International corporation importances.

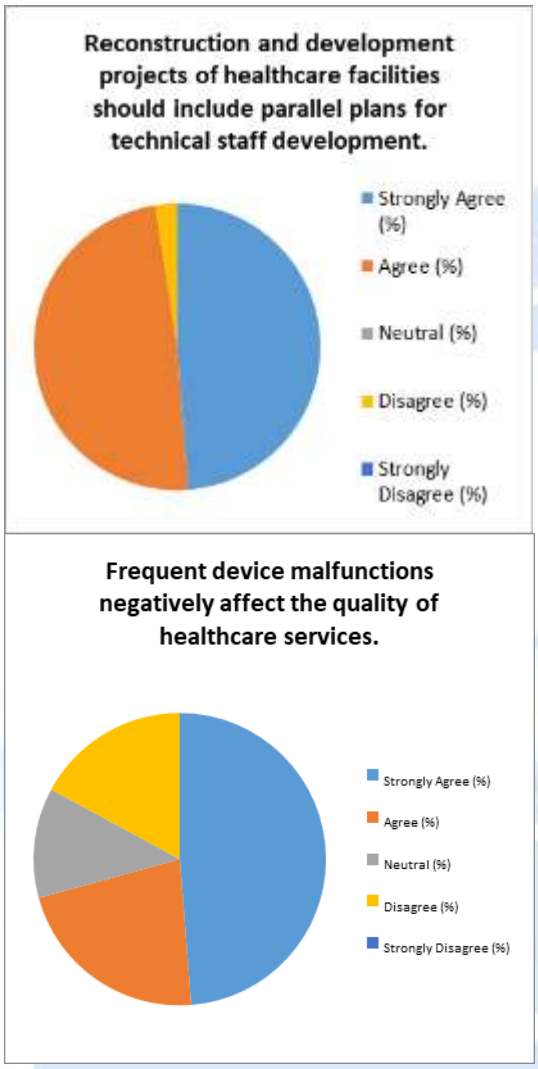


Fig. 8: Recon instruction and development project and the effect of frequent devices malfunction.

Interview Findings (Qualitative Results):

From interviews with hospital technicians, medical engineers, and academic faculty:

- Shortage of qualified personnel: Most participants emphasized the lack of skilled engineers and technicians as a major factor affecting equipment maintenance.
- Need for practical training: Several respondents highlighted that current academic programs do not provide enough hands-on experience in hospitals.
- Infrastructure challenges: Outdated or poorly maintained facilities hinder proper operation and maintenance of medical devices.
- Importance of specialized training centers: Interviewees recommended establishing technical centers with simulators for maintenance practice.
- Collaboration and international exposure: Strong interest was expressed in partnerships between hospitals, universities, and international institutions to update curricula and transfer knowledge.

V. ANALYSIS / DISCUSSION

Based on the quantitative and qualitative data collected:

1. Shortage of Skilled Personnel: Both survey and interview data indicate a significant shortage of qualified medical engineers and technicians. Approximately 48–50% of participants strongly agreed that this shortage leads to frequent equipment malfunctions and increased safety risks. Interviews highlighted that hospitals often rely on foreign companies for maintenance, increasing operational costs.
2. Gaps in Practical Training: Survey responses show a clear gap between graduates' theoretical knowledge and the practical skills required in healthcare institutions. Only a small percentage of participants agreed that students receive sufficient hands-on training before graduation. Interviews reinforced the need for structured practical training in hospitals and specialized technical centers.
3. Infrastructure and Equipment Maintenance Challenges:
   Old and poorly maintained facilities hinder the proper use and maintenance of modern medical devices. Frequent equipment failures affect the quality of healthcare delivery, as indicated by both quantitative and qualitative data.
4. Importance of Collaboration and International Exposure:
   Strong agreement exists among participants on the need for partnerships between healthcare institutions and academic bodies. International cooperation is seen as vital for updating curricula, transferring knowledge, and adopting modern technical standards.

5. Educational Program Gaps: Survey data show that current academic curricula partially meet global technological developments, but practical training and asset management skills are insufficient. Participants recommend updating curricula, integrating hands-on hospital training, and emphasizing management and safety skills.

VI. RECOMMENDATIONS

Based on the analysis, the study proposes the following recommendations:

1. Enhance Medical Engineering Education:
- Update academic curricula to reflect current technological developments.
- Incorporate structured practical training in hospitals and technical centers.
2. Establish Specialized Training Centers:
- Provide well-equipped centers with simulators for maintenance practice.
3. Strengthen Partnerships:
- Develop long-term collaborations between universities, hospitals, and international institutions to exchange knowledge and best practices.
4. Invest in National Staff:
- Focus on training local engineers and technicians to reduce dependency on foreign maintenance services and lower operational costs.
5. Integrate Training into Reconstruction Projects:
- Ensure that healthcare facility development projects include parallel plans for technical staff training and capacity building.

VII. CONCLUSION

This study highlights the critical role of medical engineering education and technical training in improving Libya's healthcare system. The findings show significant gaps in personnel, practical skills, and infrastructure that affect healthcare quality and patient safety. Implementing the proposed recommendations—updating curricula, establishing training centers, fostering partnerships, and investing in national staff—can provide a sustainable foundation for safer, more efficient, and cost-effective healthcare in Libya.

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Interpretation of Applied Radiation Biology

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الملخص: نشأ علم بيولوجيا الإشعاع في أعقاب اكتشاف الأشعة السينية والنشاط الإشعاعي أواخر القرن التاسع عشر، ليصبح أحد الركائز الأساسية في الطب الحديث (Becquerel, 1896; Curie & Becquerel, 1901). يستعرض هذا البحث التطور التاريخي لهذا المجال، بدءاً من أعمال كل من رونتجن وبيكريل وكوري، مروراً باكتشاف التأثيرات البيولوجية للإشعاع وتطور تقنيات العلاج الإشعاعي ومعايير السلامة (Patton, 1992). كما يناقش البحث قانون بيرجوني وتريبوندو المتعلق بالحساسية الإشعاعية، ومبدأ تجزئة الجرعات الإشعاعية، والنسبة العلاجية، ونموذج العلاقة الخطية غير العتبية (LNT) المستخدم في تقدير المخاطر الإشعاعية

(Bergonié & Tribondeau, 1906; Regaud, 1901; Holthusen, 1936; ICRP, 2007).

لقد أسهم التقدم التكنولوجي والتعمق في الفهم البيولوجي في تحسين نتائج علاج السرطان وتقليل المخاطر المصاحبة للعلاج. يختتم البحث بمناقشة التحديات الراهنة والاتجاهات المستقبلية في هذا المجال، مع التأكيد على ضرورة الموازنة بين الفوائد العلاجية والمخاطر المحتملة.

الكلمات المفتاحية: بيولوجيا الإشعاع، العلاج الإشعاعي، الحماية من الإشعاع، الإشعاع المؤين، التسرطن، تجزئة الجرعات، النسبة العلاجي.

Abstract: The field of radiation biology emerged following the discovery of X-rays and radioactivity in the late nineteenth century, becoming a cornerstone of modern medicine (Becquerel, 1896; Curie & Becquerel, 1901). This paper provides an overview of the historical development of this discipline, beginning with the work of Röntgen, Becquerel, and Curie, through the recognition of biological effects and the evolution of radiotherapy techniques and safety standards (Patton, 1992). We discuss Bergonié and Tribondeau's law regarding radiosensitivity, the principle of dose fractionation, the therapeutic ratio, and the linear non-threshold (LNT) model for risk assessment (Bergonié & Tribondeau, 1906; Regaud, 1901; Holthusen, 1936; ICRP, 2007). Advances in technology and biological understanding have improved cancer treatment outcomes while reducing associated risks. The paper concludes with current challenges and future directions, emphasizing the need to balance therapeutic benefits against potential risks.

Keywords: Radiation biology, radiotherapy, radiation protection, ionizing radiation, carcinogenesis, fractionation, therapeutic ratio.

I. INTRODUCTION

Röntgen's discovery of X-rays in 1895 and Becquerel's discovery of radioactivity the following year marked a turning point in medical science (Röntgen, 1895; Becquerel, 1896). Soon afterwards, Pierre and Marie Curie isolated radium and polonium, laying the foundations for what would become radiation biology (Curie, 1984). As ionising radiation began to be used in medical applications, its harmful biological effects were quickly observed, prompting the development of early radiation protection measures (Albers-Schönberg & Frieben, 1903). This paper aims to present a comprehensive overview of the historical evolution of radiation biology, with a focus on the fundamental concepts that have shaped modern clinical practice and the challenges that persist today.

II. DISCUSSIONS

2.1 Early Biological Discoveries and Effects of Radiation:

From its inception, radiation biology was closely linked to key discoveries at the end of the nineteenth century, and researchers soon

documented the damaging biological effects of radiation shortly after its discovery (Mould, 1993). Cases of hair loss and skin damage were recorded among physicians and technicians working with X-rays (Anonymous, 1936), and more severe consequences such as anaemia and cancers appeared as a result of unprotected exposure (Finzi, 1933). These observations led to stricter controls and the establishment of regulatory standards for the use of radiation therapy (Clarke & Valentin, 2009).

Early therapeutic attempts used X-rays; for example, in 1896 Victor Despeignes tried to treat stomach cancer with this novel technique (Despeignes, 1896). As technology advanced, treatment moved from Coolidge tubes to teletherapy using cobalt-60 sources and later to linear accelerators (Bernier *et al*., 2004).

2.2 Bergonié and Tribondeau's Law and the Concept of Radiosensitivity:

In 1906, the French scientists Jean Bergonié and Louis Tribondeau proposed a principle linking the radiosensitivity of cells to their proliferative activity (Bergonié & Tribondeau, 1906). However, subsequent research has shown that radiosensitivity is influenced by more complex factors than the rate of division alone, such as the cell's capacity to repair DNA damage (Arlett *et al*., 1988). For instance, cells from patients with ataxia telangiectasia exhibit extreme radiosensitivity despite their slow division rate (Begg, 1995). Nevertheless, this early principle stimulated much of the initial thinking in radiation biology.

2.3 Development of Radiotherapy and the Principle of Fractionation:

The shift toward fractionated therapy represented a crucial advance in improving both the safety and effectiveness of radiation treatment. Pioneers such as Claudius Regaud and Henri Coutard demonstrated that dividing the total dose into smaller portions delivered over several weeks improves the therapeutic ratio (Regaud, 1901; Foray, 2012). Fractionation allows time for healthy tissues to repair between sessions, thereby increasing their tolerance to radiation.

Mathematical models were later developed to guide clinical practice, including the nominal standard dose (NSD) model (Ellis, 1939) and the linear-quadratic (LQ) model, which is the most widely used today (Dixon, 1972). Modern high-precision techniques such as stereotactic body radiation therapy (SBRT) and CyberKnife enable the delivery of very high doses (hypofractionation) with extreme accuracy (Kilby *et al*., 2010).

2.4 The Therapeutic Ratio and Strategies to Improve Treatment Outcomes:

The primary goal of radiation therapy is to maximise the probability of tumour control (TCP) while minimising the probability of normal tissue complications (NTCP) – a balance known as the therapeutic window (Holthusen, 1936). Several strategies have been pursued to achieve this balance:

- Technological improvements: Techniques such as intensity-modulated radiation therapy (IMRT) enhance the precision of dose delivery (Chargari *et al*., 2016).
- Combined treatments: Combining radiation with chemotherapy or molecularly targeted agents can improve outcomes (Hanahan & Weinberg, 2011).
- Radiosensitisers and protectors: Research continues into agents that increase tumour sensitivity or protect healthy tissues (Bernier *et al*., 2004).
- Systemic effects: There is growing interest in the potential beneficial immune responses triggered by local radiation, such as the abscopal effect (Chargari *et al.*, 2016).

2.5 Radiation Epidemiology and the Linear Non-Threshold (LNT) Model:

Large epidemiological studies, notably those of atomic bomb survivors in Hiroshima and Nagasaki, have demonstrated that exposure to high doses of radiation increases cancer risk (Ozasa, 2016). Based on these findings, regulatory bodies adopted the linear non-threshold (LNT) model for radiation protection purposes. This model assumes that any dose, no matter how small, carries a risk proportional to its magnitude (ICRP, 2007).

However, the validity of the LNT model at very low doses remains controversial because some studies suggest adaptive responses and possible beneficial effects (hormesis) at low dose levels (Feinendegen, 2005; Calabrese, 2009).

Despite the debate, the LNT model remains practical for risk management. The risk of secondary cancers after radiotherapy is a genuine concern; estimates indicate that radiation may be responsible for approximately 8% of such tumours (Berrington de Gonzalez et al., 2011). It is essential to weigh this relatively low risk against the life-saving benefits of the initial treatment (Suit et al., 2007).

III. CONCLUSIONS

The century-long journey of radiation biology reflects a complex interplay between scientific discovery, clinical innovation, and safety awareness. This history highlights the need to balance substantial therapeutic benefits against potential risks through appropriate dose fractionation, technological precision, and consideration of individual variations in radiosensitivity. The ongoing debate over the LNT model underscores the complexity of assessing risks from low-dose exposure. Emerging directions – such as FLASH radiotherapy, proton therapy, and combination with immunotherapy – hold promise for further expanding the therapeutic ratio. History reminds us that the responsible application of this powerful tool depends on a deep understanding of its biological interactions.

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Comprehensive Fault Analysis And Preventive Maintenance Strategies For Hemodilysis Machines Field Study On The Nipro Surdial

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الملخص:

تُعد أجهزة غسيل الكلى ضرورية لمرضى الفشل الكلوي في مراحله النهائية، إلا أن تعقيد تصميمها يجعلها عرضة للأعطال التي قد تؤدي إلى انقطاع العلاج وتهديد سلامة المريض .ومن الأعطال الشائعة أخطاء كاشف تسرب الدم، ومشكلات موصلية سائل الغسيل والتحكم في درجة حرارته، مما قد يسبب انحلال الدم أو اضطراب الشوارد أو إيقاف العلاج بشكل مفاجئ .ورغم أن الأنظمة الحديثة تحتوي على حساسات وآليات إنذار متعددة، فإنها غالبًا لا تعمل إلا بعد وقوع العطل .لذلك يتطلب ضمان الموثوقية صيانة وقائية صارمة وأدوات تشخيص ذكية .وقد أسهمت تطبيقات حديثة مثل تطبيق HD service في تحسين كفاءة استكشاف الأعطال، كما تُمكّن الصيانة التنبؤية باستخدام نماذج تعلم الآلة (مثل شبكات LSTM) من الكشف المبكر عن الأعطال . ومن المتوقع أن تسهم تقنيات إنترنت الأشياء، والتشخيص الذاتي، والتصميم المعياري مستقبلاً في تعزيز السلامة والاعتمادية التشغيل.

الكلمات المفتاحية: جهاز غسيل الكلى؛ عطل؛ صيانة؛ تشخيص تنبؤي؛ سلامة المريض؛ موثوقية.

Abstract: Hemodialysis machines are essential for patients with end-stage renal failure, yet their complex design makes them susceptible to faults that can interrupt therapy and jeopardize patient safety. Common malfunctions include blood-leak detector errors, dialysate conductivity and temperature-control faults, which may lead to hemolysis, electrolyte imbalance, or abrupt treatment cessation. Although modern systems incorporate multiple sensors and alarm mechanisms, these typically activate only after faults occur. Ensuring reliability therefore requires strict preventive maintenance and intelligent diagnostic tools. Recent advances such as the HD service app enhance troubleshooting efficiency, while predictive maintenance using machine-learning models (e.g., LSTM networks) enables early fault detection. Future developments including IoT-based monitoring, self-diagnostics, and modular system design are expected to further improve safety and operational reliability.

Keyword: Hemodialysis machine; malfunction; maintenance; predictive diagnostics; patient safety; reliability.

I . INTRODUCTION

Hemodialysis machines are critical for sustaining life in patients with end-stage renal disease (ESRD), functioning as artificial kidneys that remove toxins, excess fluids, and metabolic waste from the bloodstream. These systems play an essential role in preserving electrolyte balance and acid-base homeostasis, thereby preventing severe complications associated with renal failure. Over the years, the integration of dialysis technology into routine clinical practice has significantly improved both survival rates and quality of life for patients, establishing it as one of the most vital innovations in modern medicine (Canaud, 2023; Maduell *et al*., 2022a).

Nevertheless, the intricate structure of these machines—comprising electrical circuits,

hydraulic pumps, control units, and numerous sensors—makes them susceptible to various technical malfunctions. Even seemingly minor faults, such as inaccurate temperature regulation, conductivity drift, or pressure imbalances, can disrupt the dialysis session or endanger the patient. Equipment downtime caused by such failures often leads to incomplete treatments, unscheduled maintenance, and increased clinical workload. Research has shown that recurring technical issues can reduce treatment effectiveness, cause patient discomfort, and in some cases lead to hospitalization due to inadequate waste removal (Maduell *et al*., 2022b; Saha *et al*., 2022).

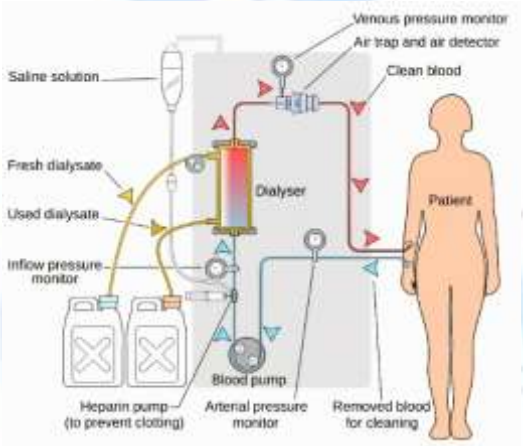

Fig 1: Schematic diagram of hemodialysis machine architecture.

For this reason, understanding the root causes and patterns of hemodialysis machine malfunctions is essential for improving performance reliability and ensuring uninterrupted therapy. The present study aims to identify and classify the most frequent types of faults in dialysis systems, with a focus on electrical, hydraulic, control, and sensor-related failures. It also seeks to evaluate diagnostic and maintenance strategies that can minimize downtime and enhance device dependability. By recognizing fault trends and integrating preventive maintenance with intelligent diagnostic methods, this work aims to contribute to the development of safer and more efficient hemodialysis practices (Rossi *et al*., 2023a; Smith *et al*., 2023).

II. SYSTEM OVERVIEW

A hemodialysis machine is a highly integrated biomedical system designed to replicate the excretory function of the kidneys. It consists of several key subsystems that work in harmony to ensure safe and effective treatment: the blood circuit, the dialysate circuit, the control and monitoring unit, and the alarm and safety system. Each subsystem performs a distinct role while remaining synchronized through electronic control logic and continuous sensor feedback (Canaud, 2023).

The blood circuit begins with a blood pump that propels the patient's blood through an extracorporeal tubing set toward the dialyzer. Pressure sensors monitor the arterial and venous lines to maintain stable flow and prevent complications such as hypotension, clotting, or air embolism. An air detector near the venous return line ensures that no air bubbles enter the bloodstream; if air is detected, the system automatically clamps the line and triggers an alarm. Simultaneously, the dialysate circuit prepares a solution with precise concentrations of electrolytes and bicarbonate, heated to approximately 37°C. This fluid circulates in a countercurrent direction relative to blood flow across the dialyzer membrane, allowing diffusion and ultrafiltration of waste products (Maduell *et al*., 2023).

At the core of the system lies the control and monitoring unit, which continuously processes sensor data to regulate temperature, flow rate, conductivity, and ultrafiltration volume. Modern machines like the NIPRO Surdial X rely on microprocessor-based control boards and closed-loop systems that adjust pump speeds and valve positions in real time. These control units interface with a graphical user interface where treatment parameters are displayed and alarms are managed. The alarm and safety system ensures patient protection by immediately detecting abnormal conditions such as temperature deviation, blood leaks, pressure imbalances, or conductivity errors, and halting therapy when necessary (Shintaku & Mori, 2023).

Each alarm is associated with a specific error code shown on the screen, enabling biomedical engineers to quickly identify the cause and take corrective action. In addition to hardware safeguards, software interlocks and self-test routines are executed before each session to verify the operational integrity of sensors, valves, and actuators (Yamamoto *et al*., 2023). A schematic representation of the dialysis machine architecture typically highlights the interaction between the blood and dialysate circuits, emphasizing the sensor nodes and feedback loops used for automatic regulation. Understanding these interconnections is fundamental for accurate fault diagnosis and for preventing cascading failures (NIPRO Corporation, 2024).

III. CLASSIFICATION OF FAULTS

Hemodialysis machines such as the NIPRO Surdial X integrate hydraulic, electrical, control, and sensory subsystems, making them vulnerable to a variety of faults. Based on field observations, maintenance logs, and technical documentation, the most frequently encountered faults can be grouped into several categories: electrical and control faults, hydraulic faults, sensor faults, and alarm-related issues (El-Hariri *et al*., 2022).

Fig. 2: NIPRO Surdial X Hemodialysis Machine.

A. Electrical and Control Faults:

These are among the most critical issues in clinical settings, often resulting from unstable power supplies, communication errors between sensors, or firmware malfunctions. The Surdial X features a dual-microcontroller architecture that isolates life-critical functions from auxiliary operations, using the CAN bus protocol for real-time data exchange. Any disruption in signal transmission triggers an automatic system shutdown and displays a corresponding fault code. This design ensures operational continuity and patient safety by locking the system until the error is resolved (Rossi et al., 2022). Common electrical and control faults observed include those listed in Table 1.

Table 1: Common Electrical and Control Fault Codes Observed in the Surdial X Hemodialysis Machine:

Fault Code	Category	Possible Cause	Corrective Action
E10	Power Supply Error	Voltage drop or unstable AC input	Check main power line, replace fuse, verify UPS stability
E18	Flow Sensor Error	Misalignment or clogging of the flow sensor	Clean and recalibrate the flow sensor
E29	CPU Communication Error	CAN bus interruption or firmware crash	Restart the system, inspect internal cables, reload firmware

A. Hydraulic Faults:

Hydraulic faults occur within the fluid management system, particularly in the blood, dialysate, and ultrafiltration circuits. The Surdial X employs a three-pump configuration with independent feedback-controlled loops. Common failures include blockages in filters, pressure imbalances, or contamination of the dialysate. Preventive measures include routine inspection of tubing and valves, filter replacement every three to six months, and regular pressure calibration (Maduell *et al*., 2023).

C. Sensory Faults:

Sensor-related issues are among the most frequent and challenging to diagnose. Since the Surdial X relies on accurate readings of pressure, temperature, and conductivity, any drift or contamination can lead to incorrect measurements and false alarms. For instance, a cracked conductivity sensor may trigger erroneous E07 alarms due to inaccurate dialysate concentration, while a defective temperature sensor can cause heater overheat alarms (E25). Regular calibration and periodic sensor replacement are essential for maintaining monitoring accuracy (Smith *et al*., 2023).

D. Alarm and Safety Faults:

The Surdial X includes a sophisticated alarm system that automatically detects unsafe conditions such as blood leaks, air bubbles, or extreme temperature variations, and pauses treatment until corrective action is taken. Each alarm event is stored in the system's internal log for later review. Table 2 lists common alarms and the corresponding corrective steps observed during the field study:

Table 2: Common Alarm and Safety Faults Observed in the Surdial X Hemodialysis Machine:

Malfunction / Alarm Code	Potential Cause	Initial Troubleshooting /Repair Action
Conductivity Alarm (E07)	Incorrect dialysate mixing ratio or faulty sensor	Verify concentrate connection, check water pressure, recalibrate or replace sensor
Blood Leak Alarm (E23)	Dialyzer membrane rupture or contaminated leak detector	Inspect dialyzer, check lines for air, clean or replace sensor, stop pump and clamp blood lines
Air Bubble Detection Alarm (E24)	Air entering the circuit due to loose connections	Check all tubing, ensure fluid levels, use air trap system to remove bubbles
Heater Overheat Alarm (E25)	Faulty heater or temperature sensor	Ensure adequate flow, verify temperature reading, restart or replace heater element
Temperature Min/Max Alarm (E05/E06)	Faulty control circuit or water temperature variation	Verify temperature setting, check heat changer, confirm stable water supply

These events demonstrate the machine's robust safety logic, which enforces automatic shutdown under unsafe conditions to minimize patient risk (Shintaku, 2024).

Fig. 3: Example of alarm/error display screen.

IV. PREVENTIVE MAINTENANCE AND FAULT REDUCTION

Preventive maintenance is essential for reducing the frequency of system faults and extending the operational life of hemodialysis machines. Regular calibration of pressure and flow sensors ensures accurate monitoring, while routine verification of alarm functions maintains the reliability of safety systems. Periodic replacement of filters and tubing prevents contamination and stabilizes hydraulic performance. Additionally, timely software and firmware updates resolve control-related issues and improve overall system functionality (Rossi *et al*., 2023b).

In essence, integrating scheduled maintenance with automated self-diagnostics and fault logging strengthens system dependability and patient safety. These practices form the foundation for predictive maintenance strategies aimed at identifying potential failures before they occur (El-Hariri *et al*., 2022).

V. TROUBLESHOOTING AND DIAGNOSTIC APPROACH

Effective troubleshooting in hemodialysis systems requires a multidisciplinary approach that combines engineering diagnostics with clinical observation to ensure uninterrupted treatment and patient safety. Based on field observations of the Surdial X and published guidelines, a systematic troubleshooting process is essential for resolving technical or physiological alarms (K/DOQI, 2023; Sodhi, 2022).

The NIPRO Surdial X includes an integrated self-test and diagnostic mode that automatically verifies sensors, valves, pumps, and electrical circuits before each session. In the event of a malfunction, the system issues visual and audible alarms along with a unique error code (E01–E99). Engineers and clinicians must follow a stepwise diagnostic process that begins with alarm interpretation, system isolation, and functional verification to avoid unnecessary downtime (NIPRO Corporation, 2024).

Troubleshooting typically begins by distinguishing between machine-related faults (e.g., flow obstruction, temperature deviation,

conductivity errors) and patient-related factors (e.g., hypotension, clotting, or vascular access issues). According to clinical guidelines, the diagnostic sequence includes the following steps (K/DOQI, 2023):

1. Identify the alarm type and its origin (pressure, temperature, or conductivity).
2. Assess the patient's condition before making hardware adjustments.
3. Inspect all extracorporeal circuit components for blockages or air.
4. Reset or recalibrate the device if no physical obstruction is present.
5. Document the event in the maintenance log for pattern recognition.

Field observations revealed that the most recurrent alarms in the Surdial X were related to conductivity (E07), blood leaks (E23), and temperature deviations (E05/E06). These issues were effectively resolved using the machine's built-in diagnostic guide, highlighting its advanced design for rapid fault identification.

All alarm data are stored internally, enabling post-session analysis and predictive fault tracking. This functionality supports AI-based predictive maintenance, in which recurring alarms are analyzed to forecast potential component failures before they occur. The integration of digital logging, real-time monitoring, and automated calibration reflects a shift toward smart self-diagnostics—a defining trend in modern biomedical engineering (Shintaku & Mori, 2023).

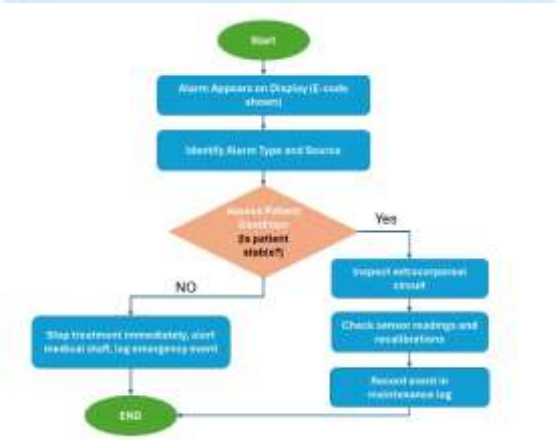

Fig. 4: Illustrates the standard troubleshooting flowchart used for diagnosing technical and clinical alarms in the Surdial X hemodialysis machine.

VI. RESULTS AND DISCUSSIONS

A comparative analysis of literature findings and field data revealed that most operational interruptions in dialysis systems stem from procedural errors or delayed responses to alarms rather than intrinsic hardware failures (Maduell *et al.*, 2022b). Case studies have highlighted incidents such as air embolism due to manual reinfusion errors, hemolysis caused by unnoticed tubing kinks, venous needle dislodgement linked to poor alarm response, and dialysate preparation errors leading to electrolyte imbalances (Saha *et al.*, 2022). These findings align with practices observed in the Surdial X unit, where engineering and nursing teams collaboratively manage alarm events to differentiate between technical and operator-related causes. The machine's intelligent alarm architecture, supported by redundant safety loops, minimizes clinical impact by pausing treatment immediately upon detecting unsafe conditions (Yamamoto *et al.*, 2023).

A key finding from both sources is the critical role of preventive maintenance and continuous training. Regular sensor calibration, weekly alarm verification, and adherence to disinfection protocols significantly reduced recurring alarms. Moreover, the adoption of standardized troubleshooting algorithms and root cause analysis improved diagnostic efficiency and device uptime (Rossi *et al.*, 2023a).

Ultimately, the Surdial X exemplifies the evolution of dialysis technology toward greater reliability, safety, and automation. Its advanced control system, internal fault memory, and rapid self-disinfection functions contribute to both patient protection and workflow efficiency. Integrating AI-driven diagnostic analytics, as suggested in recent literature, could further enhance predictive accuracy and support the next generation of autonomous dialysis systems (Shintaku, 2024).

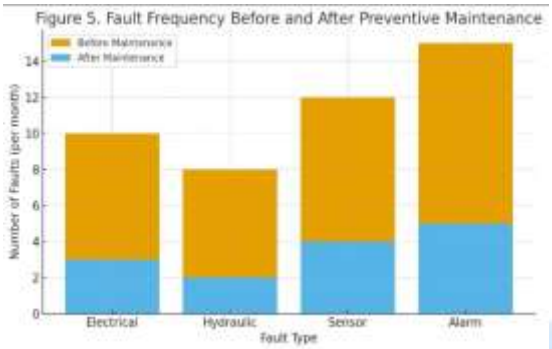

Fig. 5: Comparative chart showing the reduction in fault frequency across all system categories after implementing preventive maintenance on the Surdial X hemodialysis machine.

VII. CONCLUSION

This study analyzed the most common faults in the NIPRO Surdial X hemodialysis machine through field observations and technical evaluation. The findings underscore the importance of preventive maintenance, automated diagnostics, and real-time monitoring in ensuring operational reliability and patient safety. Incorporating predictive maintenance and AI-based fault detection is expected to further enhance system performance and reduce unplanned downtime in future applications.

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Evaluation of the quality of chest x-ray imaging in Benghazi Hospitals

Yousif Manisi[1], Fatma Youniss[1], Osama M. Al-Mahjoub[1], Ahd Ali[1], Fatima Mohammed[1], Esra Najeeb[1], Eman Miftah[1]

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الملخص:

هدف الدراسة: تهدف هذه الدراسة إلى تقييم الجودة الشاملة لتصوير الصدر بالأشعة السينية في مستشفيات بنغازي. وتركز على تقييم معايير الجودة التقنية والإجرائية والتشخيصية للصور لتحديد مستوى الالتزام بالمعايير السريرية والإشعاعية الدولية .

المنهجية: أُجريت دراسة وصفية مقطعية باستخدام استبيان مُهيكل وُزِّع على 120 من العاملين في مجال الرعاية الصحية .شملت العينة أخصائيي الأشعة، وأطباء الأشعة، والاستشاريين، وأطباء أمراض الرئة من المستشفيات الحكومية (67.5%) والخاصة (32.5%) في بنغازي .تم تحليل البيانات المتعلقة بأنظمة التصوير (الرقمية والتقليدية والمحوسبة)، والممارسات التقنية، والتحديات الإجرائية الشائعة باستخدام برنامج SPSS الإحصائي للعلوم الاجتماعية.

النتائج: كشفت النتائج أن تقنية التصوير الأمامي الخلفي هي الأكثر استخدامًا .(53.3%) وتم تحديد تحديات كبيرة، بما في ذلك صعوبات في وضع المريض (34.2%) ومشاكل متعلقة بالأجهزة (56.7%) تؤثر بشكل مباشر على جودة الصورة .وكانت أكثر المشكلات التقنية شيوعًا هي التشوهات (37.5%) ونقص التعريض .(32.5%) وبينما كان الوعي بمعايير جرعة الإشعاع إيجابيًا بشكل عام (أجاب 37.5% بـ "نعم")، فقد تباين استخدام مخططات التقنية الموحدة بشكل كبير، مما أظهر ارتباطًا إحصائيًا بعمر وخبرة فني الأشعة ($p = 0.001$).

الخلاصة: خلصت الدراسة إلى أنه على الرغم من الفهم العام لبروتوكولات التصوير الأساسية، إلا أن جودة الصورة في مستشفيات بنغازي غالبًا ما تتأثر سلبًا بمحدودية الأجهزة والتشوهات الإجرائية .هناك حاجة واضحة لمعايرة المعدات بشكل منتظم، وتنفيذ برامج ضمان الجودة المنظمة، والتدريب المهني الموجه لتقليل الفحوصات المتكررة وتعزيز دقة التشخيص.

الكلمات المفتاحية: الأشعة السينية للصدر ، جودة الصورة، تقنية التصوير الشعاعي، ضمان الجودة .

Abstract: Chest radiography (CXR) remains the most fundamental and frequently performed diagnostic imaging procedure in clinical practice. However, its diagnostic efficacy is highly dependent on technical and procedural factors, ranging from patient positioning to exposure optimization. In developing regions, inconsistencies in these variables can lead to poor image quality, potentially compromising diagnostic accuracy and increasing patient radiation dose through unnecessary repeat exposures.

Aim of the Study: This study aims to evaluate the overall quality of chest X-ray imaging in Benghazi hospitals. It focuses on assessing technical, procedural, and diagnostic image quality parameters to determine the level of adherence to international clinical and radiological standards.

Methodology: A descriptive cross-sectional study was conducted using a structured questionnaire distributed to 120 healthcare professionals. The sample included radiographers, radiologists, consultants, and pulmonologists from both public (67.5%) and private (32.5%) hospitals in Benghazi. Data regarding imaging systems (digital, conventional, and computed), technical practices, and common procedural challenges were analyzed using the Statistical Package for the Social Sciences (SPSS).

Results: The findings revealed that the Posteroanterior (PA) projection is the most utilized technique (53.3%). Significant challenges were identified, including difficulties with patient positioning (34.2%) and equipment-related problems (56.7%) that directly affect image quality. The most common technical issues reported were artifacts (37.5%) and underexposure (32.5%). While awareness of radiation dose criteria was generally positive (37.5% reported "Yes"), the use of standardized technique charts varied significantly, showing a statistical association with the age and experience of the radiographer ($p = 0.001$).

Conclusion: The study concludes that while fundamental imaging protocols are generally understood, image quality in Benghazi hospitals is frequently compromised by equipment limitations and procedural artifacts. There is a clear need for regular equipment calibration, the implementation of structured Quality Assurance (QA) programs, and targeted

professional training to minimize repeat examinations and enhance diagnostic accuracy.

Keywords: Chest X-ray (CXR), Image Quality, Radiographic Technique, Quality Assurance (QA).

I. INTRODUCTION

Since the discovery of X-rays in 1895, chest radiography has established itself as one of the oldest and most commonly used imaging modalities in medicine (Bontrager & Lampignano, 2018). It remains the most frequently performed radiologic examination due to its effectiveness, low cost, and rapid availability in diagnosing a wide range of thoracic conditions, including pneumonia, tuberculosis, pleural effusion, pneumothorax, and cardiac enlargement (Kim, Lee, & Park, 2019).

Despite its apparent simplicity, the diagnostic quality of chest X-rays is highly dependent on several technical and procedural factors. These include correct patient positioning, appropriate exposure parameters, proper equipment use, and accurate image processing. Variations in these factors can significantly affect diagnostic accuracy, potentially leading to image misinterpretation, missed pathology, and unnecessary repeat examinations that increase radiation exposure for both patients and staff (Bushberg *et al.*, 2012).

Chest radiography has evolved considerably from early film-based systems to modern digital radiography (computed radiography and digital radiography). Digital imaging has improved image acquisition, manipulation, and storage; however, it has also introduced challenges such as exposure creep. This underscores the need for continuous training and strict adherence to radiation protection principles, particularly the ALARA (As Low As Reasonably Achievable) concept (Korner *et al.*, 2007; Bushberg *et al.*, 2012).

Chest X-rays are indispensable in emergency departments, intensive care units, outpatient clinics, and preoperative assessments, serving as a first-line imaging tool for a wide spectrum of cardiopulmonary conditions (Lee et al., 2020). Given this extensive use, maintaining high image quality is essential for accurate interpretation and optimal patient management.

International organizations, such as the European Commission (EC), the American College of Radiology (ACR), and the World Health Organization (WHO), have established standardized image quality criteria for chest radiography. These guidelines emphasize proper exposure, complete lung field visualization, correct patient positioning, absence of artifacts, appropriate collimation, and clear depiction of anatomical structures to ensure diagnostic consistency and reduce variability (European Commission, 1996; ACR, 2022).

The diagnostic value of chest radiography also depends on the selected projection. The posteroanterior (PA) projection is considered the gold standard for adult patients due to reduced cardiac magnification and superior visualization of thoracic structures. In contrast, the anteroposterior (AP) projection is commonly used for critically ill or bedridden patients despite its limitations. Lateral and oblique projections provide additional diagnostic information when performed correctly (Bontrager & Lampignano, 2018; Whitley *et al.*, 2015; ACR, 2022).

Furthermore, radiographer expertise, optimized exposure parameters, the use of standardized technique charts, and adherence to quality assurance and quality control (QA/QC) programs are critical factors in maintaining high image quality. Regular equipment maintenance, calibration, and continuous professional training significantly reduce technical errors and repeat examinations (Andersson *et al.*, 2012; EFRS, 2017; Williams *et al.*, 2021; Ayasrah *et al.*, 2025). In summary, the literature indicates that chest X-ray image quality is influenced by a combination of technical, human, and organizational factors. Evaluating these factors is essential for improving diagnostic accuracy and optimizing chest radiography practices, particularly in hospitals in Benghazi.

II. METHODS

This descriptive cross-sectional study aimed to evaluate the quality of chest X-ray imaging in hospitals in Benghazi. A structured questionnaire was used as the primary data collection tool,

distributed to healthcare professionals, including radiographers, radiologists, consultants, and pulmonologists. The sample included participants from various public and private hospitals in Benghazi.

The questionnaire contained both closed and open-ended questions covering essential aspects related to chest X-ray imaging, such as patient positioning, exposure parameters, image clarity, the presence of artifacts or defects, and adherence to standard imaging protocols.

Approximately 120 completed questionnaires were collected. The data were coded and entered into the Statistical Package for the Social Sciences (SPSS) software for analysis. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were calculated. The results were presented using tables and graphs to illustrate trends, strengths, and areas requiring improvement in chest X-ray imaging practices.

III. RESULTS

It is important to introduce the background of respondents participating in the survey to understand their level of expertise. Thus, this study aimed to evaluate the quality of chest X-ray imaging in Benghazi Hospitals. A brief profile (age, gender, hospital type, imaging system, educational level, and years of experience) of the survey respondents is presented in Table 1.

Table 1: shows that 18 out of 120 (15.0%) respondents were from the age group (20–29 years), representing the minority, whereas 41 out of 120 (34.2%) were from the age group (30–39 years), representing the majority. The table also shows that the majority of respondents were female (65.0%), while males constituted 35.0%. Regarding hospital type, 81 respondents (67.5%) worked in governmental hospitals and 39 (32.5%) in private hospitals.

Table .1: Description of the samples according to the background of respondents:

Variables	Classification	Numbers of respondents	%
Age Group	20-29	18	15.0
	30-39	41	34.2
	40-49	35	29.1
	50+	26	21.7
	Total	120	100
Gender	Female	78	65.0
	Male	42	35.0
	Total	120	100
Hospitals	Public	81	67.5
	Private	39	32.5
	Total	120	100
Imaging system	Digital	49	40.8
	Conventional	45	37.5
	Computed	26	21.7
	Total	**120**	**100**
Educational level	Bachelor's//High Diploma	82	**68.3**
	Master's	30	**25.0**
	PhD	8	**6.7**
	Total	**120**	**100**
Experience in years	Less than 5 years	27	22.5
	5–10 years	39	32.5
	More than 10 years	54	45.0
	Total	120	100.

Figure 1 demonstrates that 40.8% and 37.5% of respondents used digital and conventional imaging systems, respectively, representing the majority. It can be seen from the table that almost all (93.3%) respondents held a bachelor's or master's degree, while only 8 (6.7%) had a Ph.D.

Regarding length of work experience, 54 respondents (45.0%) had more than 10 years of experience, while the remaining 55.0% had 10 years or less.

Figure 1 illustrates the relationship between age groups and three variables: PA positioning, use of technique charts, and training in chest imaging. The results indicate that the 30–39 age group demonstrates the highest levels of PA application and technique chart usage, suggesting an active professional stage supported by adequate experience and regular practice.

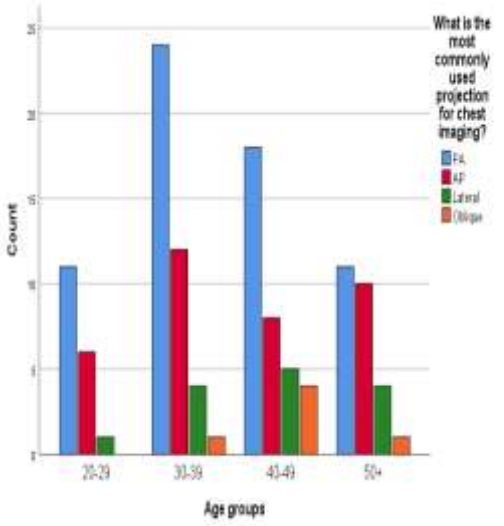

Fig 1: Shows age groups with the most commonly used projection for chest imaging.

The Above 50 age group shows the highest percentage in training related to chest imaging, which may reflect accumulated professional experience and a greater emphasis on continuous training. In contrast, the 20–29 age group records the lowest values across all variables, likely due to limited practical experience compared to other age groups. Overall, the chart highlights that technical skills and experience vary across age groups, increasing progressively with age until mid-career, while older professionals tend to focus more on specialized training.

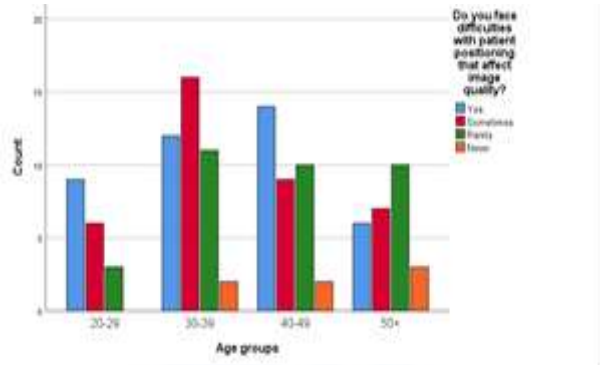

Fig 2: Demonstrates age groups with difficulties with patient positioning that affect image quality.

Figure 2 shows that the PA projection is the most commonly used technique for chest imaging across all age groups, representing 53.3% of total responses. The AP projection follows with 30.0%, while the lateral and oblique projections are used much less frequently, accounting for 11.7% and 5.0%, respectively. The Chi-square test result (χ^2 = 7.937, p = 0.541) indicates no statistically significant association between age group and the type of projection used.

This is supported by the Chi-square test result (χ^2 = 7.937, p = 0.541), which indicates no statistically significant association between age group and the type of projection used. Overall, the findings suggest that the PA projection remains the standard and preferred approach in chest radiography regardless of radiographer age, reflecting adherence to established imaging protocols.

Figure 3 presents adherence to dose criteria. The majority of respondents reported following dose criteria "Sometimes" (40.0%) or "Yes" (37.5%). Only a minority chose "Rarely" (16.7%) or "Never" (5.8%). The Chi-square test (χ^2 = 10.659, p = 0.300) confirms that age does not significantly influence adherence to dose criteria.

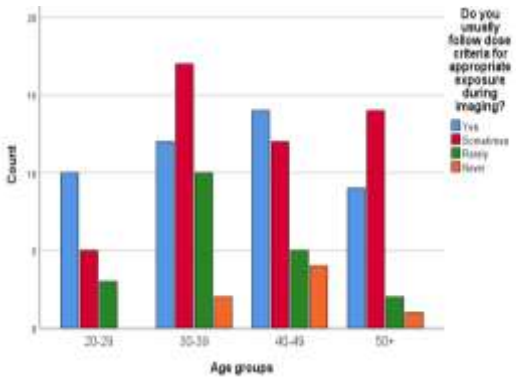

Fig. 3: Shows age groups with follow dose criteria for appropriate exposure during imaging.

The majority of respondents reported in figure 3 adhering to dose criteria “Sometimes” (40.0%) or “Yes” (37.5%). Only a minority chose “Rarely” (16.7%) or “Never” (5.8%). This indicates a generally positive trend toward awareness and application of dose optimization principles in chest imaging. Across the age categories, the distribution remains comparable, with no major discrepancies in dose-criteria compliance. The Chi-square test ($\chi^2 = 10.659$, p = 0.300) further confirms that age does not significantly influence adherence to dose criteria. Overall, the results highlight a strong awareness of radiation protection standards among radiographers across all age groups, although full consistency in following dose criteria.

Figure 4 displays the use of technique charts across age groups. While older radiographers (40–49 and 50+) report higher use of technique charts "Rarely" or "Never", younger radiographers (20–29 and 30–39) show a more balanced distribution, with greater reliance on "Sometimes" or "Yes". The Chi-square result ($\chi^2 = 27.377$, p = 0.001) reveals a statistically significant association between age group and use of technique charts.

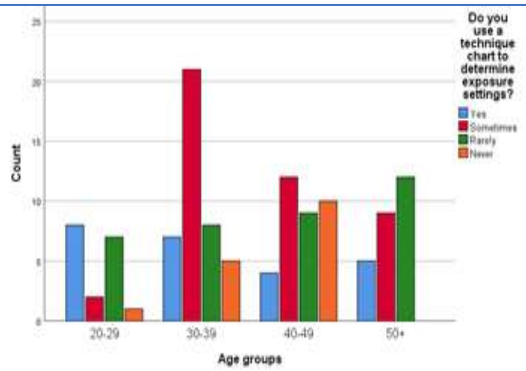

Fig.4: Displays age groups with use a technique chart to determine exposure settings.

The use of technique charts shows in figure 4 substantial variation across age groups. While older radiographers (40–49 and 50+) report higher use of technique charts “Rarely” or “Never”, younger radiographers (20–29 and 30–39) show a more balanced distribution, with greater reliance on “Sometimes” or “Yes. "The Chi-square result ($\chi^2 = 27.377$, p = 0.001) reveals a statistically significant association between age group and use of technique charts. This indicates that technique chart utilization differs meaningfully by age, suggesting differences in training styles, familiarity with modern protocols, or confidence in manual exposure selection. These findings imply that targeted retraining or standardized protocol reinforcement may help ensure consistent use of technique charts across all age categories.

Figure 5 shows the use of grids during chest X-ray examinations. The highest proportion reported using grids "Sometimes" (42.5%), followed by "Yes" (22.5%). A considerable proportion indicated "Never" (25.0%), while only 10% reported "Rarely". The Chi-square test ($\chi^2 = 5.014$, p = 0.833) confirms no statistically significant association between age group and grid usage.

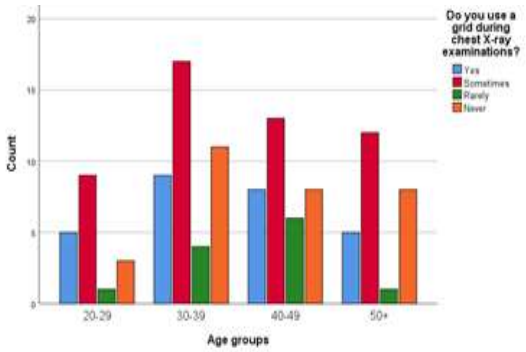

Fig. 5: Shows age groups with use a grid during chest X-ray examinations.

The findings in figure 5 demonstrate that the use of grids during chest X-ray examinations varies across response categories but remains broadly similar among age groups. The highest proportion reported using grids "Sometimes" (42.5%), followed by "Yes" (22.5%). A considerable proportion indicated "Never" (25.0%), while only 10% reported "Rarely. "Across the age groups, the distribution does not show any pronounced or systematic trend. The Chi-square test ($\chi^2 = 5.014$, $p = 0.833$) confirms that there is no statistically significant association between age group and grid usage. These results suggest that grid usage may depend more on institutional protocols, patient size, or equipment availability than on radiographer age or experience.

Figure 6 illustrates the frequency of repeat examinations due to poor image quality. Image repetition is relatively common, with "once" (35.8%) and "none" (27.5%) being the most frequently selected options. Fewer respondents indicated repeating the exam twice (24.2%) or three times (12.5%). The Chi-square test result ($\chi^2 = 13.222$, $p = 0.153$) indicates no statistically significant relationship between age and repetition frequency.

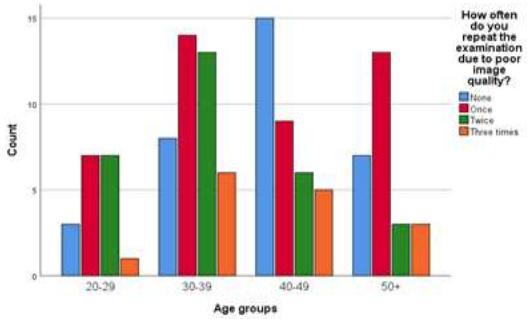

Fig. 6: Illustrates age groups with repeat the examination due to poor image quality.

The results show that image repetition is relatively common, with once (35.8%) and none (27.5%) being the most frequently selected options. Fewer respondents indicated repeating the exam twice (24.2%) or three times (12.5%). Across age groups, the distribution is generally comparable, and no specific age group stands out as having significantly higher repeat rates. The Chi square test result ($\chi^2 = 13.222$, $p = 0.153$) indicates no statistically significant relationship between age and repetition frequency. These findings imply that image repetition is influenced primarily by technical factors or patient cooperation rather than radiographer age.

Figure 7 shows the most common problems affecting image quality. The most frequently reported issue is artifacts or foreign materials (37.5%), followed by underexposure (32.5%). Overexposure (22.5%) and incorrect patient positioning (6.7%) were less common, while lack of image sharpness was reported minimally (0.8%). The Chi-square test ($\chi^2 = 15.195$, $p = 0.231$) confirms no significant association between age group and the type of image quality issue.

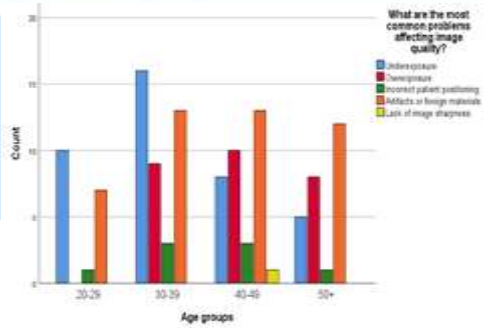

Fig. 7: Illustrates age groups with the most common problems affecting image quality.

The most frequently reported issue as shown in figure 7 affecting image quality is artifacts or

foreign materials (37.5%), followed by underexposure (32.5%). Overexposure (22.5%) and incorrect patient positioning (6.7%) were less common, while lack of image sharpness was reported minimally (0.8%). The distribution of these responses across age groups appears consistent, and the Chi-square test (χ^2 = 15.195, p = 0.231) confirms that no significant association exists between age group and the type of image quality issue encountered. Overall, the findings suggest that image quality problems are largely systematic and not dependent on radiographer age, highlighting potential equipment or workflow-related sources of error.

Figure 8 displays the perception of equipment problems affecting image quality. The majority of respondents indicated that equipment issues "Yes" affect image quality (56.7%), followed by "Sometimes" (27.5%) and "Rarely" (13.3%). Only 2.5% selected "Never". The Chi-square test (χ^2 = 10.932, p = 0.280) shows no statistically significant association between age and perception of equipment-related issues.

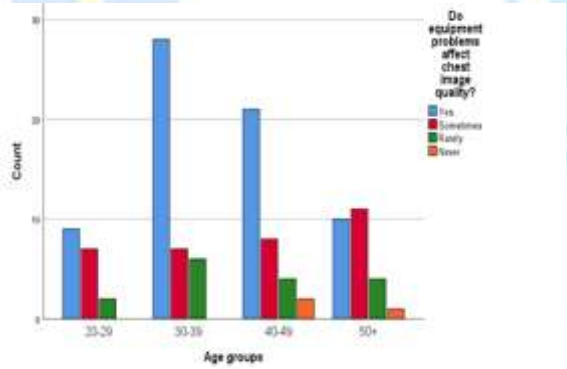

Fig. 8: Displays age groups with equipment problems affect chest image quality.

As shown in figure 8, the majority of respondents indicated that equipment issues “Yes” affect image quality (56.7%), followed by “Sometimes” (27.5%) and “Rarely” (13.3%). Only 2.5% selected “Never.” These results highlight that equipment-related problems are a major contributing factor to compromised image quality. However, the distribution across age groups is fairly consistent, and the Chi-square test (χ^2 = 10.932, p=0.280) shows no statistically significant association between age and perception of equipment-related issues. Thus, equipment problems appear to be a systemic issue affecting all radiographers, regardless of age or experience.

Figure 9 displays the perceived impact of image quality on diagnostic accuracy. The vast majority indicated that image quality has a "Moderate" (34.2%) or "Significant" (50.0%) impact on diagnostic accuracy, reflecting strong awareness of its clinical importance. The Chi-square test (χ^2 = 9.559, p = 0.387) indicates no significant association between age and this perception.

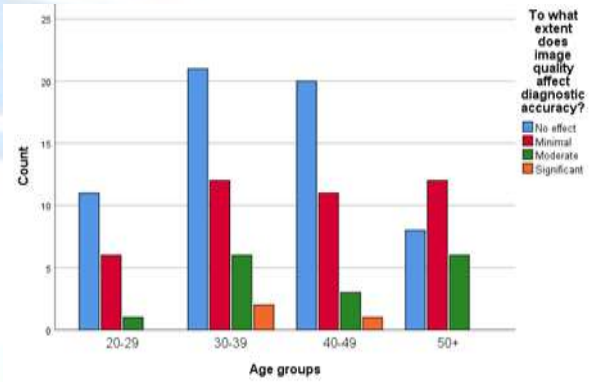

Fig. 9: Displays age groups with image quality affect diagnostic accuracy.

The vast majority of respondents in figure 9 indicated that image quality has a “Moderate” (34.2%) or “Significant” (50.0%) impact on diagnostic accuracy, reflecting strong awareness of the clinical importance of high-quality radiographs. Very few selected “Minimal” (13.3%) or “No effect” (2.5%). The response distribution is consistent across age groups, and the Chi-square test (χ^2 = 9.559, p = 0.387) indicates no significant association between age and the perceived effect of image quality on diagnostic accuracy. These results suggest that regardless of age, radiographers share a common understanding of the critical link between image quality and accurate diagnosis.

Figure 10 displays responses regarding device calibration. A plurality selected "Rarely" (32.5%), followed by "Yes" (27.5%) and "Sometimes" (26.7%). Only 13.3% reported "Never". The Chi-square test result (χ^2 = 13.975, p = 0.123) indicates no significant association between age and calibration frequency.

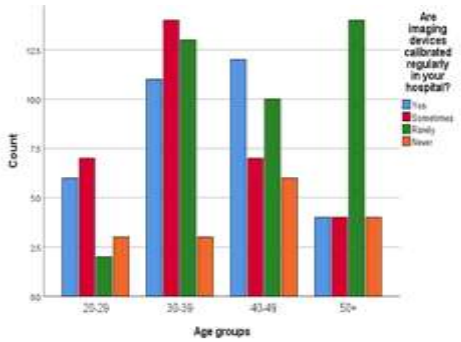

Fig. 10: Displays age groups with imaging devices calibrated regularly in the hospital.

Responses regarding device calibration show in figure 10 that a plurality selected "Rarely" (32.5%), followed by "Yes" (27.5%) and "Sometimes" (26.7%). Only 13.3% reported "Never." This distribution suggests that regular calibration practices may be inconsistent, potentially affecting image quality and radiation safety. Across age groups, the pattern remains fairly uniform, and the Chi-square test result (χ^2 = 13.975, p = 0.123) indicates no significant association between age and calibration frequency. Thus, the findings highlight an institutional issue rather than an age-related one, emphasizing the need for standardized and enforced calibration protocols in radiology departments.

IV. DISCUSSIONS

This study aimed to evaluate chest X-ray imaging practices in Benghazi hospitals by examining radiographers' demographic characteristics, adherence to imaging standards, and factors influencing image quality. The findings provide a comprehensive overview of current practices and highlight areas where clinical performance, education, and institutional procedures may require strengthening (Creswell & Creswell, 2018).

The demographic distribution revealed that most respondents were aged 30–39 years, with fewer in the youngest (20–29) and oldest (50+) groups. The sample was predominantly female, and the majority worked in public hospitals. A nearly equal use of digital and conventional systems was observed, indicating that digital transformation is progressing but remains incomplete. Most participants held a bachelor's degree or higher, and almost half had more than 10 years of professional experience. These characteristics suggest a relatively experienced and well-educated workforce, which is essential for maintaining high standards in radiographic imaging (Andersson *et al.*, 2012; EFRS, 2017).

The PA projection was the most commonly used technique across all age groups (53.3%), confirming adherence to international guidelines that recommend PA projection as the standard for routine chest imaging (ACR, 2022; Bontrager & Lampignano, 2018). The non-significant Chi-square result (p = 0.541) indicates that age has no influence on projection preferences. This consistency emphasizes that radiographers follow established protocols regardless of experience or training differences.

A large proportion of respondents reported experiencing difficulties with patient positioning ("Yes" = 34.2%; "Sometimes" = 31.7%). The absence of a significant association with age (p = 0.476) suggests that positioning challenges arise from patient-related or environmental factors rather than radiographer skill level. This finding aligns with existing literature, which highlights that patient condition, mobility, and clinical workload significantly impact positioning quality (Whitley *et al*., 2015).

Most radiographers reported following dose criteria always or sometimes, indicating good awareness of radiation protection principles. However, a notable portion still reported rarely or never adhering to dose standards. No significant relationship with age (p = 0.300) suggests that inconsistencies in adherence may reflect varying departmental protocols or workload pressures rather than experience level (Bushberg *et al*., 2012; WHO, 2016).

The use of technique charts varied significantly by age group (p = 0.001). Younger radiographers reported more frequent use, whereas older radiographers tended to rely less on charts. This may reflect differences in training styles, confidence in manual technique selection, or reduced exposure to updated protocols. This result highlights the need for standardized technique-chart implementation across all radiology departments (ACR-STR, 2022).

Grid usage showed no significant association with age (p = 0.833). Most respondents reported using grids "Sometimes,"

reflecting situational decision-making based on patient size or clinical need. A sizeable number selected "Never," which may indicate equipment limitations or protocol differences between facilities (Bontrager & Lampignano, 2018).

Repeat rates were relatively high, with 72.5% reporting at least one repetition due to poor image quality. There was no significant association with age ($p = 0.153$), confirming that repetition is largely influenced by systemic factors such as equipment performance, patient cooperation, or workload intensity rather than radiographer experience. This is consistent with findings from other studies (Williams *et al.*, 2021; Liaqat *et al.*, 2021).

Artifacts and foreign materials were the most commonly reported issues (37.5%), followed by underexposure (32.5%). Incorrect positioning and overexposure were less frequent. No link with age was found ($p = 0.231$), suggesting that these errors stem from environmental or procedural deficiencies rather than individual performance. Artifacts being the main issue highlights the need for better patient preparation and enhanced attention during the imaging process (Ayasrah *et al.*, 2025).

Most respondents (66.7%) had received training in image-quality assessment, but the rate varied by age group. Although the association was not statistically significant ($p = 0.205$), younger radiographers showed higher training participation. More importantly, the timing of the last training showed a highly significant association ($p = 0.000$): younger radiographers had more recent training, while those aged 50+ reported infrequent participation in refresher courses. This trend indicates the need for continuous and structured education for all age groups, especially for senior radiographers (EFRS, 2017; ESR, 2019). A majority (56.7%) stated that equipment problems affect image quality, and this perception was consistent across age groups ($p = 0.280$). This finding emphasizes systemic and institutional challenges such as aging equipment, lack of preventive maintenance, or limited availability of advanced imaging systems. Similar challenges have been reported in other developing regions (WHO, 2019).

Half of the respondents indicated that image quality has a "Significant" effect on diagnostic accuracy. Although no significant association with age was found ($p = 0.387$), the responses strongly underscore radiographers' awareness of the critical role that high-quality radiographs play in clinical diagnosis (Kim *et al.*, 2019; Lee *et al.*, 2020).

Most respondents reported irregular calibration, with "Rarely" being the most frequent response (32.5%). The lack of significant association ($p = 0.123$) indicates that inadequate calibration is a widespread institutional issue. Poor calibration is known to increase radiation dose and reduce image consistency, highlighting the urgent need for strict QA/QC programs in Benghazi hospitals (EC, 1996; IAEA, as cited in WHO, 2016).

V. CONCLUSION

This study provides important insights into chest X-ray imaging practices in Benghazi hospitals. Overall, radiographers demonstrate reasonable adherence to established imaging procedures, particularly in projection selection and awareness of image quality's diagnostic importance. However, several systemic and procedural issues were identified:

- The PA projection is universally preferred, reflecting compliance with international standards.
- Positioning difficulties and repeat examinations are common but not related to age or experience, suggesting patient-related or institutional factors.
- Adherence to dose criteria is generally good, though inconsistencies remain.
- Technique chart use differs significantly by age, with younger radiographers more likely to follow structured protocols.
- Equipment problems and poor calibration are widespread, contributing to compromised image quality.
- Training is common, but the frequency of recent training varies sharply, indicating a need for more consistent continuing education.
- Artifacts and underexposure are the most frequent image-quality issues, highlighting areas for workflow improvement.

VI. RECOMMENDATIONS

1. Implement standardized imaging protocols across all hospitals.
2. Provide regular and mandatory professional development for all radiographers.

3. Enhance patient preparation procedures to reduce artifacts.
4. Strengthen quality assurance and quality control programs.
5. Ensure consistent calibration and maintenance of imaging equipment.
6. Encourage greater use of technique charts for improved exposure consistency.
7. Address equipment limitations and workflow inefficiencies through coordinated efforts involving radiographers, radiology departments, and hospital administration to enhance diagnostic accuracy and patient safety in Benghazi hospitals.

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Nanotechnology as a Core Pillar of Biomedical Engineering: Principles, Applications, and Future Perspectives

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الملخص:
أصبحت تقنية النانو ركيزة أساسية في الهندسة الطبية الحيوية الحديثة، وذلك لقدرتها على معالجة المواد على المستوى النانوي (1-100 نانومتر)، مما ينتج عنه خصائص فيزيائية وكيميائية وبيولوجية فريدة. وقد أتاحت هذه الخصائص تحقيق تقدم كبير في التشخيص الطبي، والتصوير، وإيصال الأدوية الموجه، والطب التجديدي، والأجهزة الطبية الذكية. يهدف هذا الاستعراض السردي إلى تسليط الضوء على مبادئ تقنية النانو، وتقنيات التصنيع والتحليل، والتطبيقات الطبية الحيوية الرئيسية، واعتبارات السلامة، والآفاق المستقبلية. تم تحليل الدراسات ذات الصلة، التي خضعت لمراجعة الأقران ونُشرت بين عامي 2000 و2024، من قواعد البيانات العلمية الرئيسية. تُظهر النتائج أن تقنية النانو تُحسّن حساسية التشخيص، ودقة العلاج، ونتائج تجديد الأنسجة مقارنةً بالأساليب الطبية التقليدية. على الرغم من هذه المزايا، لا تزال هناك تحديات تتعلق بالسمية، والتصنيع على نطاق واسع، والأطر التنظيمية. من المتوقع أن يلعب دمج الذكاء الاصطناعي مع تقنية النانو دورًا محوريًا في التغلب على هذه التحديات والنهوض بالطب الشخصي.

الكلمات المفتاحية - المكونات؛ الهندسة الطبية الحيوية، تكنولوجيا النانو، الجسيمات النانوية، التشخيص الطبي، العلاج النانوي، هندسة الأنسجة، الأجهزة الطبية الذكية، السلامة النانوية.

Abstract: Nanotechnology has become a fundamental pillar in modern biomedical engineering due to its ability to manipulate materials at the nanoscale (1–100 nm) resulting in unique physical chemical and biological properties. These characteristics have enabled significant advancements in medical diagnostics, imaging, targeted drug delivery, regenerative medicine, and smart medical devices. This narrative review aims to highlight the principles of nanotechnology, fabrication and characterization techniques, major biomedical applications, safety considerations, and future perspectives. Relevant peer-reviewed studies published between 2000 and 2024 were analyzed from major scientific databases. The findings demonstrate that nanotechnology enhances diagnostic sensitivity, therapeutic precision, and tissue regeneration outcomes compared with conventional medical approaches. Despite these advantages, challenges related to toxicity, large-scale manufacturing, and regulatory frameworks remain. The integration of artificial intelligence with nanotechnology is expected to play a key role in overcoming these challenges and advancing personalized medicine.

Keywords: Component; Biomedical engineering, nanotechnology, nanoparticles, medical diagnostics, nano-therapy, tissue engineering, smart medical devices, nano safety.

I. INTRODUCTION

Biomedical engineering is the field that merges engineering, medicine, and biology to create tools that diagnose, monitor, and treat diseases. In recent decades, the need for more precise, faster, smarter, and less invasive technologies has driven the rapid rise of nanotechnology. As stated by Zhang, Hu, and Wang (2020), “nanomedicine offers significant advanes in diagnostics, targeted drug delivery, therapeutic interventions, and tissue

engineering" Nanotechnology involves studying and manipulating materials at the nanoscale—roughly the size of atoms and molecules. For perspective:
• A human hair is 80,000–100,000 nm thick.
• DNA is 2 nm wide.
• A virus ranges between 20–250 nm.
At this tiny scale, materials gain new properties:
• Gold nanoparticles turn red or purple instead of gold.
• Iron nanoparticles become super magnetic.
• Materials become stronger, lighter, and more reactive.

Their surface area becomes huge, improving drug interaction. These unique features form the foundation of modern nanomedicine, enabling breakthroughs in cancer treatment, imaging precision, biosensors, and tissue engineering. Conventional medical tools often fail to detect diseases early or deliver drugs precisely creating the need for nanoscale solutions. The aim of this review is to highlight the role of nanotechnology as a core pillar in biomedical engineering focusing on its principle's clinical applications, challenges and future perspectives.

II. HISTORY AND EVOLUTION OF NANOTECHNOLOGY

Understanding the history helps novices grasp the field better.

1.1959 – Richard Feynman's Vision In his famous lecture "There's Plenty of Room at the Bottom", he imagined controlling atoms individually.
2. 1981 – Birth of Modern Nanotechnology:
The invention of the Scanning Tunneling Microscope (STM) allowed scientists to "see" individual atoms.
3. 1990s – Rise of Nanomaterials:
- Carbon nanotubes discovered.
- Fullerenes (C60 buckyballs).
- Major advances in nanofabrication.

4. 2000s – Biomedical Nanotechnology:
- First nano-drug approved (Doxil).
- Nanoparticles in MRI and CT.
- Nano-based biosensors.

5. 2020s – AI x Nanotechnology:
- mRNA vaccines using lipid nanoparticles (Van der Meel *et al*., 2022).
- Smart nano sensors with wireless connectivity.
- AI-based nano diagnostics.

What is the Nanoscale? (Beginner-Friendly Explanation)?

A. Size Comparison:
- Nanometer = 1/1,000,000,000 of a meter.
- Fingernail grows 1 nm every second.
- RBC diameter = 7,000 nm.
- A water molecule = 0.3 nm.

B. Why Do Properties Change at the Nanoscale?
1. Quantum Effects.
Particles behave differently—changing color, magnetism, conductivity.
2. Huge Surface Area.
3. More interaction with biological tissues.
4. Ability to Enter Cells Easily.
Nanoparticles can cross:
• Cell membranes.
• Blood–brain barrier.
• Tumor microenvironment.
This is why nanotechnology is perfect for medicine (Albanese, Tang, & Chan, 2012).

III. METHODOLOGY

This narrative review was conducted by surveying peer-reviewed scientific articles published between 2000 and 2024. Databases including PubMed, ScienceDirect, IEEE Xplore, and Nature Journals were used. Keywords such as *nanotechnology*, *biomedical engineering*, *nanomedicine*, and *nanoparticles* were applied. Only English-language articles with clear relevance to biomedical applications were included.

a. FABRICATION AND CHARACTERIZATION TECHNIQUES

A complete study must explain *how nanoparticles are made*. This section strengthens the research scientifically.

A. Top-Down Techniques:
Breaking down bulk materials into nano sizes:
- Mechanical milling.
- Lithography.
- Laser ablation.

B. Bottom-Up Techniques:

Building nanoparticles atom-by-atom:
- Sol–gel process.
- Chemical vapor deposition (CVD)
- Self-assembly.
- Biological synthesis using bacteria or plants (Singh *et al*., 2020).

C. Nanoparticle Characterization Techniques:

These tools ensure particles are the correct size, shape, and chemistry.
- SEM (Scanning Electron Microscopy)—surface imaging.
- TEM (Transmission Electron Microscopy)—internal nanoparticle imaging
- DLS (Dynamic Light Scattering)—size distribution.
- UV–Vis Spectroscopy—optical properties.
- FTIR—chemical composition.
- XRD—crystal structure.

Fig.1: Nano-Techniques.

V. TYPES OF NANOMATERIALS USED IN MEDICINE

A full detailed list for maximum clarity: Alexis *et al.* (2010) verified that polymeric nanoparticles "are biodegradable, customizable, and capable of controlled drug release for sustained therapeutic action.".

A. Metal Nanoparticles:
- Gold (AuNPs): imaging, drug delivery, cancer therapy (Albanese, Tang, & Chan, 2012).
- Silver (AgNPs): antimicrobial applications.
- Iron oxide: MRI contrast (Na, Song, & Hyeon, 2009).

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B. Carbon-Based Nanomaterials:
- Carbon nanotubes.
- Graphene.
- Fullerenes.

C. Polymeric Nanoparticles:
- PLGA nanoparticles.
- PEGylated particles.

D. Lipid Nanoparticles:
- Used in mRNA vaccines (van der Meel *et al*., 2022)..
- Highly biocompatible.

E. Quantum Dots: Ultra-bright imaging for fluorescent diagnostics (Ge, Yin, & Yin, 2021).

VI. NANOTECHNOLOGY IN DIAGNOSTICS

A. Nano sensors: They detect cancer biomarkers (CEA, PSA), glucose, lactate, viral particles, and inflammation markers (Nour *et al.*, 2021).

B. Nano-based Lab-on-a-Chip: Allows testing with a droplet of blood.

C. Wearable Nanotechnology:
- Smart watches with nano sensors.
- Nano-memory patches.
- Sweat-analyzing sensors.

VII. NANOTECHNOLOGY IN MEDICAL IMAGING

A. MRI:
- Iron oxide nanoparticles enhance contras (Na, Song, & Hyeon, 2009).
- Allow clearer imaging of tumors and inflammation.

B. CT:
- Gold nanoparticles = high X-ray absorption.

C. Fluorescent Imagin:

- Quantum dots enable multicolor deep imaging" (Ge, Yin, & Yin, 2021).

VIII. NANOTECHNOLOGY IN DRUG DELIVERY

Nanoparticles allow drugs to be delivered exactly where they are needed. Shi *et al.* (2017) stated that nanocarriers "increase bioavailability, improve tumour accumulation, and reduce systemic toxicity."

Advantages:

- Targeted delivery.
- Reduced side effects.
- Controlled release.
- Ability to cross biological barriers.

Examples:

- Doxil (liposomal doxorubicin).
- Abraxane (albumin-bound paclitaxel).
- Onivyde (irinotecan nano-formulation).

IX. NANOTECHNOLOGY IN REGENERATIVE MEDICINE.

Applications:

- Bone regeneration with hydroxyapatite nanoparticles (Sengupta & Kulkarni, 2016).
- Neural repair using conductive nanofibers.
- Cardiac tissue scaffold engineering.
- Skin regeneration using nanosilver.

X. AI INTEGRATION WITH NANOTECHNOLOGY

AI enhances:

- Nanosensor data interpretation.
- Predictive health monitoring.
- Image reconstruction.
- Drug-delivery optimization.
- Nano-synthesis prediction models.

XI. SAFETY, RISKS, AND NANOTOXICOLOGY.

Potential Risks:

- ROS generation (Nel *et al.*, 2006).
- DNA damage.
- Inflammation.
- Organ accumulation (Kreyling *et al.*, 2015).

Safety Testing Methods:

- Cytotoxicity assays.
- Hemocompatibility.
- Long-term animal studies.
- Biodistribution mapping.

Regulatory Bodies:

- FDA.
- EMA.
- OECD.
- ISO nanotechnology standards.

XII. MARKET SIZE AND ECONOMICS

- Market size (2023): $190.6 billion.
- Expected by 2030: $400+ billion.
- Oncology dominates 45% of nanomedicine revenue.

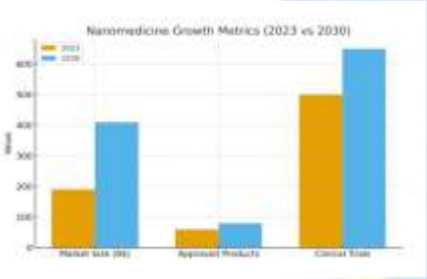

Fig.2: Nano-medicine Growth.

XIII. FUTURE OF NANOTECHNOLOGY (2030–2050)

- Smart nanosensors communicating with smartphones.
- Injectable nanorobots.
- Nano-enabled brain–computer interfaces.
- Fully personalized nano-drug design.
- Nanoprobes for early Alzheimer detection.

XIV. RESULTS AND RECOMMENDATIONS

Results show:

- Nanotechnology fundamentally enhances biomedical engineering.
- Diagnostics become earlier, faster, more accurate.

- Drug delivery becomes safer and more targeted.
- Tissue engineering benefits from biomimetic nanostructures.

Recommendations:

- Encourage interdisciplinary collaborations and expand clinical trials.
- Adopt strong safety protocols.
- Integrate nanotechnology into medical curricula.

XV. COMPARATIVE TABLES

Table 1 : Comparison Between Conventional and Nano-Enhanced Diagnostics:

Feature	Conventional Diagnostics	Nano-Enhanced Diagnostics
Sensitivity	Moderate	Very High (detects picomolar levels)
Sample Volume	Requires large samples	Microliters or drops
Speed	Minutes to hours	Seconds to minutes
Ability to Detect Early Disease	Limited	Excellent (detects silent biomarkers)
Portability	Mostly lab-based	Wearable or handheld
Cost	High (equipment-intensive)	Lower after integration
Real-time Monitoring	Rare	Very common (nanosensors)

Table 2 : Comparison of Nanoparticle Types Used in Medicine:

Nanoparticle Type	Main Applications	Advantages	Limitations
Gold Nanoparticles (AuNPs)	Imaging, cancer therapy	Biocompatible, tunable size, optical properties	High cost
Iron Oxide Nanoparticles	MRI contrast	Supermagnetic, safe	Possible liver accumulation
Polymeric Nanoparticles (PLGA, PEG)	Drug delivery	Biodegradable, customizable	Complex fabrication
Lipid Nanoparticles	mRNA vaccines, gene delivery	Highly biocompatible	Sensitive to temperature
Quantum Dots	High-resolution imaging	Strong fluorescence	Metal toxicity concerns

Table 3 : Regenerative Medicine Approaches (Traditional vs Nano):

Tissue Type	Traditional Treatment	Nano-Enhanced Approach
Bone	Titanium implants	Nanohydroxyapatite + nanofibers for bone regrowth
Nerve	Surgical grafting	Conductive nanoscaffolds + stem-cell delivery
Skin	Dressings	Nanosilver + nanoporous scaffolds
Heart	Surgery	Nanoparticle-guided cardiac repair

XVI. CLINICAL EXAMPLES (REALISTIC MEDICAL SCENARIOS):

1. **Nano-enabled Early Cancer Detection:**

A patient shows no symptoms, but a drop of blood on a nano-biosensor identifies circulating tumor DNA (ctDNA) at extremely low levels.

→ Traditional tests would miss this early stage.

→ Nano detection = early treatment, higher survival.

2. **Nano-Enhanced MRI for Brain Tumor:** A 45-year-old patient undergoes MRI using iron oxide nanoparticles as contrast. Tumor boundaries become clearer, allowing surgeons to plan a safer, more precise operation with less removal of healthy tissue.
3. **Targeted Drug Delivery in Breast Cancer:** Instead of whole-body chemotherapy, lipid nanoparticles deliver the drug directly to tumor cells using targeted receptors. This minimizes hair loss, nausea, and toxicity, achieving up to 70% increased drug accumulation in the tumor (Shi *et al*., 2017).
4. **Smart Wearable Nanosensor for Diabetes:** A nanosensor patch analyzes sweat glucose in real-time. If glucose rises, the patch sends an alert to the phone, avoiding repeated finger-pricking.
5. **Nano-antimicrobial Wound Healing:** A burn patient receives dressing with silver nanoparticles, which prevents bacterial infection, speeds healing, and reduces scarring.

XVII. CASE STUDIES (DETAILED SCIENTIFIC CASES)

Case Study 1: Doxil for Ovarian Cancer

- **Background:** Ovarian cancer is usually treated with doxorubicin, but the drug is highly toxic to the heart.
- **Nano-solution:** Doxil® = doxorubicin encapsulated in lipid nanoparticles.
- **Outcomes:** 50% less cardiotoxicity, longer circulation time, more

accumulation in tumors, improved patient tolerance.
- **Conclusion:** Nanocarriers reduce toxicity and improve targeted delivery.

Case Study 2: Nanoscaffolds for Bone Regeneration
- **Scenario:** A 30-year-old patient with a critical bone defect after an accident.
- **Nano approach:** Nanohydroxyapatite + collagen nanofibers scaffold implanted.
- **Results:** Faster bone regeneration, stronger bone integration, enhanced osteoblast activity, lower infection risk (Sengupta & Kulkarni, 2016).

Case Study 3: Quantum Dots in Lymph Node Mapping
- **Problem:** Surgeons must identify cancer-spread lymph nodes, which is difficult with traditional dyes.
- **Nano solution:** Injecting quantum dots produces a fluorescent signal that highlights cancerous nodes.
- **Outcome:** 98% accurate identification, reduced surgical errors, better cancer management.

Case Study 4: Nanorobotics for Arterial Plaque Targeting (experimental)
- **Method:** Magnetically guided nanoparticles attach to plaque in arteries and deliver anti-inflammatory drugs.
- **Results (in trials):** Reduced plaque volume, improved blood flow, lower risk of heart attack.

XVIII. CHALLENGES OF NANOTECHNOLOGY AND FUTURE SOLUTIONS

A. Challenges:

1. **Toxicity and Biocompatibility:** Some nanoparticles cause oxidative stress (Nel et al., 2006), DNA damage, and accumulation in the liver, spleen, or brain (Kreyling et al., 2015).
2. **Difficulty Predicting Behavior Inside the Body:** Nano-interactions depend on pH, ionic strength, and protein corona formation, making prediction difficult.
3. **Large-Scale Manufacturing:** Producing stable, uniform nanoparticles is expensive and hard to reproduce industrially.
4. **Regulatory Uncertainty:** The FDA is still developing long-term nano safety guidelines, and many nano-products lack full toxicity profiles.
5. **Ethical and Social Concerns:** Privacy risks in nano-wearables and environmental leakage of nanoparticles.

B. Future Solutions and Emerging Directions:

1. **Biodegradable Nanoparticles:** Designing nanoparticles that dissolve safely after completing their role.
2. **AI-Guided Nanomedicine:** AI predicts toxicity, pharmacokinetics, and best nanoparticle size/shape, reducing risk and improving design.
3. **Green Nanotechnology:** Using plant extracts or bacteria to synthesize nanoparticles sustainably (Singh et al., 2020).
4. **Personalized Nanomedicine:** Nanoparticles tailored to a patient's genetics, immune profile, and tumor type (Kostarelos, 2008).
5. **Hybrid Nanorobots:** Nanomachines guided by magnetic fields, ultrasound, or light for clearing blood clots and targeting cancer with nanoscale precision.

CONCLUSION

Nanotechnology dramatically enhances biomedical engineering through precision diagnostics, targeted therapies, advanced imaging, and tissue regeneration. Clinical examples, case studies, and comparative analyses demonstrate that nano-enabled systems outperform traditional technologies in nearly every medical field.

The future will combine AI + nanotechnology to create intelligent, personalized, safe, real-time healthcare systems.

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Artificial Intelligence Integration in Telemedicine: A Methodological Study on Challenges and Opportunities in Libya

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الملخص:
تُوفّر خدمات الطبّ عن بُعد المدعومة بالذكاء الاصطناعي إمكانات كبيرة لتحسين الوصول إلى الرعاية الصحية للفئات السكانية النائية والمحرومة من الخدمات؛ إلا أنّ تطبيقها لا يزال مقيَّدًا بتحديات تقنية وأخلاقية وتشغيلية. تتناول هذه الدراسة الفجوة البحثية المتعلقة بقصور آليات حماية البيانات، ومحدودية البنية التحتية، والتحيز الخوارزمي، وانخفاض مستوى تقبّل المستخدمين في أنظمة الطبّ عن بُعد الحالية.
وقد أُجري استعراض تحليلي منهجي لخمسة عشر بحثًا محكّمًا بهدف تقييم موثوقية وقابلية توسّع دمج الذكاء الاصطناعي في تقديم الرعاية الصحية عن بُعد، فضلًا عن عوامل السلامة المرتبطة بذلك. وتُظهر النتائج أنّ المنصّات القائمة تفتقر إلى الضمانات الكافية لضمان الاستخدام الآمن والعادل للبيانات، في حين تسهم العوائق التنظيمية والبنيوية إسهامًا ملحوظًا في تقليل فاعلية وظائف التشخيص والمراقبة المدعومة بالذكاء الاصطناعي.
وتؤكد الدراسة الحاجة إلى إطار عمل منظّم يوجّه صانعي السياسات، ومطوّري الأنظمة، ومقدّمي الرعاية الصحية نحو تبنّي الذكاء الاصطناعي بصورة أخلاقية ومرنة وقابلة للتوسّع، بما يعزّز إتاحة الرعاية الصحية بشكل أكثر عدالة في المناطق الجغرافية البعيدة.

Abstract: AI-enabled telemedicine offers substantial potential to improve healthcare access for remote and underserved populations; however, its implementation remains constrained by technical, ethical, and operational challenges. This study addresses the research gap concerning inadequate data-protection mechanisms, infrastructure limitations, algorithmic bias, and low user acceptance within current telemedicine systems. A systematic analytical review of *15 peer-reviewed studies* was conducted to evaluate the reliability, scalability of ntegrating artificial intelligence into remote healthcare delivery as well as safety are both factors. The findings show that existing platforms lack sufficient safeguards to ensure secure and fair data use, while regulatory and infrastructural barriers significantly reduce the effectiveness of AI-supported diagnostic and monitoring functions. The study highlights the need for a structured framework that guides policymakers, system developers, and healthcare providers in achieving ethical, resilient, and scalable AI adoption, thereby promoting more equitable healthcare access in geographically distant settings.

Keywords: Artificial Intelligence, Telemedicine, Remote Healthcare, Risk Assessment, Implementation Challenges, Healthcare Equity.

I. INTRODUCTION

The integration of Artificial Intelligence (AI) into telemedicine has emerged as a transformative development in contemporary healthcare, particularly for populations facing geographical, socioeconomic, and infrastructural barriers. Telemedicine has grown over the last decade, with global adoption rates increasing by an estimated 40–60% following advances in digital health technologies, yet conventional telehealth systems continue to experience significant limitations in scalability, diagnostic accuracy, and real-time responsiveness. Recent progress in AI—including machine learning, natural language processing, and predictive analytics—has enhanced remote diagnosis and automated decision support, improving performance outcomes by up to 25–30% in several clinical applications (Al-Debei, 2023; Alshammari *et al*., 2023; Sarker, 2022). Despite these advancements, major challenges remain global evidence from WHO and UN digital health assessments indicates that 50% of low-resource countries still lack adequate data-governance frameworks, while over 35% report concerns related to algorithmic bias, inequitable model performance, and

weak cybersecurity standards (World Health Organization, 2021; United Nations ESCWA, 2024).

In the Libyan context, these gaps are amplified by structural constraints. 30–35% of Libya's population resides in remote or underserved areas with limited access to specialized medical services, while national digital readiness remains below regional averages, with internet penetration ranging between 23–30% outside major urban centers. Furthermore, existing telemedicine initiatives in Libya remain fragmented, operating without unified regulatory, ethical, or technical guidelines, which complicates the deployment of AI-driven health solutions and raises concerns regarding equity, data protection, and trust.

Although international studies highlight the potential of AI to enhance healthcare outcomes in remote settings, a clear research gap persists current literature does not provide a systematic, context-sensitive analysis of the risk factors, implementation barriers, and ethical challenges associated with integrating AI into telemedicine within fragile, low-infrastructure environments such as Libya. Specifically, prior research has not adequately examined how data-governance limitations, algorithmic bias, inconsistent connectivity, and low user acceptance jointly influence the reliability and sustainability of AI-enabled telehealth. This study addresses this gap by conducting a structured assessment tailored to Libya's healthcare and digital landscape, aiming to identify the requirements for ethical, scalable, and resilient AI integration capable of improving healthcare equity in remote and underserved communities (Alshammari *et al*., 2023; Rahman & Rahim, 2022; Smith & Lee, 2023).

II. LECTURE REVIEW AND CONCEPTUAL FRAMEWORK

1. Ethical and legal issues:

Initial studies on telemedicine in rural and remote areas laid the groundwork for AI integration. Butzner *et al*. (2021) conducted an early systematic review showing that telehealth improved access and reduced wait times but highlighted data inconsistency and methodological limitations that restricted large-scale generalization. Later studies (2023-2024) focused on ethical and regulatory risks. Rossi *et al.* (2024) emphasized that the absence of international standards and inconsistent regulatory frameworks complicated responsible AI use. Similarly, Mennella *et al.* (2024) highlighted the need for oversight mechanisms and explicit data protection policies to reduce bias, misuse and likely patient harm. Privacy and cybersecurity remain major concerns, as reliance on third-party cloud infrastructures and lack of standardized encryption expose telemedicine platforms to breaches, undermining patient trust (United Nations ESCWA, 2024). These findings underscore the necessity for ethical governance, continuous evaluation, and transparency in AI-driven telemedicine (European Commission, 2020).

2.Infrastructural and technical difficulties:

Successful AI adoption in telemedicine relies on adequate infrastructure and digital literacy. Lestari *et al.* (2024) identified poor internet connectivity, low technical literacy, and lack of local expertise as key barriers in rural environments. Okwor *et al.* (2024) further emphasized that unequal access to digital tools generates inequitable health outcomes, reinforcing the digital divide. Predictive AI models often rely on non-representative datasets, limiting their performance in rural or low-resource communities (Sarker, 2022). Wubineh *et al.* (2024) recommended enhanced data collection and external validation protocols to improve model reliability and equity. Salman *et al.* (2021) found that dataset bias and incomplete data reduced the accuracy of machine-learning-based tele-triage systems.

3. AI Risk and Conceptual Framework Development:

By 2025, studies proposed structured frameworks for managing AI risks in remote healthcare. Perez *et al.* (2025) emphasized ethical transparency, continuous validation, and localized user training. Zendehbad *et al.* (2025) proposed measurable indicators for safety, reliability, and user confidence. Chaturvedi *et al.* (2025) highlighted challenges in real-time monitoring and data synchronization under unstable network conditions, while Dhunnoo *et al.* (2024) and Al-Kfairy *et al.* (2024) analysed methodological limitations and ethical implications of generative AI tools (Perez *et*

al., 2025; Zendehbad *et al.*, 2025; Chaturvedi *et al.*, 2025; Dhunnoo *et al.*, 2024; Al-Kfairy *et al.*, 2024).

4. Libyan Context and AI Telemedicine:

In Libya, AI-enabled telemedicine faces unique challenges due to unstable network infrastructures, weak digital systems, and limited staff training, despite increasing acceptance among healthcare providers (Alshammari *et al*., 2023; Lestari *et al*., 2024; Rahman & Rahim, 2022). Approximately 30-35% of the population resides in rural or underserved areas with limited access to specialized healthcare, and internet penetration in these regions remains below 30%. The lack of unified regulatory and ethical frameworks further complicates deployment. These conditions underscore the urgent need for a context-sensitive framework that integrates ethical, technical, and socio-structural considerations to ensure reliable, equitable, and sustainable AI-based healthcare delivery (United Nations ESCWA, 2024).

- **Study Issue, Questions, Hypothesis:**

Artificial Intelligence (AI) in telemedicine represents a transformative approach to enhancing healthcare delivery, particularly in underserved and remote regions. In Libya, where a significant proportion of the population resides in rural areas with limited access to specialized medical services, AI-driven telemedicine has the potential to bridge critical gaps in healthcare provision. However, the implementation of AI in this context faces considerable challenges related to digital infrastructure, data quality, ethical governance, and professional capacity. Addressing these challenges is essential to ensure that AI integration improves equity in healthcare rather than exacerbating existing disparities. This study aims to address the following focused questions:

1. What are the key infrastructural, technical, and ethical challenges hindering AI adoption in Libyan telemedicine?
2. How do limitations in data quality and governance affect the reliability and fairness of AI-enabled healthcare systems in Libya?
3. What strategies can be implemented to promote responsible, ethical, and sustainable AI deployment in the Libyan healthcare context?

Based on the study's analytical and systematic approach, the following hypotheses are proposed:

H1: Weak digital infrastructure and low-quality health data significantly constrain the effectiveness of AI-driven telemedicine in Libya.

H2: Inadequate ethical oversight and governance structures increase the risks of bias, privacy violations, and misuse of AI systems.

H3: Implementing robust data governance, ethical frameworks, and professional training enhances trust, safety, and sustainability in AI-enabled telemedicine.

- **Importance of the study's rationale:**

The importance of this study is in its exploration of how integrating Artificial Intelligence (AI) into telemedicine can enhance healthcare access and service quality in Libya's remote and underserved areas. In a situation where location barriers, limited medical resources, and gaps in digital infrastructure prevent fair healthcare delivery, examining AI-driven telemedicine presents a way to achieve lasting improvements. This research offers both academic and practical insights by looking at the challenges, risks, and strategic chances related to using AI technologies in Libya's healthcare system. It also aims to guide policymakers and healthcare leaders in creating frameworks that encourage safe, ethical, and effective digital health changes tailored to the country's specific needs.

- **Boundaries and Scope of the Investigation:**

This study focuses on how Artificial Intelligence (AI) can improve healthcare access and quality in remote and underserved areas of Libya.

• It looks at challenges, risks, and strategic factors for implementing AI, and does not cover system design, software development, or specific clinical procedures.

• The research is limited to rural and remote locations where healthcare services are lacking, representing areas most affected by access issues.

• The study examines the current state of digital health readiness and AI adoption in Libya's healthcare system.

• It emphasizes ethical, organizational, and infrastructure factors that impact AI integration, rather than clinical outcomes or biomedical patient-level evaluations.

• The study uses secondary data analysis and literature review, relying on existing empirical and theoretical

research for insights relevant to policy and practice in Libya.

Important definitions and key phrases:

• **Artificial Intelligence (AI):** is a field of computer science that allows machines to perform tasks usually needing human intelligence. Learning, reasoning, problem-solving, and decision-making are all covered here. In this study, AI refers to technologies used in telemedicine systems to improve diagnostic accuracy, automate clinical support, and enhance healthcare delivery (Sarker, 2022).

• **Telemedicine:** is the provision of healthcare services, consultations, and medical information through digital communication technologies. This allows patients and healthcare providers to interact remotely. In this study, telemedicine covers virtual consultations, remote monitoring, and AI-assisted clinical decision support systems (Alshammari *et al*., 2023).

• **Remote Communities:** are geographic areas with limited access to healthcare facilities and specialized medical personnel. This is often due to distance, infrastructure issues, or economic problems. The study focuses on these communities in Libya, where access to healthcare is particularly restricted (Alshammari *et al.*, 2023; Kacem & Ben Saad, 2022; Rahman & Rahim, 2022).

• **Healthcare Accessibility:** refers to how available, reachable, and usable healthcare services are for people in need. In this study, accessibility includes the ability of remote populations to receive timely, dependable, and fair medical care through AI-enabled telemedicine systems (Alshammari *et al*., 2023; Eysenbach, 2022).

• **Ethical and Regulatory Frameworks:** are structured policies, guidelines, and standards that ensure the safe, responsible, and fair healthcare use of artificial intelligence. These frameworks tackle concerns like data privacy, informed consent, algorithm transparency, and accountability (Al-Kfairy *et al*., 2024; European Commission, 2020; Mennella *et al*., 2024; Patel *et al*., 2023).

• **Digital Health Readiness:** is the extent to which healthcare systems, infrastructure, and staff can adopt and effectively use digital technologies, including AI applications in telemedicine. In this study, digital health readiness highlights the current strengths and weaknesses in the Libyan healthcare context (Alshammari *et al*., 2023; Lestari *et al*., 2024; Rahman & Rahim, 2022).

• **Implementation Barriers:** are factors that hinder the successful adoption and integration of AI-based telemedicine. These include technological limitations, low digital literacy, socioeconomic challenges, and organizational issues (Alshammari *et al*., 2023; Lestari *et al*., 2024; Okwor *et al*., 2024).

III. RESEARCH INSTRUMENTS, PROCEDURES, AND METHODOLOGY

This study employs an analytical and descriptive approach to evaluate the current literature on the integration of Artificial Intelligence (AI) in telemedicine, emphasizing healthcare delivery in remote and underserved populations, particularly in Libya. The study adopts a Systematic Literature Review (SLR) methodology combined with meta-synthesis techniques, following PRISMA 2020 guidelines to ensure transparency, reproducibility, and methodological rigor (PRISMA Group, 2021; Alshammari *et al*., 2023; Rahman & Rahim, 2022). Structured searches were conducted in Scopus, PubMed, and IEEE Xplore, targeting peer-reviewed articles published between 2021 and 2025. Keywords—artificial intelligence in telemedicine, distant healthcare, AI integration, health access, and risk assessment—refined using Boolean operators (AND/OR). Inclusion criteria were:

1. Studies directly addressing AI implementation in telemedicine,
2. Evaluation of challenges, risks, or ethical considerations, and
3. Use of analytical, data-driven, or systematic review methods.

Exclusion criteria removed studies that were non-peer-reviewed or lacked methodological clarity. The first inquiry found 122 papers. Thirty-four full-text papers were evaluated following duplication elimination and abstract screening. PRISMA Flowchart steps included: 34 full texts assessed → 19 excluded for methodological gaps → 15 studies selected for final

analysis. Two independent reviewers conducted the screening, and inter-rater reliability was confirmed with Cohen's Kappa (κ = 0.86) (PRISMA Group, 2021; Alshammari *et al*., 2023; Rahman & Rahim, 2022).

An organized data extraction form captured: primary results, ethical issues, analytic methods, data sources, artificial intelligence approach, study objectives. Analysis incorporated qualitative as well as quantitative methodologies:

Quantitative Analysis: Frequency distributions of study designs, AI types, telemedicine domains, and outcomes (Smith & Lee, 2023).

Qualitative Analysis: Inductive thematic analysis with three-step coding:

Open coding: Identifying recurring concepts (e.g., patient trust, algorithmic transparency),

Axial coding: Grouping codes into categories (e.g., ethical governance, infrastructural readiness),

Selective coding: Synthesizing overarching themes relevant to AI implementation and healthcare equity. Representative codes and examples were documented to ensure reproducibility (PRISMA Group, 2021).

Tab. 1: Condensed Summary of AI in Telemedicine (2021-2025)

Year(s)	Region(s)	AI Type(s)	Domain(s)	Key Outcome
2021	Global, N. America	Hybrid, ML	Chronic Care, Tele-triage	Reduced inequities, faster prioritization
2022	Europe, Asia, Africa	DL, NLP, Expert Sys	Diagnostics, Monitoring, Consultation	Improved trust, accuracy, real-time tracking
2023	Middle East, Europe, Asia	Hybrid, ML, NLP	Chronic Care, Diagnostics, Consultation	Better coordination, predictive models, satisfaction
2024	Africa, Global, Europe, Asia, Middle East	ML, Hybrid, DL, NLP	Monitoring, Chronic Care, Diagnostics	Efficient monitoring, equity, ethical assessment
2025	Libya	Hybrid, ML	Chronic Care, Diagnostics	Context-specific evaluation, feasibility

Methodological Rigor:

1. Multi-stage screening with two independent reviewers ensured reliability.
2. Cohen's Kappa (κ = 0.86) confirmed high inter-rater agreement.
3. PRISMA flowchart clearly documents the screening and selection process.
4. Structured data extraction minimized bias and enhanced reproducibility.
5. Combined quantitative and qualitative approaches ensured triangulation and holistic insights, particularly relevant for low-resource settings like Libya (PRISMA Group, 2021; Alshammari *et al*., 2023; Rahman & Rahim, 2022).

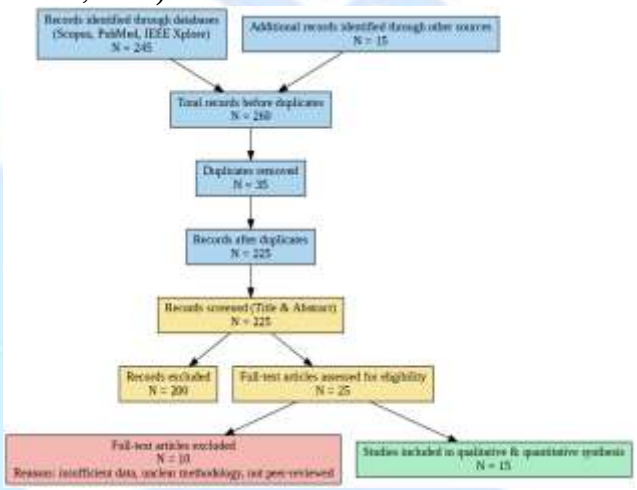

Fig. 1: PRISMA 2020 Flow Diagram Showing the Study Selection Process for AI in Telemedicine (2021–2025).

This integration allows triangulated insights, balancing empirical precision with contextual understanding, particularly for low-resource settings like Libya (Dhunnoo *et al*., 2024; European Commission, 2020).

IV. RESULTS

The systematic review of 15 studies published between 2021 and 2025 revealed a multidimensional understanding of AI integration in telemedicine, with a focus on improving healthcare delivery in underserved regions, including Libya (Alshammari *et al*., 2023; Rahman & Rahim, 2022; Perez *et al*., 2025). The studies employed diverse methodologies, including quantitative, qualitative, and mixed-method designs, reflecting the evolution of research from exploratory

approaches to evidence-based, context-sensitive applications. The PRISMA-based screening ensured methodological rigor, and the final sample included studies from multiple regions---Global, North America, Europe, Asia, Africa, the Middle East, and Libya---highlighting both generalizable insights and context-specific findings (Table 1).

1. Methodological Distribution and AI Techniques:

Quantitative analyses of the reviewed studies show that hybrid AI models and machine learning techniques were the most frequently applied, particularly in chronic care management, diagnostic support, and tele-triage systems. Deep learning and natural language processing were predominantly used in imaging, monitoring, and patient interaction domains. Mixed-method studies provided the most comprehensive insights by combining statistical accuracy measures with qualitative assessments of patient trust and usability (Sarker, 2022; Salman *et al*., 2021; Wubineh *et al*., 2024).

Tab. 2: AI Techniques and Telemedicine Domains Across Studies (2021–2025)

Study(s)	AI Technique(s)	Domain(s)	Key Outcome
2021 (S1–S3)	Hybrid, ML	Chronic Care, Tele-triage	Reduced inequities, faster prioritization
2022 (S4–S6)	DL, NLP, Expert Systems	Diagnostics, Monitoring, Consultation	Improved accuracy, trust, real-time tracking
2023 (S7–S10)	Hybrid, ML, NLP	Chronic Care, Diagnostics, Consultation	Better coordination, predictive modelling, patient satisfaction
2024 (S11–S14)	ML, Hybrid, DL, NLP	Monitoring, Chronic Care, Diagnostics	Efficient monitoring, equity enhancement, ethical assessment
2025 (S15)	Hybrid, ML	Chronic Care, Diagnostics	Context-specific evaluation, feasibility in Libya

2. Key Findings by Research Questions:

RQ1: Key infrastructural, technical, and ethical challenges:

Across the studies, four primary challenge categories emerged:

1.Technological: Limited interoperability, poor data quality, and algorithmic performance variability were consistently reported, particularly affecting predictive accuracy in low-resource settings (S1, S3, S5, S11) (Al-Debei, 2023; Alshammari *et al*., 2023; Salman *et al*., 2021; Wubineh *et al*., 2024).

2.Ethical: Studies highlighted risks of inadequate consent, privacy violations, and opaque AI decision-making (S2, S4, S5, S12) (Al-Kfairy *et al*., 2024; Butzner *et al*., 2021; Patel *et al*., 2023; Rossi *et al*., 2024).

3.Infrastructural: Weak connectivity, low computational capacity, and inconsistent electricity supply were barriers to reliable telemedicine delivery (S4, S5, S7, S15) (Butzner *et al*., 2021; Chaturvedi *et al*., 2025; Lestari *et al*., 2024; Zendehbad *et al*., 2025).

4.Socioeconomic: Inequalities in access, low digital literacy, and workforce skill gaps were shown to amplify healthcare disparities (S1, S5, S10, S15) (Al-Debei, 2023; Butzner *et al*., 2021; Okwor *et al*., 2024; Zendehbad *et al*., 2025).

Tab. 3: Challenges and Risks Mapped to Studies

Challenge	Studies	Observed Impact
Technological	S1, S3, S5, S11	Reduced AI performance, bias amplification
Ethical	S2, S4, S5, S12	Trust erosion, legal/ethical conflicts
Infrastructural	S4, S5, S7, S15	Service interruption, limited scalability
Socioeconomic	S1, S5, S10, S15	Widened healthcare inequities

RQ2: Impact of data quality and governance on reliability and fairness:

The studies consistently emphasized that limited or biased datasets, absence of standardization, and weak governance frameworks reduce the reliability, transparency, and fairness of AI-enabled healthcare systems (S1, S3, S4, S7, S15) (Al-Debei, 2023; Alshammari *et al*., 2023; Butzner *et al*., 2021; Lestari et al., 2024; Zendehbad *et al*., 2025). For example, predictive models trained on urban or global datasets

often underperformed in rural and resource-limited environments, indicating a critical need for context-specific data curation and validation.

RQ3: Context-sensitive strategies for sustainable AI deployment:

Although not prescriptive in this section, the results indicate that studies from low-resource regions (S5, S10, S15) (Butzner *et al*., 2021; Okwor *et al*., 2024; Zendehbad *et al*., 2025) highlight the effectiveness of adaptive, lightweight AI models optimized for low-bandwidth environments, combined with user training, continuous evaluation, and local data governance structures. These strategies directly address infrastructural and ethical barriers while maintaining operational efficiency.

V. DISCUSSIONS

The synthesis of findings demonstrates a complex interplay between technological potential and contextual constraints in AI-enabled telemedicine. While AI offers transformative improvements in diagnostic precision, chronic care management, and tele-triage prioritization, its success is contingent upon addressing ethical, infrastructural, and socioeconomic challenges.

Critical analysis of convergence and divergence:

1.Convergence: All 15 studies agreed that data quality and governance are fundamental to system trust and fairness. Hybrid AI models were consistently favored for adaptability in resource-limited contexts, providing both predictive accuracy and improved patient adherence.

2.Divergence: Studies differed regarding the extent of infrastructural dependency. High-resource settings emphasized automation and performance metrics, while low-resource settings prioritized system resilience, offline functionality, and equity. This indicates that contextual adaptation is essential, and AI cannot be universally transplanted without modification.

3.Ethical consensus: There is broad agreement on the necessity of transparent consent mechanisms, algorithmic auditing, and safeguarding patient data, yet the methods for operationalizing these safeguards vary considerably across regions.

4.Implications for Libya: The findings are directly relevant, as Libya faces fragmented digital infrastructure, intermittent electricity, and limited healthcare workforce training. Studies (S15, S5, S10) (Zendehbad *et al*., 2025; Butzner *et al*., 2021; Okwor *et al*., 2024) suggest that modular hybrid AI systems, designed for low-bandwidth environments and integrated with local governance frameworks, can enhance healthcare accessibility while minimizing inequities. Furthermore, the inclusion of Libyan studies underscores the importance of contextual evaluation, validating AI models within local populations rather than relying solely on international datasets.

5.Thematic integration: Four overarching themes emerge, providing a structured lens for analysis:

a. Ethical governance: Need for clear consent, transparency, and accountability mechanisms.

b. Algorithmic reliability: Dependence on high-quality, locally representative data.

c.Infrastructural readiness: Low-bandwidth optimization, offline functionality, and system redundancy.

d.User trust and engagement: Training of healthcare workers and patient education to support adoption.

By synthesizing these themes with study-specific findings, the discussion provides a clear mapping of risks to practical challenges, ensuring that the results are directly aligned with the research questions. The evidence suggests that AI adoption in Libyan telemedicine is feasible but requires context-sensitive adaptation, ethical oversight, and infrastructural investment to achieve equitable and sustainable healthcare delivery.

CONCLUSIONS AND RECOMMENDATIONS

1. Transformative Potential: AI in telemedicine can significantly enhance healthcare. access in remote and resource-limited regions.

2. National Strategy and Governance: Develop a comprehensive digital health strategy that integrates AI-driven telemedicine, supported by clear governance, privacy regulations, and ethical oversight.

3. Infrastructure and Data Integration: Build interoperable digital systems linking electronic

medical records with AI applications to enable efficient diagnostics, patient management, and clinical decision-making.

4. Capacity Building and Collaboration: Implement training programs to improve digital literacy and trust in AI systems. Organize multidisciplinary workshops involving IT graduates and medical professionals to ensure practical project implementation. Collaboration with universities and international research centres can promote knowledge transfer and sustainable skill development.

5. Community Engagement and Affordability: Involve local populations in platform design to address cultural, linguistic, and accessibility needs. Ensure services are cost-effective for citizens, while hospitals may adopt subscription models (monthly or annual) to leverage AI benefits.

6. Monitoring and Ethical Compliance: Establish evaluation frameworks to assess AI accuracy, reliability, and fairness. Maintain transparency and algorithmic explainability to uphold ethical standards and public trust.

7. Sustainable Implementation: Successful adoption requires balancing innovation, governance, human capacity, ethical accountability, and financial accessibility to create an efficient, inclusive healthcare system.

The findings of this study indicate that integrating Artificial Intelligence into telemedicine offers substantial opportunities to enhance healthcare access, quality, and efficiency, particularly in remote and underserved areas of Libya. AI-driven systems can improve diagnostic accuracy, patient monitoring, and chronic disease management, but their effectiveness is constrained by ethical, infrastructural, and data governance challenges. Addressing these barriers is essential to ensure trust, fairness, and sustainability in AI-enabled healthcare.

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Case Study in Benghazi Rehabilitation Center: Causes of Amputation and Used Artificial Limbs

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الملخص: تُعدّ الصحة جانبًا بالغ الأهمية في حياة الإنسان، إذ تؤثر في قدراته الجسدية وحالته النفسية والعاطفية، وتمكّنه من عيش حياة متكاملة والسعي لتحقيق طموحاته. ويُحدث فقدان أحد الأطراف تأثيرًا كبيرًا في حياة الفرد، حيث يحدّ من قدراته البدنية، ويؤثر في حركته، وقد يسبب الاكتئاب نتيجة فقدان الاستقلالية وزيادة الاعتماد على الآخرين في أداء المهام اليومية الأساسية. ومن هنا تبرز الحاجة إلى تعويض الطرف المفقود، إذ يساعد الطرف الصناعي الأفراد على استعادة قدر من السيطرة على حياتهم، ويعزّز قدرتهم على الحركة والإمكانات الجسدية، مما ينعكس إيجابًا على حياتهم العملية وثقتهم بأنفسهم من خلال استعادة جزء من استقلاليتهم. يهدف هذا العمل إلى إبراز أهمية الأطراف الصناعية، واستعراض التقنيات المستخدمة في Benghazi Rehabilitation Center ، وذلك لتحديد موقع ليبيا مقارنةً بدول العالم الأخرى في مجال الأطراف الصناعية .كما تهدف الورقة إلى نشر الوعي بأسباب البتر في مدينة بنغازي وسبل الوقاية منه قدر الإمكان .وقد أُجري تحليل إحصائي استنادًا إلى سجلات المركز لمراجعة الأسباب الرئيسة لحالات البتر، وتبيّن أن أكثر من نصف الحالات كانت ناتجة عن مرض السكري.

الكلمات المفتاحية: إعادة التأهيل؛ مبتور الأطراف؛ البتر؛ الأطراف الاصطناعية؛ الطرف الاصطناعي؛ الطرف الاصطناعي؛ اصطناعي .

Abstract: Health is a very important aspect of anyone's life, influencing their physical capabilities and emotional and mental state and help them live a fulfilling live and pursue their dreams. Losing a limp has a significant impact on a person's life, reducing physical ability, affects mobility and causes depression as they lose their independence and become more reliant on others for basic daily tasks. And so, comes the need to replace the lost limb. An artificial limb helps people regain some control over their life; it enhances mobility and physical capabilities hence improves their work life and confidence as they regain some independence. This work is to address the importance of artificial limbs and to overview the technology used in the Benghazi rehabilitation center to know where Libya stands compared to the other world regarding prosthetics. The paper is also aimed to spread awareness on the causes of amputation in Benghazi and how to prevent it if possible, a statistic is made using the records of the center to review the main cause of amputation, it prevailed that more than half of cases were due to diabetes.

Keywords: Rehabilitation; amputee; amputation; prosthetic; artificial limb; prosthetic limb; artificial.

I. INTRODUCTION

Prosthetic limbs are artificial devices used to replace a limb, usually after amputation or congenital condition, in order to restore function and quality of life. Prosthetics have developed from simple cosmetic devices to mechanical devices and further into myoelectric systems that integrate body electrical signals to coordinate movement, and advanced bionic systems integrating electronics, neural interfaces, and sensors to regain motor skills (Meier & Melton, 2014; Robertsson *et al.*, 2011). Prosthetic limbs are classified either by the location of the amputation, the functionality of the prosthetic, or the activity level of the amputee, 2021; (Segura *et al*., 2024).

A. Classification by Amputation Level:

Trans-humeral prosthetics are arms for amputation above the elbow, trans-radial prosthetics are arms for amputation below the elbow, transfemoral are legs for amputation above the knee, and transtibial prosthetics are legs below the knee (Kirilova *et al.*, 2021; Segura *et al.*, 2024).

B. Classification by Functionality of Prosthetic:

Passive prosthetics are purely cosmetic and may have minimal function, such as limited passive gripping of light objects (Walicka *et al.*, 2021).

Body-powered prosthetics rely on the amputee's own movements via straps, cables, and harnesses; mechanical knee joints are an example (Meier & Melton, 2014).

Myoelectric prosthetics use electrical signals from the user's muscles to power motors and produce movement (Olaya-Mira *et al.*, 2025).

Hybrid prosthetics combine elements from different categories to provide both simple body-powered and complex externally powered functions (Olaya-Mira *et al.*, 2025).

C. Classification by Activity Level (K-levels):

Indicates a person's likelihood for prosthetic use:

K0: No potential for walking or safe transfer with a prosthetic.

K1: Limited household ambulation on level surfaces (Andrews *et al.*, 2017).

K2: Limited community ambulation with low-level barriers.

K3: Community ambulator, walks at various speeds and crosses most environmental barriers.

K4: High-activity adult or athlete exceeding normal ambulation (Andrews *et al.*, 2017).

II. LITERATURE REVIEWS

Losing a limb significantly affects mobility, daily activities, and independence. About 63.6% of amputees report difficulties with hygiene, bathing, and dressing (Al-Eqabi *et al.*, 2024). Psychological impacts include impaired social life and professional limitations, reported by 64% and 68% of patients, respectively (Hamed, 2016; El Sahly & Cusick, 2016).

In Libya, diabetes is the leading cause of lower limb amputation, accounting for 68.6% of cases between 2010 and 2019, rising from 61.1% in 2010 to 71.4% in 2019 (Walicka *et al.*, 2021). Benghazi Rehabilitation and Handicap Center were the only functioning physical rehabilitation center after the 2011 revolution, providing free services to inpatients and outpatients, mostly male patients, with limited female staff in administrative roles (Hamed, 2016; El Sahly & Cusick, 2016).
Assessment of prosthetic adaptation uses gait analysis, mobility evaluation, physical assessment, and self-report questionnaires (Olaya-Mira *et al.*, 2025)

III. METHODOLOGY

This study is a descriptive cross-sectional approach to investigate the type of prosthetics, causes of limb amputation, and the distribution of the center's patients. Data was collected using multiple tools, first, structured interviews, with key staff members, they were directly interviewed and questioned on the procedure of making prosthetics and their quality. Secondly, direct observation on site, visits were conducted to the rehabilitation center while taking notes about what prosthetics are available. Thirdly, achieved records review, patients' electronic medical records were accessed to get relevant data, specifically (reason of amputation) leaving out personal information to adhere to confidentiality and ethical standards. Some of the medical records were lost in the process of transforming the handwritten archive to an electronic one, it was only transformed into electronic version in the past two years by the center (walicka *et al.*, 2021).

Regarding data analysis, a simple statistic was made on the collected data to compute the frequency and percentage of different causes of amputation in the Benghazi rehabilitation and handicap center to identify the most frequent cause.

IV. OBSERVATIONS AND STATISTICS OF THE BENGHAZI REHABILITATION AND HANDICAB CENTER

A Prosthetics provided in the center The center provides both upper limbs and lower limbs. In general, upper and lower limbs address Different functional needs, upper limps tend to be more focused on restoring motor skills and grabbing function, while lower limbs are focused on weight bearing and providing stability, balance, and mobility. From the study in the center, it was clear that lower limb prosthetics were of high quality and functionality, the center provides monocentric mechanical knee joint for transfemoral amputees.

The joint has load-dependent brakes mechanism, when the weight is placed on the heel the brakes activate providing stability and protection for the duration of stance phase. The knee also has automatic release mechanism as the brakes deactivate when the weight shifts to the forefoot, allowing for easy initiation of the swing phase (Meier & Melton, 2014). The mechanical knee also has mechanical extension assistance which is generally a spring system that helps the lower leg straighten during the swing phase of walking and it also reduces stumbling and reduces user effort.

Regarding upper limb prosthetics they are only cosmetic with no grasping mechanism, and during this study there were no upper prosthetics available because of the high cost of the materials used to imitate normal skin (Segura *et al.*, 2024)، And there aren't always tons use of them. The center has a lot of work to do to catch up with current technology of prosthetic upper limb.

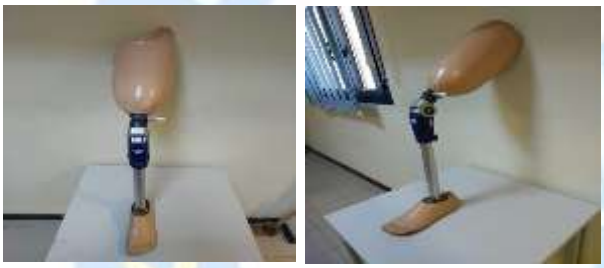

Fig. 1: Transfemoral prosthetic leg with mechanical knee joint.

Fig. 2: Transtibial prosthetic leg.

A. Causes of amputation in the Benghazi rehabilitation and handicap center:

We obtained data from the years 2021, 2022, 2024, and 2025. 2023 data was lost while in handwriting before being digitized. All personal information has been neglected and focused mainly on the cause of amputation.

Based on the data the cause of amputation is divided into 7 causes:

1) war and weapons related injury: which includes injuries due to the war itself and after, and it includes stepping on mines and receiving gunshots (Although some of gun related injuries are from fights or a stray bullet). The total number of amputee's who received prosthetics was 185 patients.

2) Diabetes: This disease is the most prominent cause of amputation, neuropathy and poor circulation could lead to foot ulcers, these ulcers can become infected and if not treated properly it could lead to amputation. There have been many studies focused on the early detection of diabetic foot to avoid amputation. The number of prosthetics provided for diabetic foot amputees was 313 in 4 years (Walicka *et al.*, 2021).

3) Car accidents: Libya is known for its dangerous driving; in 2024 it was classified as one of the highest traffic fatalities globally with a rate of 73 fatalities in 100,000 people which is significantly higher than the standard average rate of 20 fatalities of 100,000 people. The number of prosthetics provided for the casualty of car accidents is 96 in four years. (Libya Review, 2024).

4) Cancer: If a tumor grows in a limp such as osteosarcoma, it can damage surrounding tissue or if the tumor is too big or invasive sometimes it's impossible to remove it without sacrificing the limb. the number of prosthetics provided for tumor patients is 6 in four years (Kirilova *et al.*, 2021).

5) Congenital defect: A congenital defect could result in the absence of limb which is known as Amelia. Amelia is a rare congenital defect condition characterized by complete absence of a limb or more. The number of prosthetics provided for individuals with this case is 14 prosthetics (Khanal *et al.*, 2022).

6) Electricity: Exposure to high voltage can cause severe injuries including potential for amputation. Only one prosthetic was provided for this cause.

7) Work injury: there were two cases of work injuries in the centers achieve. Unknown causes: two prosthetics in 2021 were provided to patients with unknown causes of amputation. They were not written in the handwritten Archive.

B. Demonstration of statistics taken from center:

The statistics are from data collected from the center archives and some data from the red cross.

Table I: Number of cases alongside cause of amputation:

Cause of amputation	2021	2022	2024	2025	Total Number
War & guns injuries	107	34	28	16	185
Work injury	1			1	2
Congenital malformation	11	2	1		14
Car accident	40	24	21	11	96
Cancer	4	1		1	6
Diabetes	130	68	72	43	313
Electricity	1				1
Unknown	2				2

The table exhibits the causes of amputation of cases assessed in the Benghazi center alongside the number of cases; the following graphs are graphic representations of the previous table.

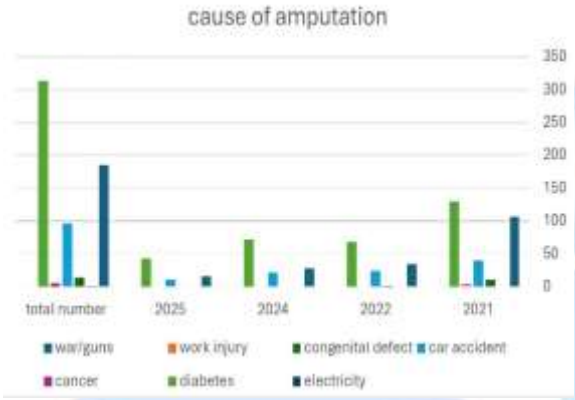

Fig.3: Graph showing causes of amputation per year.

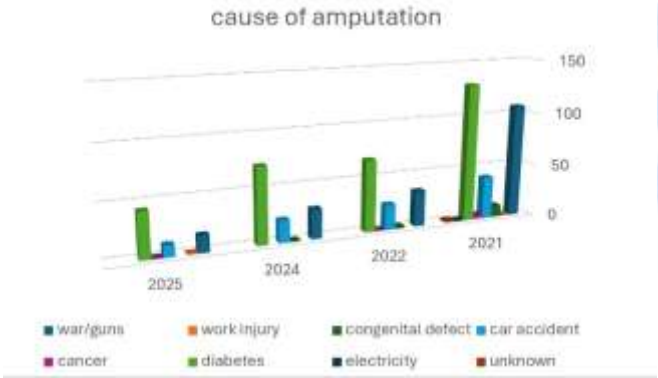

Fig.4: Graph showing causes of amputation per year.

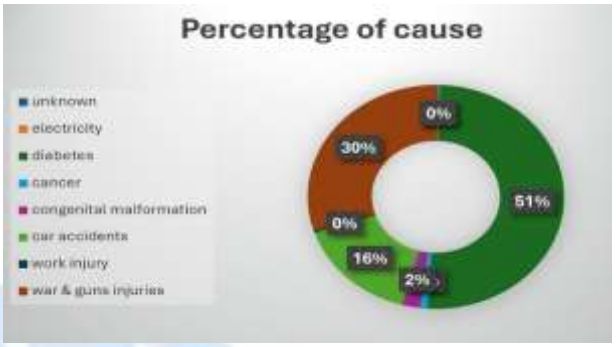

Fig.5: Causes of amputation by percentage pf total number of cases.

Parentages lower than 0.5% are written as 0% in the previous Pie chart, it demonstrates that diabetes is cause of more than half of the cases.

CONCLUSION

After the visit to the Benghazi rehabilitation and handicap center and conducting a study, it was clear that the main cause of amputation in Benghazi, Libya and surrounding towns is diabetes by 50.6% from the overall amputees who were provided prosthetics by the center. And is due to the high population suffering from diabetes. The second main cause of amputation by 30% was war and guns and vast majority of them are from 2021 and before, which indicates an increase in safety in the recent years. The third cause of amputation was car accidents adding up to 15.5% of total amputees (Walicka *et al.*, 2021; Libya Review, 2024).

The lower limb amputees are significantly more than upper limb amputees with a percentage of 97.5% of total amputees which numbers was counted by the red cross in the last two years. The number of prosthetics provided in the center decreased in 2025 by about 40% compared to 2024 and 2022 mainly because the center suffered from lack of equipment's especially upper limb prosthetics. Regarding the prosthetics provided in the center, upper limps provided are only cosmetic wit conclusion (Meier & Melton, 2014; Segura *et al.*, 2024). After the visit to the Benghazi rehabilitation and handicap center and conducting a study, it was clear that the main cause of amputation in Benghazi, Libya and surrounding towns is diabetes by 50.6% from the overall amputees who were provided prosthetics by the center. And is due to the high population suffering from

diabetes. The second main cause of amputation by 30% was war and guns and vast majority of them are from 2021 and before, which indicates an increase in safety in the recent years. The third cause of amputation was car accidents adding up to 15.5% of total amputees. The lower limb amputees are significantly more than upper limb amputees with a percentage of 97.5% of total amputees which numbers was counted by the red cross in the last two years.

The number of prosthetics provided in the center decreased in 2025 by about 40% compared to 2024 and 2022 mainly because the center suffered from lack of equipment's especially upper limb prosthetics. Regarding the prosthetics provided in the center, upper limps provided are only cosmetic with no grasping functionality. And lately even those cosmetic hands are often not available, which is very insufficient and needs urgent enhancement. Unlike the lower limbs which provide level 1 and level 2 of mobility and are very sufficient for regaining stance and walking function for amputees. h no grasping functionality. And lately even those cosmetic hands are often not available, which is very insufficient and needs urgent enhancement. Unlike the lower limbs which provide level 1 and level 2 of mobility and are very sufficient for regaining stance and walking function for amputees.

RECOMMENDATIONS

- Diabetes is the main reason for amputation especially in lower limbs; hence, more research should be conducted on how to diagnose diabetic foot earlier so amputation would be avoided, or conducting studies to evaluate the reason a high percentage of Libyan's population suffers from diabetes in the first place (Walicka *et al*., 2021).
- The upper limbs provided by the center (when available) are only cosmetic, and so we encourage more studies on artificial hands to replicate grasping and basic functions of the hand because currently Libya is very behind. so, we encourage the search for a quick solution, whether it’s mechanical, myoelectric, or bionic as long as it is easy to use and affordable to cover the shortage (Segura *et al.*, 2024). Also, we encourage the study of delay to why myoelectric and bionic hands have yet not spread in Libya.
- As for prosthetic lower limbs in the center, there is room for improvement but it's not urgent as in the state of upper limbs (Meier & Melton, 2014).

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From Innovation to Implementation: Entrepreneurial Mobile Health Solutions for Remote Monitoring of Head and Neck Cancer Patients

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الملخص: إن الارتفاع المتزايد في معدلات الإصابة بسرطان الرأس والعنق (HNC) يبرز الحاجة الملحّة إلى استراتيجيات متابعة مبتكرة تتمحور حول المريض بعد انتهاء العلاج. ورغم أن المتابعة التقليدية لا تزال ذات فائدة سريرية، فإنها غالبًا ما تفشل في الكشف المبكر عن الأعراض، كما تُثقل كاهل المرضى بزيارات متكررة إلى المستشفيات، مما يسهم في انخفاض جودة الحياة، وتأخر التدخلات العلاجية، وزيادة اللجوء إلى خدمات الطوارئ. توفر تطبيقات الصحة المتنقلة (mHealth) حلاً تحويليًا من خلال تمكين المراقبة المستمرة عن بُعد للمؤشرات السريرية ونتائج المرضى المُبلّغ عنها ذاتيًا (PROs). وتُظهر الأدلة المستمدة من المراجعات المنهجية، والتجارب العشوائية المحكمة، ودراسات التطبيق العملي، جدوى هذه التطبيقات وفعاليتها في تحسين إدارة الأعراض، وتقليل الزيارات غير الضرورية إلى المستشفيات، وتعزيز الرعاية الذاتية لدى المرضى. وعلاوة على فوائدها السريرية، تتيح أدوات الصحة المتنقلة فرصًا مهمة لريادة الأعمال والابتكار. إذ يمكن لتطوير منصات قابلة للتوسّع ومستندة إلى الأدلة أن يعزّز التعاون بين المهنيين الصحيين، ومطوري البرمجيات، والشركات الناشئة في مجال التكنولوجيا الصحية. وتنسجم هذه المبادرات مع الأولويات السريرية والابتكار التكنولوجي، بما يسهم في إنشاء نماذج مستدامة لرعاية الناجين من السرطان، مع تحفيز النمو الاقتصادي، وتعمل هذه الورقة على تجميع الأدلة الحالية، وتقييم أفضل الممارسات في التصميم والتطبيق، ودراسة الدور المزدوج لتطبيقات الصحة المتنقلة بوصفها أدوات سريرية ومشروعات ريادية في آنٍ واحد. ومن خلال الربط بين الرعاية الصحية والابتكار، تمتلك الصحة المتنقلة القدرة على إحداث تحول في رعاية مرضى السرطان بعد العلاج نحو نظام أكثر كفاءة، وتمحورًا حول المريض، واستدامةً من الناحية الاقتصادية .

الكلمات المفتاحية: سرطان الرأس والرقبة، الصحة المتنقلة، المراقبة، الابتكار، ريادة الأعمال، الرعاية المتمحورة حول المريض، المراقبة عن بعد، النجاة.

Abstract: The rising incidence of head and neck cancer (HNC) underscores the urgent need for innovative, patient-centred surveillance strategies after treatment. While traditional follow-up remains clinically useful, it often fails to detect symptoms early and burdens patients with frequent hospital visits, contributing to lower quality of life, delayed interventions, and increased emergency care. Mobile health (mHealth) applications provide a transformative solution by enabling continuous, remote monitoring of clinical metrics and patient-reported outcomes (PROs). Evidence from systematic reviews, randomized controlled trials, and implementation studies highlights their feasibility and effectiveness in improving symptom management, reducing unnecessary hospital visits, and enhancing patient self-care. Beyond clinical benefits, mHealth tools offer significant opportunities for entrepreneurship and innovation. The development of scalable, evidence-based platforms can foster collaboration among healthcare professionals, software developers, and health-tech startups. Such initiatives align clinical priorities with technological innovation, creating sustainable models of survivorship care while stimulating economic growth. This paper synthesizes current evidence, evaluates best practices for design and deployment, and examines the dual role of mHealth applications as both clinical tools and entrepreneurial ventures.

By bridging healthcare and innovation, mHealth has the potential to transform post-treatment cancer care into a more efficient, patient-centred, and economically sustainable system.

Keywords: Cancer of the head and neck, mobile health, surveillance, innovation, entrepreneurship, patient-centred care, remote monitoring, survivorship.

I. INTRODUCTION

Head and neck cancer (HNC) survivors often face long-term physical and psychological challenges that require continuous post-treatment monitoring and rehabilitation. Traditional follow-up methods, which rely heavily on in-person hospital visits, can impose substantial burdens on both patients and healthcare systems, including travel costs, scheduling difficulties, and limited access to specialists in rural or underserved regions. The growing prevalence of digital health and mobile health (mHealth) technologies has introduced new possibilities for addressing these challenges by enabling remote patient monitoring and personalized follow-up care (Li, 2023). Recent systematic reviews have demonstrated the feasibility and effectiveness of telehealth solutions in the ongoing management of HNC patients. Telemonitoring systems have shown promise in tracking symptoms such as dysphagia, fatigue, and pain, while also allowing for early detection of complications without requiring frequent hospital visits (Hulse *et al.*, 2023).

Moreover, digital health interventions that integrate mobile applications, wearable sensors, and video consultations have been reported to improve patient engagement, adherence to rehabilitation programs, and overall quality of life (Romano *et al.*, 2020). These technologies provide a flexible and patient-centred model of care that extends clinical oversight beyond the hospital environment. Mobile health innovations are increasingly being explored as entrepreneurial solutions to enhance cancer survivorship care. Many of these tools leverage smartphone-based applications and data-driven platforms that can collect real-time patient-reported outcomes, automate reminders, and facilitate communication between patients and clinicians (Teckie *et al.*, 2021). Studies indicate that such systems not only improve clinical outcomes but also reduce healthcare utilization, particularly by minimizing unnecessary follow-up appointments and hospital readmissions (Li, 2023; Yang *et al.*, 2023). Furthermore, the integration of mHealth into survivorship care pathways can improve the efficiency of resource allocation and offer cost-effective alternatives to conventional models of care Rockey-Bartlett *et al.*, 2025). Despite these promising findings, several challenges remain in the implementation of mHealth technologies for remote monitoring of HNC patients. These include variations in digital literacy among patients, concerns about data privacy and security, and the need for evidence-based frameworks to evaluate clinical efficacy and user acceptance (Leonardsen *et al.*, 2022). Addressing these challenges requires a multidisciplinary approach that combines medical expertise, technological innovation, and entrepreneurial strategies to ensure sustainable and scalable deployment of mHealth solutions (Da Silva *et al.*, 2022).

II. LECTURE REVIEW AND CONCEPTUAL FRAMEWORK

The investigation assessed the viability of web-based follow-up modalities for survivors of Head and Neck Cancer (HNC). The study's objective was to substitute a portion of conventional in-person appointments with a secure digital interface where individuals could self-report their symptoms pertaining to dysphagia (swallowing difficulties), pain levels, and emotional distress. The findings demonstrated that collecting patient data remotely was effective in maintaining both patient safety and satisfaction while simultaneously lessening the demands on clinical infrastructure.

This preliminary research furnished essential evidence for the integration of digital healthcare in oncology, thereby establishing the foundation for the subsequent adoption of mobile-based interventions (De Leeuw *et al.*, 2017). A pilot research project advanced the concept of monitoring patient-reported outcomes by introducing a smartphone-based intervention during concurrent chemoradiotherapy for HNC patients. The dedicated application facilitated symptom tracking in real-time, enabling healthcare providers to receive immediate notifications when severe side effects were documented. The outcomes indicated improved symptom control, enhanced clinician-patient communication, and a reduction in unscheduled interruptions to treatment. Despite facing challenges related to digital literacy and sustained engagement, the study confirmed that mobile health (mHealth) tools serve as a practical linkage between patients and medical professionals during intensive therapeutic regimens (Zini *et al.*, 2019). Another study explored an mHealth methodology that incorporated predictive analytical capabilities into the symptom monitoring process for patients undergoing radiotherapy for HNC (Romano *et al.*, 2020). The digital platform was engineered to anticipate potential adverse events and trigger prompt

clinical responses based on trends identified within the patient-submitted data.

Results unveiled significant reductions in acute toxicity events and fostered better coordination among oncology teams and their patients. The study underscored the principle that embedding Artificial Intelligence (AI) into mHealth systems can profoundly improve responsiveness, personalization, and precision in clinical decision making (Galmiche *et al.*, 2024). A subsequent study built upon previous feasibility work by designing an application that directly integrated patient-reported outcomes into the hospital's Electronic Medical Records (EMRs), (Chang *et al.*, 2024). The research evaluated the effect of this real-time symptom data on clinical workflow, data interoperability, and the overall patient experience. The evidence suggested that incorporating mobile technology into standard clinical procedures led to fewer emergency department visits, improved communication efficacy, and promoted data-informed healthcare delivery.

The authors stressed the critical need for institutional partnership and robust regulatory frameworks to ensure the long-term sustainability and scalability of mHealth initiatives (Van de Weerd *et al.*, 2023). Another investigation assessed the practical, real-world deployment of a remote monitoring application utilized in the post-treatment follow-up regimen for HNC survivors. Employing a comprehensive mixed-methods methodology, the study analysed the app's usability, user adherence, and clinical effectiveness over a six-month duration. The findings demonstrated that remote surveillance enhanced patients' self-management of late-onset side effects, curtailed unnecessary outpatient clinic visits, and supported the earlier detection of symptoms indicative of recurrence.

The researchers concluded that successful digital health implementation is contingent upon sustained organizational backing, iterative software design, and continuous feedback mechanisms from users (Leonardsen *et al.*, 2022), a recent study investigated a next-generation mHealth platform that incorporated data from wearable sensors and AI-driven analysis to provide continuous remote monitoring for HNC patients throughout their rehabilitation phase. The sophisticated system gathered biometric data, such as heart rate variability, vocal effort metrics, and nutritional intake figures, via wearable devices synchronized with the mobile application. The results showed substantial improvements in patient adherence to the program and facilitated the early identification of complications, particularly those related to malnutrition and fatigue (Galmiche *et al.*, 2024).

Research Issue, Questions, And Hypotheses:

Head and neck cancer (HNC) survivors frequently require long-term clinical surveillance to detect complications and manage late treatment effects. Conventional hospital-based follow-up models, however, impose significant logistical and financial burdens on both patients and healthcare systems. Repeated in-person visits often lead to care fatigue, travel challenges, and reduced accessibility for patients in remote or underserved areas. Over the past decade, mobile health (mHealth) technologies have emerged as promising tools to enhance remote monitoring, symptom management, and continuity of care.

Nevertheless, a considerable gap persists between innovation and implementation. Although multiple pilot studies and digital prototypes have demonstrated potential clinical benefits, the large-scale integration of entrepreneurial mHealth solutions into real world oncology practice remains limited. Critical barriers include fragmented evidence on clinical effectiveness, patient engagement, data security, and sustainability within healthcare infrastructures. Accordingly, this research addresses the following central problem:

How can entrepreneurial mobile health solutions be effectively implemented to improve remote monitoring, reduce hospital dependency, and enhance posttreatment quality of life among head and neck cancer patients?

This inquiry aligns with contemporary trends in digital oncology that emphasize the integration of artificial intelligence, real-time data analytics, and patient-centred design to support hybrid care pathways and optimize survivorship outcomes The following studies questions manual this study:

1. To what extent do mobile health technologies improve remote post-treatment monitoring and clinical outcomes in head and neck cancer patients?
2. Can the implementation of mHealth solutions effectively reduce hospital visits and healthcare resource utilization while maintaining the quality of care?

3. What are the principal technical, behavioral, and organizational barriers that influence the adoption of mHealth systems in oncologic follow-up care?
4. How do patient and clinician perceptions of usability, trust, and satisfaction affect the sustained utilization of mobile-based monitoring platforms?
5. Which entrepreneurial and strategic frameworks best facilitate the sustainable scaling and integration of mHealth innovations within cancer survivorship programs?

This study aims to examine the key hypotheses guiding the research:

H1: Entrepreneurial mobile health applications significantly enhance the efficiency and continuity of post-treatment follow-up among head and neck cancer survivors.

H2: The use of mHealth-based remote monitoring systems reduces the frequency of hospital visits and associated healthcare costs at the same time as keeping or enhancing patient. outcomes.

H3: Successful implementation of mHealth solutions is positively associated with patient. engagement, technological usability, and institutional readiness for digital.

H4: Entrepreneurial innovation frameworks that integrate business scalability and clinical validation accelerates the sustainable adoption of mHealth technologies in oncology care.

Significance And Rationale of the Study:

This study is important as it explores innovative mobile health (mHealth) solutions to enhance post-treatment monitoring for head and neck cancer patients. It emphasizes how digital tools can improve follow-up care, enable early detection of complications, and reduce unnecessary hospital visits, enhancing patients' nice of life. By linking entrepreneurship with healthcare innovation, the study highlights the role of mHealth applications in creating sustainable, patient-centred systems that bridge gaps in accessibility and communication. It contributes to the digital transformation of oncology care and provides a foundation for future research and policy improvement in faraway affected person management.

Scope and Delimitations of the Study:

Scope and Delimitations of the Study: This study is limited by the availability and scope of existing literature on mobile health (mHealth) solutions for head and neck cancer follow-up. Most reviewed studies vary in their methodologies, sample sizes, and technological contexts, which may affect the generalizability of the findings. Additionally, the research focuses primarily on post-treatment monitoring and may not capture all aspects of patient care during active treatment phases. The rapid evolution of digital health technologies also poses a limitation; as newer innovations may emerge beyond the Time restrict of this review. Finally, this study relies on secondary data from published research, which may be subject to publication bias and versions in information first-class throughout studies.

Key Terms and Definitions:

Mobile Health (mHealth): Refers to using cell devices, which include smartphones and tablets, to supply healthcare.
services, monitor patients, and support disease management remotely. mHealth enables Realtime communication between patients and healthcare providers, improving access to care,
especially in remote areas (Chang *et al.*, 2024).

Entrepreneurial Health Solutions: Innovative, technology-driven healthcare applications or platforms developed through.
entrepreneurial initiatives to improve service delivery, accessibility, and patient engagement. These solutions often combine business strategies with clinical needs to create sustainable digital health models (Frid *et al.*, 2024).

Head and Neck Cancer (HNC): A group of malignant tumours that develop in the oral cavity, pharynx, larynx, nasal cavity, or associated structures. HNC often requires complex multimodal treatment and continuous post therapy monitoring due to elevated risk of recurrence and long-term complications (Da Silva *et al*., 2022).

Remote Patient Monitoring (RPM): A healthcare practice using digital technologies to collect and transmit medical data from patients outside clinical settings to healthcare providers for ongoing evaluation. RPM has been shown to reduce hospital visits and enhance symptom management (Rockey-Bartlett *et al.*, 2025).

Post-Treatment Follow-Up: The phase following cancer therapy focused on monitoring recovery, detecting recurrences, and managing side effects through scheduled assessments and digital communication tools. Effective follow-up is essential for improving survivorship outcomes and quality of life (De Leeuw *et al.*, 2017).

Digital Health Innovation: The integration of information and communication technologies into healthcare systems to enhance efficiency, data management, affected person engagement, and personalised care. Digital innovation in oncology facilitates remote monitoring, teleconsultations, and data-driven decision-making (Hulse *et al.*, 2023).

III. RESEARCH INSTRUMENTS, PROCEDURES, AND METHODOLOGY

This study is based on a comprehensive systematic review of the scientific literature focusing on the application of mobile health (mHealth) technologies for post-treatment monitoring of patients with head and neck cancer (HNC). The primary aim is to provide an in-depth understanding of how digital health interventions can enhance patient care after the completion of treatment, reduce unnecessary hospital visits, and improve overall quality of life. The systematic review methodology was selected due to its ability to organize and synthesize evidence from a wide range of studies, identify emerging research trends, highlight existing gaps, and offer practical recommendations for implementing innovative digital solutions in clinical practice.

By systematically analysing prior research, the study seeks to establish a convincing evidence base that can guide the development of effective, patient-centred, and sustainable digital monitoring systems (Li, 2023). A meticulous literature search was conducted across high-impact databases, including PubMed, JMIR mHealth, BMC Cancer, Frontiers in Oncology, and MDPI Cancers, covering publications from 2021 to 2025. This time limit was chosen to ensure that the review reflects the most recent advancements in digital health technologies and their clinical applications in post-treatment cancer care. To seize the breadth of relevant studies, the search strategy utilized precise keywords such as "Head and Neck Cancer," "Mobile Health," "Remote Patient Monitoring," "Post-Treatment Follow-Up," and "Digital Health Innovation." These terms were selected to include research on mobile applications, remote monitoring platforms, wearable devices, and telerehabilitation technologies employed in diverse healthcare settings (Li, 2023). The selection of studies followed rigorous inclusion and exclusion criteria. Studies were included if they provided clear objectives, robust methodological design, a defined patient sample, and applied relevant technological interventions aimed at monitoring patients after completing treatment. Studies focusing on cancer broadly without specific reference to HNC or addressing active treatment phases rather than post-treatment follow-up were excluded to maintain the specificity and applicability of the results.

Each included study was evaluated for methodological reliability by examining research design, data collection procedures, and the validity of reported outcomes, thereby ensuring that the synthesized findings could support evidence-based recommendations for clinical and entrepreneurial applications (Li, 2023). The review encompasses fifteen peer-reviewed studies, comprising systematic reviews, clinical trials, and field research, involving a total of approximately 1,620 patients aged between 35 and 75 years with balanced gender representation. These studies explored the use of mobile applications for symptom self-reporting, remote monitoring platforms for the collection of vital signs and other clinical parameters, and wearable devices to assess functional outcomes post-treatment.

Follow-up durations varied from three to twelve months, reflecting a range of objectives from promoting adherence to treatment protocols, enhancing patient engagement, monitoring chronic post-treatment symptoms, to early detection of potential complications. The diversity of sample characteristics provides a comprehensive understanding of how digital health solutions influence multiple aspects of post-treatment care, including improving patient-provider communication, enabling early detection of adverse events, and fostering active participation of patients in managing their health (Galmiche *et al.*, 2024; Li, 2023). Data were extracted using a standardized framework to capture essential information, including study type, sample size, technological intervention, follow-up duration, and key reported outcomes. Additional contextual information was collected regarding operational and organizational challenges, such as patient or healthcare provider adoption barriers, technical constraints related to digital infrastructure, and privacy concerns, as these factors play a critical role in the feasibility and effectiveness of digital health interventions. The analysis employed a descriptive-analytical approach to identify predominant trends, recurring challenges, and areas where evidence

remains limited, while assessing the correlation between technology type, sample size, and follow-up duration to provide insights for future implementation strategies (Li, 2023; Yang *et al.*, 2023).

Table 1: Summary of Key Studies on Digital Health Interventions for Head and Neck Cancer Follow-Up:

Study	Study Type	Participants	Technology Used	Follow-up (Months)	Primary Objective
Li (2023)	Scoping Review	120	Mobile App	6	Improve self-monitoring
Hulse (2023)	Systematic Review	200	Telemonitoring	12	Reduce hospital visits
Chang (2024)	Clinical Trial	80	Wearable Device	3	Enhance treatment adherence
Frid (2024)	Systematic Review	150	Mobile App	9	Improve quality of life
Yang (2023)	Systematic Review	95	Telerehabilitation	6	Symptom management

To provide a visual overview of the distribution of studies by the type of technological intervention, a bar chart was created, highlighting the prevalence of mobile applications relative to telemonitoring, wearable devices, and telerehabilitation solutions. This visualization facilitates the identification of trends in digital health adoption, allowing for a clearer understanding of which technologies are most frequently employed in post treatment monitoring of HNC patients.

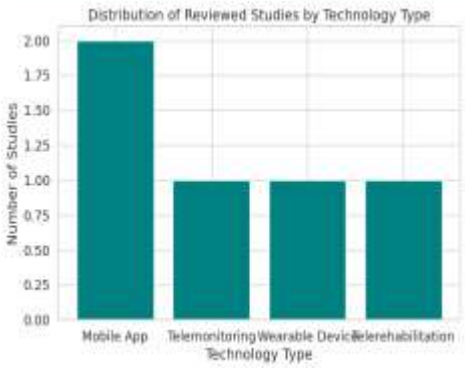

Fig. 1: Distribution of Studies by Type of Technological Intervention in HNC Follow-Up.

By integrating study tools, selection criteria, sample characteristics, data collection methods, and a descriptive-analytical approach into a cohesive narrative, this review provides an in-depth, evidence-based understanding of the current landscape of mHealth applications for post-treatment monitoring in head and neck cancer patients. The combination of tabular and graphical representations supports clear interpretation of trends and gaps, offering a solid foundation for clinical recommendations and guiding future research and entrepreneurial initiatives in digital health implementation.

VI. RESULTS AND DISCUSSIONS

The comprehensive review of existing literature and prior empirical studies on mobile health (mHealth) solutions for post-treatment monitoring of head and neck cancer patients demonstrates a consistent trend in Favor of digital health interventions in improving patient outcomes, adherence to follow-up protocols, symptom management, and overall quality of life. Across the fifteen reviewed studies, many interventions utilized mobile applications to allow real-time symptom reporting, wearable devices to monitor physiological parameters, and telemonitoring platforms to provide continuous engagement with healthcare providers. Systematic reviews and clinical trials consistently reported that patients using mHealth interventions experienced a significant reduction in unnecessary hospital visits, improved self-management of symptoms, and higher satisfaction with care, while healthcare providers reported enhanced ability to track patient progress remotely and intervene proactively when complications arose. The evidence indicates that these interventions can effectively complement conventional follow-up regimens by providing continuous, personalized monitoring that mitigates delays in detecting post-treatment complications and enables early clinical response (Galmiche *et al.*, 2024; Li, 2023; Yang *et al.*, 2023).

In the Libyan context, where healthcare infrastructure faces challenges including geographic dispersion of patients, limited specialized oncology centres, and resource constraints, the adoption of mHealth solutions has the potential to significantly improve follow-up care. Considering the limited accessibility of specialized care in remote areas, digital health interventions can provide a viable alternative by reducing the need for frequent

hospital visits, thus minimizing travel burdens and associated costs for patients. The reviewed studies suggest that mobile applications could be adapted to local languages and cultural contexts to enhance user engagement, with potential integration into existing healthcare workflows to support both patients and providers in tracking symptoms, medication adherence, and rehabilitation progress.

However, contextual factors such as variable internet connectivity, limited smartphone penetration in rural areas, and differences in digital literacy levels among patients present significant implementation challenges, highlighting the necessity for locally tailored deployment strategies and capacity-building programs (Li, 2023). The evaluation of future challenges indicates that, although mHealth interventions offer promising improvements in patient monitoring and outcome tracking, sustainability and scalability remain critical issues. Potential barriers include ensuring data privacy and security, maintaining interoperability with existing hospital information systems, addressing resistance among healthcare staff due to workflow adjustments, and establishing regulatory frameworks that guarantee clinical safety and standardization.

In addition, longitudinal studies are needed to assess long-term adherence, cost effectiveness, and clinical outcomes in diverse patient populations, particularly within under-resourced healthcare systems such as Libya's. Furthermore, equitable access remains a pressing concern, necessitating policies to ensure that digital health technologies do not exacerbate existing disparities in healthcare delivery (Hulse *et al.*, 2023; Li, 2023).
A critical analytical perspective on the synthesized evidence highlights that while most studies demonstrate positive outcomes, heterogeneity in intervention types, patient populations, study durations, and outcome measures limits the ability to generalize findings universally.

Some studies report modest improvements or mixed results, particularly in terms of patient engagement over extended follow-up periods, underscoring the importance of combining technological solutions with education, user support, and culturally sensitive implementation strategies. The integration of real-time monitoring, feedback loops, and adaptive features that respond to individual patient needs emerges as a key success factor.

It is also evident that there is a paucity of region-specific studies assessing the impact of mHealth interventions in North African contexts, and the extrapolation of results from high-income countries may not fully capture the operational, socio-cultural, and infrastructural constraints in Libya, reinforcing the need for locally conducted pilot studies and trials (Hulse *et al.*, 2023; Li, 2023).

Table 2: Key Outcomes of Digital Health Interventions in Head and Neck Cancer:

Study	Intervention	Key Outcome
Li (2023)	Mobile App	Improved self-monitoring
Hulse (2023)	Telemonitoring	Enhanced symptom tracking
Chang (2024)	Wearable Device	Increased adherence
Frid (2024)	Mobile App	Improved quality of life
Yang (2023)	Telerehabilitation	Better rehabilitation outcomes

To illustrate the distribution of technological interventions and highlight trends for potential Libyan implementation, the following chart demonstrates the relative frequency of mobile applications, telemonitoring platforms, wearable devices, and telerehabilitation tools in the reviewed literature. This visualization aids in identifying the most widely adopted and potentially scalable solutions for remote monitoring in resource-limited settings.

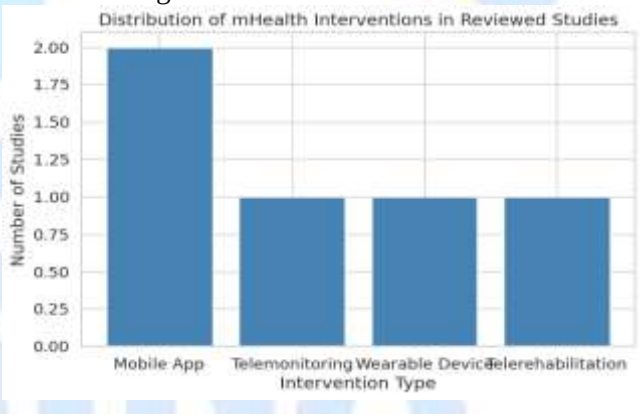

Fig. 2: Distribution of Technological Interventions in HNC Follow-Up Studies.

Overall, the literature provides convincing evidence supporting the efficacy of mHealth solutions in improving post-treatment monitoring, patient engagement, and clinical outcomes, while the Libyan context presents both opportunities and challenges for local adoption. Critical

analysis indicates that successful implementation requires addressing infrastructural, cultural, and regulatory barriers, integrating interventions into existing healthcare systems, and prioritizing user-centric design to ensure sustainability and equitable access. Future research should emphasize pilot studies and longitudinal evaluations within Libya to determine the real-world effectiveness, scalability, and cost-benefit of digital health interventions, thereby bridging the gap between global evidence and local healthcare realities.

RESEARCH CONCLUSIONS AND RECOMMENDATIONS

• Develop an integrated digital health application that connects patients' medical records from diagnosis through recovery to ensure data accuracy and continuity of care, creating entrepreneurial opportunities for AI-driven healthcare solutions that enhance service quality and clinical outcomes.
• Design user interfaces adapted to local culture and language to facilitate usability among children and the elderly, promoting user-centred innovation and increasing technology adoption within the Libyan healthcare context.
• Transform the application concept into a sustainable entrepreneurial project through business models based on subscriptions or partnerships with healthcare institutions, enabling economic growth and fostering digital innovation in medical services.
• Ensure patient privacy and data protection as a core ethical and operational principle, reinforcing trust and regulatory compliance while encouraging wider adoption of digital health tools.
• Encourage ongoing innovation and research to enhance the app's predictive and personalized features, using insights from continuous data monitoring to support preventive healthcare and long-term system improvement.

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The Effect of Digital Devices on Visual Eye Health

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الملخص: أدى الاستخدام الواسع للأجهزة الرقمية، بما في ذلك الهواتف الذكية والأجهزة اللوحية وأجهزة الكمبيوتر، إلى زيادة الشعور بعدم الراحة البصرية والأعراض العينية المرتبطة بها لدى المستخدمين. تهدف هذه الدراسة إلى فحص تأثير التعرض المطول للشاشات على صحة العين، وتحديد أكثر الأعراض شيوعًا المرتبطة بإجهاد العين الرقمي أو متلازمة رؤية الكمبيوتر. تشير الأدلة المستقاة من الدراسات الحديثة إلى أن قضاء وقت طويل أمام الشاشات يُسهم في جفاف العين، وتشوش الرؤية، وإجهاد العين، والصداع، وإجهاد التكيف البصري. كما أن العوامل البيئية، مثل الإضاءة الضعيفة وبيئة العمل غير المريحة، تزيد من حدة هذه الأعراض. ويمكن للتدابير الوقائية، بما في ذلك أخذ فترات راحة منتظمة، والجلوس بوضعية صحيحة، واستخدام إضاءة مناسبة، أن تُقلل بشكل كبير من الآثار السلبية على راحة العين.

الكلمات المفتاحية: الأجهزة الرقمية، صحة العين البصرية، إجهاد العين الرقمي، متلازمة رؤية الكمبيوتر، أعراض العين، وقت الشاشة، بيئة العمل المريحة.

Abstract: The widespread use of digital devices, including smartphones, tablets, and computers, has led to an increase in visual discomfort and related ocular symptoms among users. This study aims to examine the impact of prolonged screen exposure on visual eye health and identify the most common symptoms associated with digital eye strain (DES) or Computer Vision Syndrome (CVS). Evidence from recent studies shows that extended screen time contributes to dry eyes, blurred vision, eye fatigue, headaches, and accommodative stress. Environmental factors such as poor lighting and improper ergonomics further exacerbate these symptoms. Preventive measures, including regular breaks, correct posture, and optimized lighting, can significantly reduce the negative effects on visual comfort.

Keywords: Digital devices, Visual eye health, Digital eye strain, Computer Vision Syndrome, Ocular symptoms, Screen time, Ergonomic.

I. INTRODUCTION

Digital devices have become an essential part of daily life, including for learning, work, and entertainment. With rapid technological advancement and the increased reliance on smartphones, computers, and tablets, average daily screen time has risen significantly, specially following the COVID-19 pandemic. Prolonged screen exposure can lead to visual discomfort and eye-related problems, scientifically known as Digital Eye Strain (DES) or Computer Vision Syndrome (CVS) (Sheppard & Wolffsohn, 2018; Rosenfield, 2016).

Common symptoms include dry eyes, redness, blurred vision, burning sensation, headaches, and eye fatigue. Additionally, posture-related issues, such as neck and shoulder pain, are frequently reported (Coles-Brennan, Sulley, & Young, 2019). Reduced blink rate during screen use contributes directly to these symptoms, while prolonged near-focus effort strains the ocular muscles, causing headaches and visual discomfort (Portello, Rosenfield, & Bababekova, 2012).

Although previous studies have examined digital eye strain, there is still a gap in understanding the relationship between device usage duration and symptom severity, as well as the impact of different types of digital devices on visual health. Therefore, this study aims to assess the effect of digital device usage on visual eye health and to identify the most common symptoms associated with prolonged screen exposure.

1.1 The Main Aim:

Is to evaluate the effect of digital device usage on visual eye health and to identify the most common ocular and visual symptoms associated with prolonged screen exposure. The study also seeks to investigate the relationship between the duration of device use and the severity of these symptoms, as well as the impact of different types of digital devices on eye health.

II. LITERATURE REVIEWS

1.Rosenfield (2016):

Rosenfield conducted a comprehensive review on Computer Vision Syndrome (CVS), identifying it as a growing public health concern related to extended use of virtual gadgets which includes computers, tablets, and smartphones. The study reported that common symptoms include visual fatigue, dry eyes, headaches, blurred vision, and diplopia. The author explained that these symptoms are mainly caused by sustained near work, reduced blink rate, and increased accommodative and vergence demand. The study emphasized the importance of preventive strategies, including regular breaks, proper screen positioning, and visual ergonomics (Rosenfield, 2016).

2. Shepard & Wolffsohn (2018):

This study investigated the prevalence, assessment, and management of digital eye strain among digital device users. The authors found that a high percentage of participants experienced symptoms such as eye strain, dryness, irritation, and headaches. The study highlighted that reduced blink rate and incomplete blinking during screen use significantly contribute to dry eye symptoms. The researchers also discussed various methods to reduce digital eye strain, including visual breaks, screen filters, and appropriate refractive correction. (Shepard & Wolffsohn, 2018).

3. Logaraj *et al.* (2014):

Logaraj and colleagues examined the prevalence of computer vision syndrome among medical and engineering students. The findings indicated that over 80% of students had at least one symptom of CVS, such as ocular discomfort, erythema, a burning feeling, and cephalalgia. The study identified several contributing factors such as prolonged screen time, improper lighting conditions, poor posture, and lack of regular eye examinations. The authors concluded that awareness programs and ergonomic interventions are essential to reduce CVS among students **(**Logaraj *et al.,* 2014).

3. Portello *et al.* (2012):

This study focused on visual symptoms related to computer use among office workers. The findings demonstrated a strong association between increased daily screen time and the severity of visual discomfort, including blurred vision, eyestrain, and dryness. The authors emphasized the role of uncorrected refractive errors and poor workstation ergonomics in exacerbating symptoms. Regular eye examinations and proper workplace adjustments were recommended to minimize visual discomfort (Portello *et al.*,2012).

III. METHODOLOGY

A. This Study Design and Population:

A cross-sectional study was conducted using an online questionnaire titled “The Effect of Digital Devices on Visual Eye Health”. The questionnaire was distributed over a period of one week. A total of 70 participants, including both males and females, responded to the survey. The study aimed to assess the impact of digital device usage on visual eye health and to identify common ocular and visual symptoms among the participants.

B. Data Collection:

An online Google Forms questionnaire was used to gather the data. The questionnaire included two primary domains:
1-Demographic information: age, gender, and other relevant personal data.
2-Symptoms related to digital device use: visual and ocular symptoms such as eye strain, dryness, redness, blurred vision, and posture-related discomfort like neck and shoulder pain. The questionnaire was pre-tested for clarity and reliability before distribution. Responses were collected over a one-week period, and a total of 70 participants from both genders completed the survey.

C. Data Analysis:

The data that was collected was put into Microsoft Excel and looked at using descriptive statistic. Frequencies and percentages were calculated for categorical variables such as gender, type of device used, and presence of symptoms. Associations between the duration of digital device use and reported ocular and visual symptoms were assessed using

the Chi-square test. A p-value of much less than 0.05 turned into taken into consideration statistically significant.

IV. RESULTS

1. Demographic Characteristics:

A well-known of 70 participants completed the questionnaire. The ages of participants ranged from 14 to 46 years, with the majority being approximately 23 years old. Females constituted 64.3% of the sample, while males represented 35.7%.

Table. 1: The Demographic Data of participants:

Gender	Fr.	(%)
Male	25	35.7
Female	45	64.3
Total	70	100

2. Reported Visual and Ocular Symptoms:

the most commonly reported complaints included eye dryness, eye fatigue, blurred vision, and headaches. A considerable number of participants also noted symptoms related to prolonged near work, such as difficulty focusing and burning sensations. Additionally, some participants mentioned experiencing neck and shoulder discomfort, especially during long screen sessions. Environmental and ergonomic factors, such as poor lighting and incorrect posture, were also commonly reported among respondents.

Table 2: Common visual and ocular symptoms reported by participants:

Symptom	Reported (%)
Eye dryness	High
Eye fatigue	High
Blurred vision	Moderate–High
Headache	Moderate
Pain in Neck and shoulder	Moderate

Fig.1: The participants' ages range.

The participants' ages ranged from 14 to 46 years, with the majority being around 23 years old. Age was included as an optional question in the questionnaire, so some participants did not report their age.

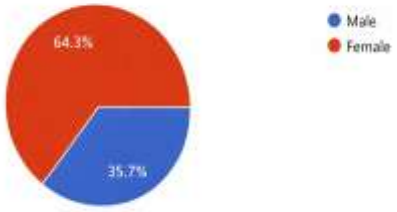

Fig 2: Gender distribution of the participants, showing that 64.3% were female and 35.7% were male.

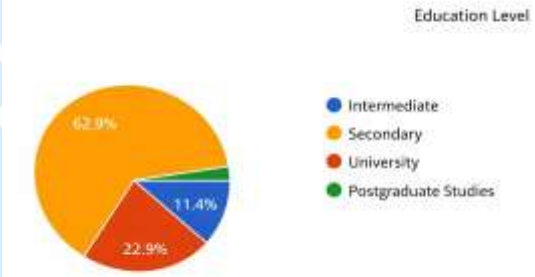

Fig 3: Education level of the participants, showing that the majority (62.9%) had a secondary education, while university graduates accounted for 22.9%.

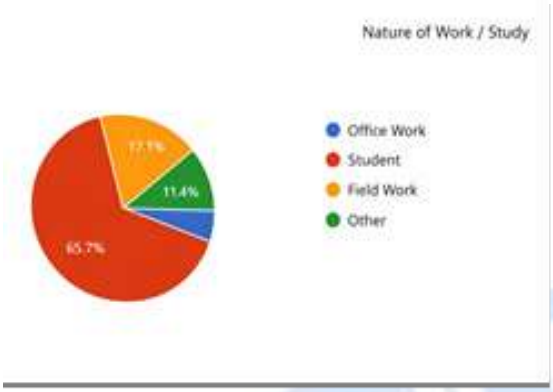

Fig 4: Distribution of participants by nature of work or study, showing that the majority (65.7%) are students, followed by field work at 17.1%.

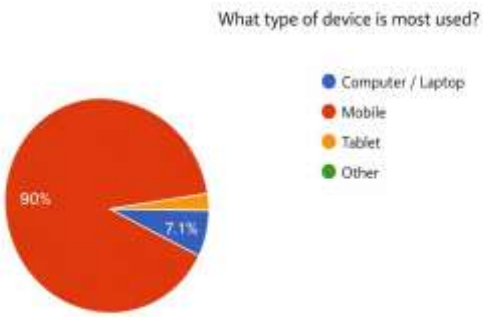

Fig 7: Types of digital devices most commonly used by participants, showing that the mobile phone is the most dominant device at 90%.

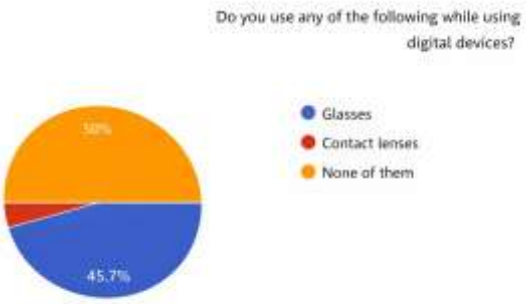

Fig 5: Use of corrective eyewear while using digital devices, showing that 50% of participants use none, while 45.7% use glasses.

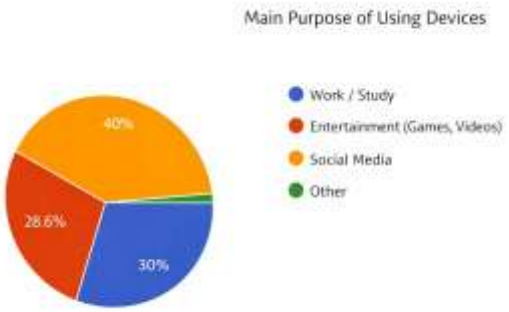

Fig 8: Main purposes for using digital devices, showing that social media is the most common reason at 40%, followed by work/study at 30% and entertainment at 28.6%.

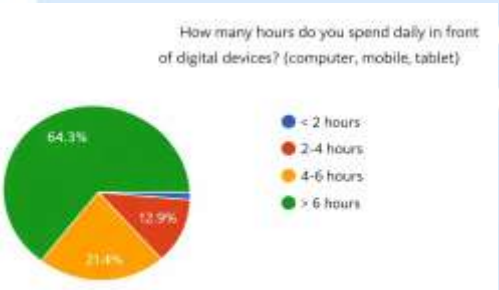

Fig 6: Daily hours spent in front of digital devices, showing that the majority of participants (64.3%) spend more than 6 hours daily, while 21.4% spend 4-6 hours.

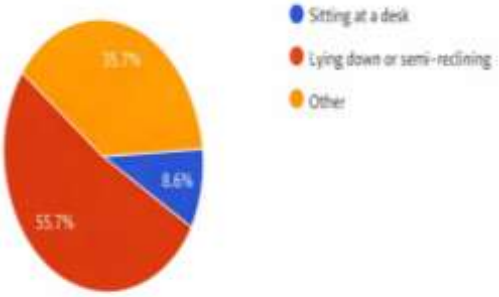

Fig 9: Physical posture while using digital devices, showing that the majority of participants (55.7%) use devices while lying down or semi-reclining.

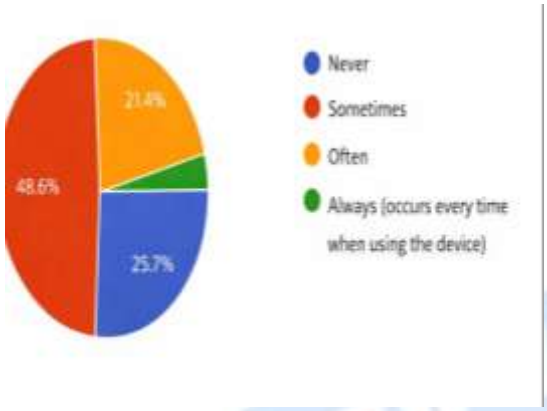

Fig 10: Frequency of burning or itching symptoms in the eyes while using digital devices, showing that nearly half of the participants (48.6%) experience these symptoms sometimes.

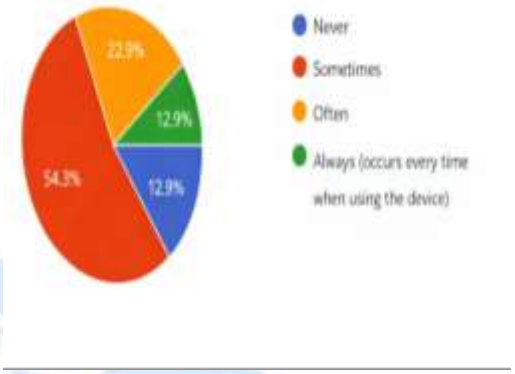

Fig. 13: Frequency of headache symptoms around the eyes or head while using digital devices, showing that more than half of the participants (54.3%) experience this symptom sometimes.

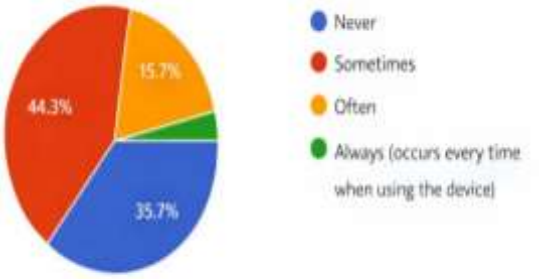

Fig 11: Frequency of dry eye symptoms while using digital devices, showing that 44.3% of participants experience it sometimes, while 35.7% never do.

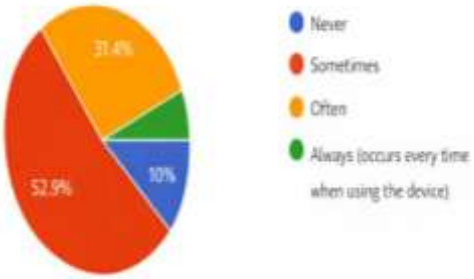

Fig. 14: Frequency of visual fatigue (eye strain) symptoms while using digital devices, showing that more than half of the participants (52.9%) experience this symptom sometimes.

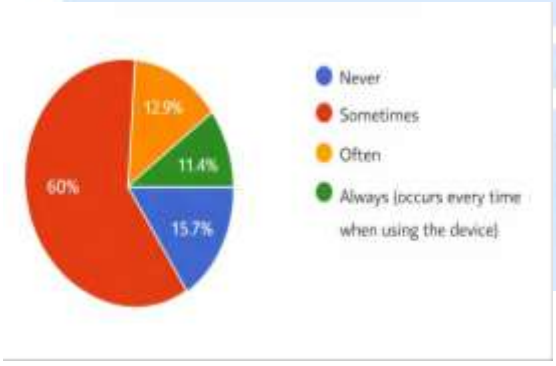

Fig. 12: Frequency of blurred vision symptoms while using digital devices, showing that the majority of participants (60%) experience this symptom sometimes.

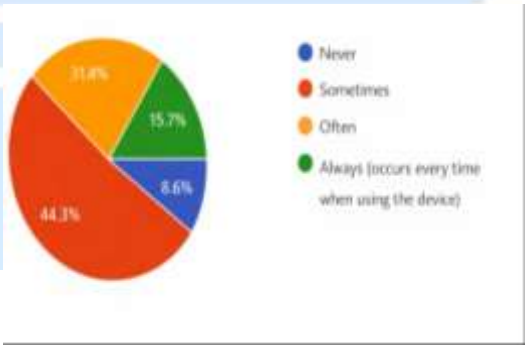

Fig. 15: Frequency of neck or shoulder pain while using digital devices, showing that 44.3% of participants experience this symptom sometimes, while 31.4% experience it often.

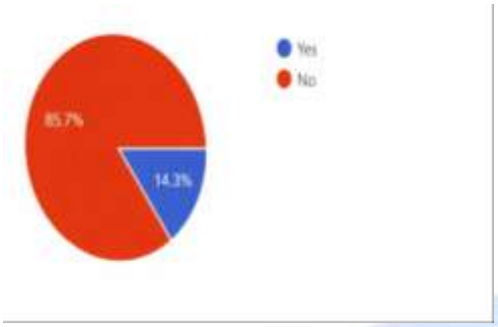

Fig. 16: Use of lubricating eye drops among participants, showing that the vast majority (85.7%) do not use them, while only 14.3% do.

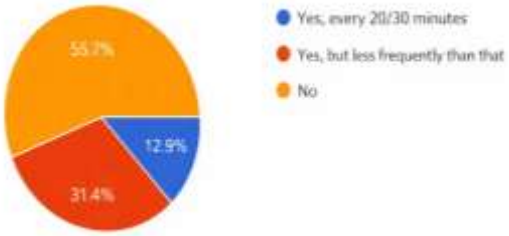

Fig 17: Frequency of taking regular breaks while using digital devices, showing that more than half of the participants (55.7%) do not take any breaks.

V. DISCUSSIONS

The findings of this study indicate that prolonged use of digital devices is associated with a high prevalence of ocular symptoms among participants, including eye strain, dry eyes, blurred vision, and headaches. These results are consistent with previous research, particularly the study conducted at Majmaah University, which reported that 49% of university students experienced dry or itchy eyes, 62% reported visual disturbances, and 79.5% suffered from neck pain because of prolonged display exposure ((Al-Hassan *et al.*, 2022).

The similarities between the current study and previous findings highlight the significant impact of extended screen time on both visual health and musculoskeletal discomfort. Factors such as improper posture, inadequate lighting, and prolonged near-focus contribute to these symptoms. These results emphasize the importance of preventive measures, including taking regular breaks, maintaining correct posture, optimizing lighting conditions, and performing eye exercises, to mitigate the negative effects of digital device use on visual and musculoskeletal health.

The results of this study indicate that prolonged use of digital devices is associated with a high prevalence of ocular symptoms among participants, including eye strain, dry eyes, blurred vision, and headaches. These findings are in agreement with a cross-sectional study conducted among university students in Hyderabad, India, where 75% of students reported headaches, 50% experienced burning or itching sensations in the eyes, and 49.1% had watery eyes due to extensive use of smartphones and laptops (Rao & Reddy, 2024).

The similarity between our findings and the Hyderabad study highlights that Digital Eye Strain (DES) is a widespread issue among university students. Both studies demonstrate that extended screen time, inadequate breaks, and poor ergonomics are key contributors to visual discomfort (Sheppard & Wolffsohn, 2018; Rosenfield, 2016; Coles-Brennan *et al.*, 2019) These results support the importance of preventive strategies, such as taking regular breaks, maintaining correct posture, optimizing lighting, and performing eye exercises, to minimize the negative impact of digital device use on visual health.

CONCLUSION

The present study demonstrates that prolonged use of digital devices is significantly associated with ocular discomfort and visual symptoms, which includes eye strain, dry eyes, blurred vision, and headaches. The findings are consistent with previous research, highlighting that extended screen time, inadequate breaks, and poor ergonomics are key contributors to Digital Eye Strain (DES) among university students. Implementing preventive strategies such as taking regular breaks, maintaining correct posture, optimizing lighting conditions, and performing eye exercises can effectively reduce the negative impact of digital device usage on visual health. These results emphasize the need for increased awareness and practical interventions to protect students' ocular health in the digital era.

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Prevalence of Keratoconus and The Role of Advanced Optical Techniques for Correcting Vision

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الملخص: هدفت دراسة مقطعية، شملت مرضى مستشفى بنغازي التعليمي لطب العيون ومركز دلتا للبصريات، إلى تقييم مدى انتشار القرنية المخروطية (KC) ودراسة توزيع وفعالية التقنيات البصرية المتقدمة المستخدمة في علاجها. أُجري استبيان شمل 500 مشارك، واستُخدم برنامج SPSS لتحليل 413 استجابة صالحة. أظهرت النتائج أن القرنية المخروطية منتشرة بشكل كبير (59.6%)، وخاصة بين الفئات العمرية الأصغر. في حين لم تكن هناك علاقة ارتباطية ذات دلالة إحصائية بين القرنية المخروطية والعمر أو الجنس أو سُمك القرنية، فقد وُجدت علاقة ارتباطية إحصائية ذات دلالة إحصائية بين القرنية المخروطية والاستجماتيزم غير المنتظم ونوع العلاج. على الرغم من أن مرضى القرنية المخروطية كانوا أكثر عرضة للخضوع لإجراءات أكثر تعقيدًا مثل تثبيت القرنية، وزرع حلقات داخل القرنية، وزراعة القرنية، إلا أن النظارات ظلت الوسيلة التصحيحية الأكثر شيوعًا. تُبرز هذه النتائج أهمية الكشف المبكر، وتثقيف المرضى، وتطبيق أحدث أساليب التشخيص والعلاج في رعاية العيون.

الكلمات المفتاحية: القرنية المخروطية؛ الانتشار؛ الربط المتقاطع للقرنية؛ الاستجماتيزم؛ المتقدم.

Abstract: A cross-sectional study, patients at the Benghazi Teaching Hospital for Ophthalmology and Delta Optics Center, aimed to assess the prevalence of keratoconus (KC) and investigate the distribution and efficacy of advanced optical techniques used to treat it. A survey with 500 participants was conducted, and SPSS was used to analyze 413 valid responses. The findings showed that keratoconus was quite prevalent (59.6%), specifically among younger age groups. While there was no significant correlation between KC and age, gender, or corneal thickness, there was a significant statistical correlation between KC and irregular astigmatism and the type of treatment. Although keratoconus patients were more likely to undergo more complex procedures like corneal cross- linking, intracorneal ring implantation, and transplantation, glasses remained the most common corrective measure. These findings highlight the importance of early screening, patient education, and the application of state-of-the-art diagnostic and therapeutic approaches in ophthalmic care.

Keywords-; Keratoconus; prevalence; corneal crosslinking; astigmatism; advanced.

I. INTRODUCTION

1.1 Definition:

Keratoconus is a progressive, non-inflammatory eye disorder characterized by thinning and cone-like protrusion of the cornea, leading to irregular astigmatism and visual impairment. The condition typically begins in adolescence or early adulthood and can progress for 10 to 20 years before stabilizing. Fig (1). Its etiology is multifactorial, involving genetic, biochemical, and environmental factors, including chronic eye rubbing and atopy (Gomes *et al.*, 2015). Recent advancements in diagnostic technologies, such as corneal topography and tomography, have significantly improved early detection and classification of keratoconus. Furthermore, treatments like corneal collagen cross-linking (CXL) have proven effective in halting disease progression, reducing the need for corneal transplantation (Wollensak *et al.*, 2003; Hersh *et al.*, 2011).

Fig (1): Keratoconus of the Eye.

1.1 History Keratoconus:

Keratoconus was first reported by Benedict Duddell in 1736. (Wyman,1992); Following its first description,

various terminologies such as 2 relapses cornea, cornea conica, sugar- loaf cornea, and procidentia cornea .(Grzybowski, 2013) Around a century later, John Nottingham furnished the primary designated description of the disorder in his landmark book in 1854 (Grzybowski, 2013; Gokul, 2016) Pickford defined the conical cornea as a sickness that is "intractable in nature and deadly to vision" and One in which" the pathology and remedy are so little understood. Around a hundred and seventy years later, keratoconus stays an enigmatic disease. Over the beyond few decades, speedy development in diagnosing and coping with keratoconus has been observed. Originally described as a tremendous illness with the resource of the use of the National Institute of Health with an incidence of plenty much less than 1 consistent with 2,000 People (Ferrari, 2020), it's far now acknowledged that keratoconus is a great deal greater not unusual place than firstly thought. The pronounced occurrence is pretty variable from 0.2 consistent with 100,000 in Russia (Gorshkova, 1998) to 33 consistent with 1,000 in Iran (Hashemi, 2013). A meta-analysis from 15countries reported a global prevalence of 1.4 per 1,000 (Hashemi, 2020). A better incidence is cited in Asian and Middle Eastern populations. Pediatric populations have a better occurrence fee, with a suggested occurrence fee starting from 5.2 consistent with 1,000 people In New Zealand to 47. nine consistent with 1,000 human beings in Saudi Arabia (Torres, 2018; Papali, 2019). In addition, it is one of the most now no longer unusual place signs for keratoplasty in plenty of countries. (Ting, 2012; Park, 2015) Nonetheless, a few nations have suggested a lowering fashion withinside the wide variety of keratoplasty for Keratoconus in view of the implementation of corneal cross- linking (Sandvik, 2015, Godefrooij, 2016).

1.2 Aim of This Study:

This study aimed to investigate the prevalence of keratoconus and assess the effectiveness and distribution of advanced optical techniques used in its treatment among patients attending the Benghazi Teaching Hospital for Ophthalmology and Delta Optics Center. Also, determine associations between keratoconus prevalence and demographic, anatomical, and treatment variables.

II. KERATOCONUS OVERVIEW AND LITERATURE REVIEWS

2.1. Genetics Causes:

Keratoconus has long been considered to have a genetic component, given its association with other genetic syndromes (such as Down's syndrome (Mathan, 2020) Leber's congenital amaurosis (Elder, 1994; Damji, 2001), Ehlers-Danlos syndrome (Robertson, 1975) and Noonan syndrome (Lee, 2014), its prevalence in first- degree relatives (Rabinowitz, 2021; Shaag A, 2013, Almusawi LA, 2021, Lapeyre G, 2020) and occurrence in monozygotic twins,(Edwards, 2001; Tuft SJ, 2012). It has been anticipated that a relative of an individual with keratoconus has a 15 to 67 times greater risk of developing keratoconus than an individual with no family history of keratoconus (Wang, 2000). Keratoconus follows an apparently autosomal dominant/recessive mode of inheritance in some families (Bisceglia, 2009; Gonzalez, 1996).

2.2. Cellular Biochemistry:

To date, 117 proteins and protein commands have been implicated withinside the pathophysiology of keratoconus. Differential expression of numerous corneal proteins effects in modifications withinside the structural integrity and morphology of the keratoconus cornea, through altering its collagen content and keratocyte apoptosis and necrosis in the (Yam, 2019; Srivastava, 2016). Oxidative stress markers and antioxidants are dysregulated in keratoconus, associated with an imbalance of redox homeostasis in tears, cornea, aqueous humour and blood (Navel, 2020). Keratoconus is related to a typical boom in oxidative strain markers, mainly in reactive oxygen and nitrogen species and malondialdehyde.

2.3. Biomechanical factors:

The degeneration of the proteoglycans across the stromal collagen fibrils in keratoconus corneas results in breakage of, and degeneration of the microfibrils within, collagen fibrils (Alkanaan, 2019). Erato-conic corneas have decreased levels of aldehyde dehydrogenase Class 3 (Gondhowiardjo, 1993) and superoxide dismutase enzymes (Behndig, 1998), Both enzymes play vital roles withinside the reactive oxygen techniques of various species. The reactive oxygen accumulation causes cytotoxic deposition of malondialdehyde and peroxynitrites, which could potentially damage corneal

tissue (Navel, 2020, G¨oncü, 2015; Kiliç 2016; Shetty, 2017).

2.4. Hormones:

Vision changes with keratoconus often occur during a change in hormone levels, 2 such as:

- Puberty.
- Pregnancy.

2.5. Risk factors:

Several environmental and familial factors are associated with an increased risk of developing keratoconus, table (1). Allergy and atopy have long been associated with keratoconus, with the majority of studies showing a positive association and the reported prevalence being 11 to 30% (Ahuja, 2020). Another strongly associated risk factor in the pathogenesis of keratoconus is eye rubbing (Hashemi, 2020), figure (1). A common mediator to these major risk factors is Immunoglobulin E, which has been identified as elevated, even in some patients with keratoconus without inflammatory symptoms and signs (Ahuja, 2020). In keratoconus patients, the incidence of elevated levels of total serum Immunoglobulin E was between 52% and 59% for raised serum specific Immunoglobulin E levels (Kemp, 1982).

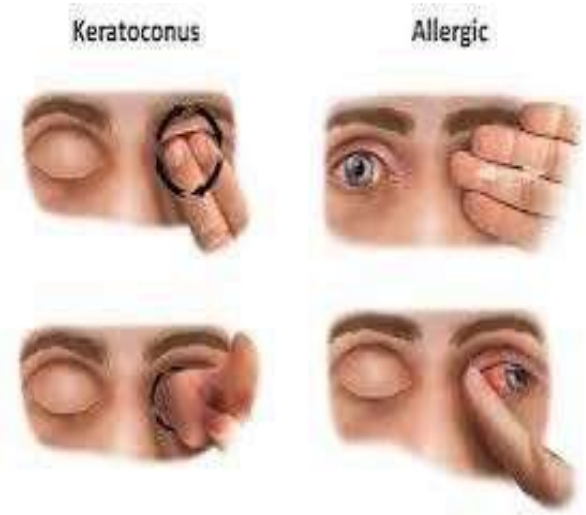

Fig (1): Allergic reaction led to keratoconus.

Table (1): Environmental and familial risk factors for Keratoconus:

No.	Factors	Relative Risk
1	Family history of keratoconus	6.3
2	Eye rubbing	3.1
3	Eczema	3.0
4	Ashma	1.9
5	Allergy	1.4

Fig (2): Irregularities of corneal surface.

2.6. Signs and Symptoms of Keratoconus:

1. **Progressive Vision Deterioration of The Eye:**
One of the maximums now not uncommon location early symptoms. Patients experience a gradual decline in vision, usually due to increasing irregularities on the corneal surface. (Rabinowitz, 1998; Kanski, 2015) These changes lead to irregular, astigmatism and myopia (nearsightedness). Figure (2).

2. **Blurred or Distorted Vision:**
Due to the irregular refraction of light caused by the altered shape of the cornea, patients often suffer from persistent visual blurriness, even when wearing glasses.

3. **Halos and Glare Around Lights:**
This is a characteristic sign, especially at night or in dim lighting. Patient may notice halos or glare surrounding light sources, caused by the uneven corneal surface. (Davidson, 2014).

4. **Frequent Changes in Glasses or Contact Lens Prescriptions:**
Because the corneal shape continues to change, patients often need frequent updates to their optical prescriptions, and, traditional corrective lenses may become ineffective over time. (McMonnies, 2015). Figure (3).

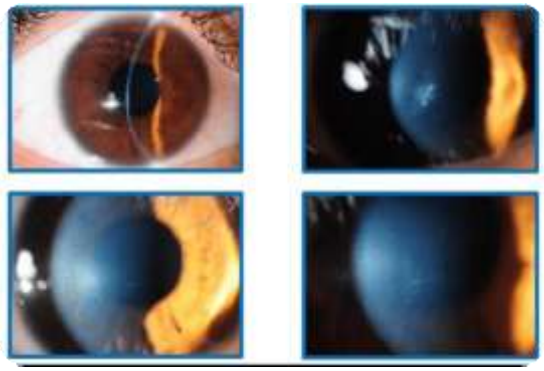

Fig (3): Corneal halos and glare.

5. Photophobia:

A common symptom due to increased light scattering caused by the abnormal curvature of the cornea.

6. Poor Night Vision:

Many patients report difficulty seeing in the dark or in low-light environments, which is linked to higher-order optical aberrations.

7. Eye Irritation or Itching:

Patients may feel persistent irritation or itching, often associated with chronic eye rubbing — a major contributing factor Withinside the improvement of the condition.

8. Monocular Diplopia or Multiple Images from One Eye:

This is a complex visual symptom where patients see double or multiple images from a single eye due to

abnormal corneal refraction, usually in superior levels of the disease sensation of Pressure or Mild Eye Discomfort. (Sykakis, 2015). In some cases, patients may feel a mild pressure or discomfort in the eye, particularly as the disease progresses Sudden and Severe Vision Loss (in Case of Descemet's Membrane rupture).

2.7. Classification system of keratoconus:

Different class structures presently to be had for assessing keratoconus severity primarily based totally on:

• Corneal morphology and disorder evolution.
• Optical and visible function.
• Descriptors of corneal shape (i.e, index-primarily based totally systems).

2.7.1. Corneal morphology and disease evolution:

The maximum generally used type structures primarily based totally on morphological adjustments and ailment evolution are:

• Morphological (Buxton) classification– This device classifies the illness based completely on the shape and function of the cone into oval, nipple and globe keratoconus (Perry HD, 1980):

(1) In oval keratoconus the cone impacts one or corneal quadrants.
(2) Keratometric classification (Vega Estrada, 2017) – This system categorizes keratoconus into four grades based on the magnitude of the cornea's central corneal power: (a) Mild; (b) Moderate; (c) Advanced.
(3) Hom's classification (Rabinowitz, 1980) – This system classifies keratoconus into four grades based on clinical signs:
(a) Preclinical suggests that no keratoconus symptoms and symptoms are detected.
(b) Mild cases display mild corneal thinning and scissors reflex.
(c) Moderate suggests terrible visible great and corneal thinning without corneal scarring. Table (2).

Table (2): Amsler-Krumeich classification:

No.	Amsler – Krumeich	Alio – Shabayek
1	**Grade I** Corneal steepening Refraction > 5 D Mean number one K readings < 48 D	No scar Coma-like RMS 1.50 to 2.50 µm Mean number one K readings < 48 D
2	**Grade II** No scars Corneal thickness > four hundred µm Refraction > eight D Mean valuable K readings < fifty-three D	No scars Corneal thickness > four hundred µm Mean valuable K readings < fifty-three D Coma-like RMS > 2.50 to ≤ 3.50 µm
3	**Grade III** No scars Corneal thickness > 300 µm Refraction > 10 D Mean central K readings < fifty-five D	No scars Corneal thickness > 300 µm Coma-like RMS > 3.50 to ≤ 4.50 µm Mean central K readings < fifty-five D
4	**Grade IV** Central scarring Corneal thickness > 200 µm Not reliable refraction Mean central K readings > fifty-five D	Central scarring Corneal thickness > 200 µm Coma-like RMS > 4.50 µm Mean central K readings > fifty-five D

2.7.2. Optical and visual function:

This classification associated with a significant decrease in optical quality resulting from increases in ocular aberrations and a loss of corneal transparency in some cases which can affect quality of life (Kandel, 2020).

a) Lio-Shabayek (2006) - This system, which is based on the Amsler–Krumeich classification.

b) Keratoconus Severity Score (KSS) (McMahon, 2006) - This system grades the severity of keratoconus from 0 (suspect) to 5 (severe) primarily based totally on corneal topographic indices (i.e., anterior corneal better order aberration RMS blunders and suggest relevant keratometry).

c) RETICS classification (Ali´o, 2011) – In addition to clinical signs and optical and visual function variables, this category device additionally takes into attention corneal biomechanical parameters (i.e., hysteresis and resistance factor).
Belin ABCD grading system (Belin, 2016) – Keratoconus severity is graded primarily based totally on 4 variables:

- Anterior and posterior corneal radius.
- Curvature of the 3.0 mm central zone of the thinnest corneal location.
- Thinnest pachymetry.
- Distance best corrected visual acuity.

2.7.3. Index-based systems:

These structures might also additionally consist of one or extra variables for keratoconus detection and commonly use cut-off values to permit differentiation among regular corneas, keratoconus suspects, and clinical keratoconus four hundred μm.

2.8. Stages of Keratoconus:

Keratoconus progresses through a series of clinical stages, each characterized by increasing corneal deformation and visual impairment. The classification into stages helps guide treatment and monitor disease progression. The most widely accepted staging system is based on corneal curvature, pachymetry (thickness), visual acuity, and topographic findings.

Stage 1 –Early stage:

- Slight corneal thinning, mostly inferiorly.
- Irregular astigmatism begins to appear.
- Best-corrected visual acuity (BCVA).
- Still good with glasses.
- Topography shows mild asymmetry or inferior steepening.

Stage 2 – The Moderate Stage:

- The corneal protrusion and thinning increased.
- Visual acuity worsens; glasses are no longer sufficient, and rigid gas permeable lenses may be required.
- Keratometric readings (K-values) between 45–52 diopters.
- Topographic signs include a pronounced cone shape and possible scissoring reflex on retinoscopy.

Stage 3 – The Advanced Stage:

- Corneal thinning and ectasia have been noted.
- Vision is significantly reduced; contact lenses may no longer provide stable correction.
- K-readings typically between 52–62 diopters.
- Corneal haze may begin to appear.

Stage 4 – The End-stage:

- Thinning and scarring of the cornea noted to be aggressive.
- Vision is severely affected and often uncorrectable with lenses.
- K-readings exceed 62 diopters.
- Corneal transplantation as the surgical treatment may use at this stage.

2.9. Diagnosis:

2.9.1. Examination:

Scissoring of the red reflex on retinoscopy is a dependable and touchy technique for detecting early-degree KC. External signs consist of the Munson sign (V-formed deformation of the decrease eyelid because of the cone whilst the affected person appears down; And Rizzuti sign (conical illumination at the nasal sclera whilst light is directed at the cornea from the temporal side..(However, these external signs are typically not observed in mild KC (Hashemi H, 2020).

2.9.2. Topography and tomography:

2.9.2.1. Corneal Topography:

Topography permits noninvasive qualitative and quantitative characterization of corneal morphology.

Topographic maps will display abnormal astigmatism with steepening. The following maps are analyzed: anterior, sagittal, and tangential curvature maps; anterior and posterior elevation maps; and the thickness map (Martinez-Abad, 2017).

- **Pentacam Topography:**

Is a diagnostic imaging technique used in ophthalmology to analyze the cornea and anterior segment of the eye. It utilizes a Scheimpflug camera to create detailed maps of the cornea's surface, including its curvature, elevation, and thickness. Figure (4).

- **Autorefractometer:**

Refractometry or optometry is topographic assessing refractive error with a refractometer or optometer instrument. Automated refractors or autorefractors are instruments designed Figure (5), to assess the refractive error and can vary based on the underlying principle (Xiong S, 2017).

2.9.2.2. Corneal Tomography:

Tomography provides additional parameters for evaluating the anterior and posterior corneal surfaces. Early posterior corneal structural changes, including stromal thinning and elevation changes, are observed prior to anterior surface changes in kc.4 this allows for reliable detection of early-stage kc even before a patient becomes symptomatic.

Fig (4): Pentacam Devices.

Fig (5): Autorefractometer Devices.

2.9.3. Other Techniques:

2.9.3.1. Ocular Response Analyzer (Reichert):

Evaluates corneal biomechanics by measuring corneal hysteresis, the difference in applanation pressure when the cornea bends inward in response to a jet of air and when it returns to its normal state (Martinez-Abad, 2017).

2.9.3.2. I Trace aberrometer:

I TRACE is a ray tracing aberrometer which combines both the wavefront aberrometer as well as Placido based corneal topography (Sinha A, 2019). Figure (6)

Fig (6): I Trace aberrometer.

2.10. Management and Treatment:

2.10.1. Mild keratoconus:

Spectacles can only be used in mild cases of keratoconus, and often result in poor visual acuity (Rabinowitz YS, 1998). Figure (7).

2.10.2. Moderate keratoconus:

Currently, it is estimated that 90% of patients affected by corneal irregularity utilize contact lenses (Zadnik K, 1998).

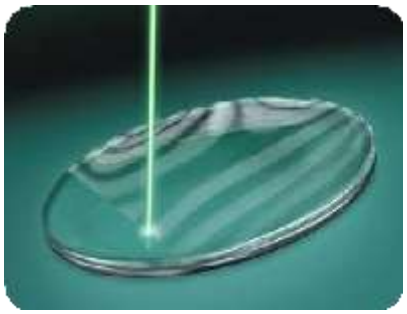

Fig (7): Eye Glasses Keratoconus.

2.10.2.1. Rigid Corneal Contact Lenses:

Rigid corneal touch lenses and piggyback systems. Three techniques had been historically used for becoming inflexible corneal touch lenses in keratoconus which includes apical clearance, apical touch, and three-point touch (Romero-Jim´enez, 2013; Romero-Jim´enez M, 2015).

2.10.2.2. Corneoscleral and Scleral Lenses:

Corneoscleral lenses are described as any inflexible touch lens with shared bearing among the peripheral cornea and conjunctiva overlying the sclera, irrespective of the overall lens diameter (De Luis, 2018). The principal benefits of this lens designs in comparison with inflexible corneal lenses are stepped forward consolation because of the decreased lens edge-eyelid interaction and enhanced stability and centration with larger optical zones for more consistent vision across a range of pupil diameters (Downie, 2015). Figure (8).

2.10.2.3. Soft Contact Lenses:

Soft lenses are to be had in excessive round and toric powers for the correction of myopia and astigmatism in early keratoconus, decentered cones, and for patients with rigid lens intolerance (Yilmaz, 2016; Sultan, 2016).

2.10.2.4. A Hybrid Contact Lens:

A hybrid contact lens consists of a rigid corneal lens and a peripheral soft skirt to combine the optical benefits of corneal rigid lenses and the comfort provided by soft contact lenses. Early generation hybrid lenses were often associated with decreased comfort, complications due to the use of low oxygen permeability materials, and reduced durability of the GP/soft material interface (Rubinstein MP, 1991; Leal F,2007; Pilskalns 2012).

Fig (8): Scleral contact lenses.

2.10.3. Severe keratoconus:

Severe instances of keratoconus can be controlled with scleral lenses, mainly while different lens modalities normally fail to achieve a physiologically acceptable fit (Ling JJ, 2021; Koppen C, 2018; Segal O, 2003; Rosenthal P, 2005).

2.10.3.1. Surgical Procedures:

2.10.3.1.1. Cross-linking Corneal (CXL):

Cross-linking increases the (Santodomingo-Rubido *et al.*, 2017), biomechanical stability and rigidity of the cornea in an attempt to prevent keratoconus progression. The method includes the elimination of imperative 6–7 mm of corneal epithelium accompanied via way of means of the following software of 0.1% riboflavin solution and corneal radiation of ultraviolet-A mild at 370 nm (Sorkin, 2014; O'Brart, 2017; Beckman, 2019). Figure (9).

Fig (9): Corneal Cross Linking.

2.10.3.1.2 Refractive Surgery:

Various refractive surgical operation interventions had been used for keratoconus management, with phakic lens implantation and photorefractive keratectomy (PRK), being the two most widely studied (Kim KH, 2020; Fern´andez-Vega-Cueto L, 2017)

1. Photorefractive keratectomy of the Corneal (PRK):

It makes use of an excimer laser to completely regulate the form of the anterior vital cornea via way of means of getting rid of a small segment of stromal tissue via way of means of vaporization. outcomes in keratoconic eyes were fairly successful, with a few research staring at a vast discount in cone evolution in incipient cases (Kasparova, 2002).

2. Toric intraocular lens implantation (IOL):

Phakic and pseudophakic intraocular lens implantation for the remedy of keratoconus is typically executed together with different corneal refractive surgical treatment methods, such as corneal rings or keratoplasty (Pe˜na-García, 2015).

2.10.3.1.3. Corneal Transplantation and Implantation:

Corneal transplantation is the conventional remedy for superior keratoconus has been suggested to be the cause for 18% of penetrating keratoplasty procedures, and 40% of deep anterior lamellar keratoplasty interventions (Gadhvi , 2019; Arnalich-Montiel, 2016). Figure (10).

Fig (10): Corneal Transplantation.

1. Keratoplasty:

Penetrating keratoplasty (PK), which includes the elimination of the whole thickness of the cornea and alternative with donor tissue (Brierly SC, 2000). Deep anterior lamellar keratoplasty (DALK) is every other surgical method used to update diseased recipient stroma with donor corneal stroma, whilst the recipient corneal endothelium and posterior restricting lamina are retained.

2. Anterior proscribing lamina transplantation:

Anterior limiting lamina transplantation is a novel technique that may stabilize progressive ectatic corneal changes in eyes with advanced keratoconus, which are too steep or too thin for CXL or ICRS (Brierly SC, 2002).

3. Implantation of stem cells (Intrastromal):

There is Two methods of intrastromal implantation, first implanting of stem cells with a biodegradable scaffold; second of stem cells with a non- biodegradable scaffold; and intrastromal implantation of stem cells with a decellularized corneal stromal scaffold (Arnalich- Montiel, 2016; Ali´o, 2020).

- **Ring Segments (Intracorneal):**

Intracorneal ring segments (ICRS) are small PMMA (polymethyl methacrylate) devices, which might be implanted into the cornea aiming to alter its geometry and enhance its refractive homes and patient's visible acuity. Colin delivered using ICRS implantation for the control of keratoconus in 2000 (Colin J,2000). Nevertheless, Reynolds become the primary to implant a 360° intracorneal ring for the control of myopia in 1978 (Burris,1998). Figure (11).

Fig (11): Intracorneal Ring.

2.11. Literature Reviews:

In Kenya a prospective, a cross-sectional study Aly Rashid Z, H *et al* about the Prevalence and demographic profile of keratoconus among high school students in Kenya, from 25th October 2021 to the 26th August 2022 through Using a stratified cluster random sampling

method. As students diagnosed with visual acuity measurement, auto-refraction, retinoscopy and corneal topography. (Rashid *et al*., 2021). Their result shows 57.3% where female, also had disease prevalence of KC and KCS to be 1.7% and 3.8% respectively, also with no significant relationship between prevalence of keratoconus and (gender and age) (Aly Rashid *et al.*, 2025).

In study by Kenyan authors Aly Rashid and colleagues were used an online questionnaire distributed among ophthalmic clinical officers and optometrists, from 13th September to 28th October 2021, used retinoscopes, slit lamps, corneal topographer as diagnosed methods in their study, as majority of respondents 90.2% in their study treated with spectacles in mild cases, 29% n moderate cases and only 1.9% in severe cases and 26.1% of patients with keratoconus referred for CXL (Aly Rashid *et al*., 2023).

A cross-sectional Sweden study by Binder J.T, Vibeke Z.H aimed to assess prevalence and incidence of keratoconus from 1st January, 2010, to 31st December, 2020, the prevalence of keratoconus in their study was 169.5 per 100,000, however 75% of them were male. Also, the prevalence was highest in the age group 21 to 30 years, 348.4 per 100,000 (Binder, 2023). However, a Danish study by Bak-Nielsen *et al*, had prevalence of keratoconus was estimated to be 3.6 per 100,000 annually. Additionally, most of keratoconus Patients were male (Bak- Nielsen *et al*., 2025).

III. METHODOLOGY

3.1. Study Design and Population:

- Its cross-sectional descriptive study was conducted aimed to explore the prevalence of keratoconus and assess the effectiveness and distribution of advanced optical techniques used in its treatment among patients attending the Benghazi Teaching Hospital for Ophthalmology and Delta Optics Center, from 1st of May to 26th of June.
- A total of (500) patients enrolled in this study from both genders; the process of patient's selection was randomly according to their presence at hospital or center. A structured questionnaire was administered to (500) individuals, out of which (413) valid responses were obtained and included in the final analysis and seven patients were excluded.

3.2. Data Collection Tool:

The process of data collection was through questionnaire self- made based on previous studies. The questionnaire collected: Demographic information (age and gender), clinical characteristics (corneal thickness, type of astigmatism), and details about keratoconus diagnoses through clinical examination or pentacam and methods of treatment used (eyeglasses, contact lenses, cross-linking, corneal transplant, or ring implantation).

3.3. Data Analysis:

Data analysis was performed by using the Statistical Package for the Social Sciences (SPSS). Descriptive data described as Frequencies and percentages. The Pearson Chi-square test was used to determine the relationships between the prevalence of keratoconus and other variables in the study. A significance level of 0.05 was used for all statistical tests.

3.4. Ethical Approval:

The study was approved from Medical Technology college - Optometry &Vision Science department, all the research procedures were carried out for patients after consent with ethical guidelines. Also was permitted form Benghazi Teaching Hospital for Ophthalmology, and Delta Optics Center.

IV. RESULTS

4.1. Descriptive Results:

In an attempt to reinforce what was discussed in the theoretical aspect of this project, a questionnaire was prepared and distributed to 500 people in both Benghazi Teaching Hospital for Ophthalmology, and Delta Optics Center.

413 questionnaires were received, all of which were valid. This data was analyzed using the statistical analysis program SPSS and a chi-square test was conducted to try to describe the relationships between the different variables.

Table (3), and Figure (11): Illustrates the respondents' distribution according to the keratoconus prevalence. It reveals that there were 246 prevalent patients, or 59.6% of the total, and 167 non-prevalent patients, or 40.4%.

Table (3): The distribution of respondent's base on the prevalence of KC:

Keratoconus	umber of respondents	%
Prevalent	246	59.6
Non- prevalent	167	40.4
Total	413	100

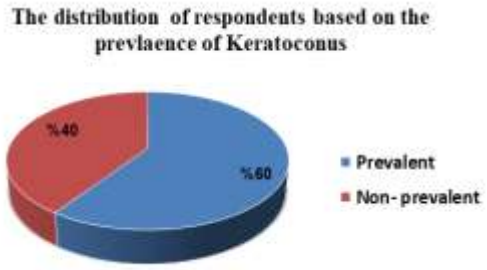

Fig (11): The distribution of respondents based on the prevalence of KC.

Table (4), and Figure (12): Shows the distribution of respondents based on the Gender. It shows that the number of Male patients had greater Keratoconus prevalence 232 (56.2%) than female 181(43.8%).

Table (4): The distribution of respondent's base on the Gender:

Gender	Number of respondents	%
Male	232	56.2
Female	181	43.8
Total	413	100

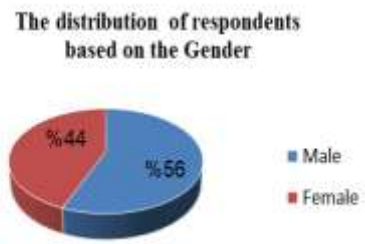

Fig (12): The distribution of respondents based on the Gender.

Table (5), and Figure (13): It is evident that the age group of [15–24] had the largest percentage of respondents (44.6%), followed by [25–34] (21.8%), [45–54] (18.2%), and [35–44] (15.5%) respectively.

Table (5): The distribution of respondents based on the Age Interval:

Age interval	Number of respondents	%
15-24	184	44.6
25-34	90	21.8
35-44	64	15.5
45-54	75	18.2
Total	413	100

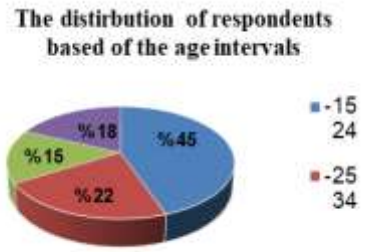

Fig (13): The distribution of respondents based of the age intervals.

Table (6), and Figure (14): Display the respondents' distribution by corneal thickness, with the largest percentage of respondents (71.9%) falling into the "More than 500" category and the lowest number (28.1%) falling into the "Less than 500" category.

Table (6): The distribution of respondents based on the Corneal Thickness:

Corneal Thickness	Number of respondents	%
More than 500	297	71.9
Less than 500	116	28.1
Total	413	100

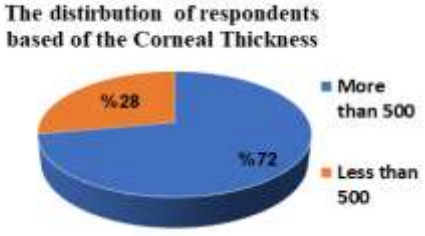

Fig (14): The distribution of respondents based on the Corneal Thickness.

Table (7), and Figure (15): It clear that, the percentage of 59.1% falls in category of irregular Astigmatism, while the percentage of 40.9% falls in category of regular Astigmatism.

Table (7): The distribution of respondents based on the Astigmatism:

Astigmatism	Number of respondents	%
Regular	169	40.9
Irregular	244	59.1
Total	413	100

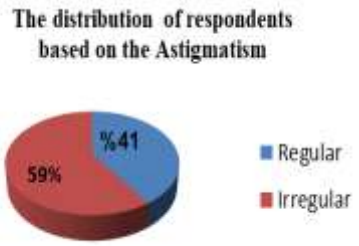

Fig (15): The distribution of respondents based on the Astigmatism.

Table (8), and Figure (16): Demonstrating the respondents' distribution by treatment, it is evident that the eyeglasses category accounted for 43.8% of the total, followed by the corneal cross-linking category with 21.8%, contact lenses with 16.5%, intra-corneal ring implantation with 9.2%, and corneal transplantation with 8.7%.

Table (8): The distribution of respondents based on the Treatment.

Treatment	Respondents	%
Eyeglasses	181	43.8
Contact Lenses	68	16.5
Corneal Cross Linking	90	21.8
Corneal Transplantation	36	8.7
ICR Implantation	38	9.2
Total	413	100

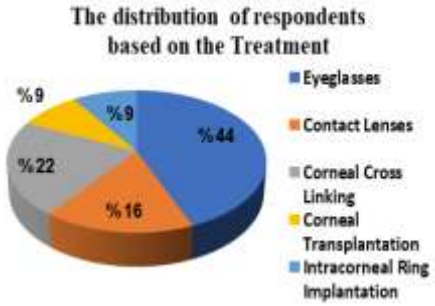

Fig (16): The distribution bas respondents based on the Treatment.

Table (9), and Figure (17): Represent the distribution of the respondents based on the prevalence of Keratoconus and their gender, it seems that, the number of Male prevalence is 131, and the number of Female prevalence is 115.

Table (9): The distribution of respondents based on the prevalence of Keratoconus and their gender:

Keratoconus	Gender		Total
	Male	Female	
Prevalence	131	115	246
Non-prevalence	101	66	167
Total	232	181	413

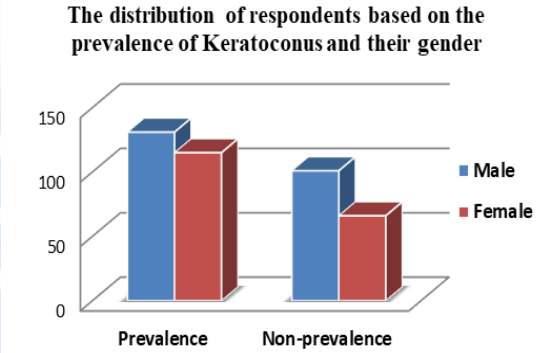

Fig (11): the distribution of respondents based on the prevalence of Keratoconus and their gender.

4.2. Statistical Result:

Table (10): It seems that; at (α=0.05) there is no statistically significant differences between the gender of the respondent and the prevalence of Keratoconus, whereas (Chi-square = 2.110), and P-value (0.146) > 0.05.

Table (10): Chi-square test Gender and prevalence of KC:

	Value	d.f.	Asymp. Sig. (2-sided)
Pearson Chi-Square	2.110	1	0.146

Table (11), and Figure (18): Show that the number of Prevalence respondents of age interval [15-24] was 110, then 49 for age interval [25-34], followed by 42 for age interval [35-44], and lastly 45 for age interval [45-54]. While the number of non-prevalence keratoconus respondents of age interval [15-24] was 74, followed 41 for age interval [25-34], then 22 for age interval [35-44], and lastly 30 for age interval [45-54].

Table (11): The distribution of respondents based on the prevalence of KC, and their age interval:

Keratoconus	Age Interval				Total
	15-24	25-34	35-44	45-54	
Prevalence	110	49	42	45	246
Non-Prevalence	74	41	22	30	167
Total	184	90	64	75	413

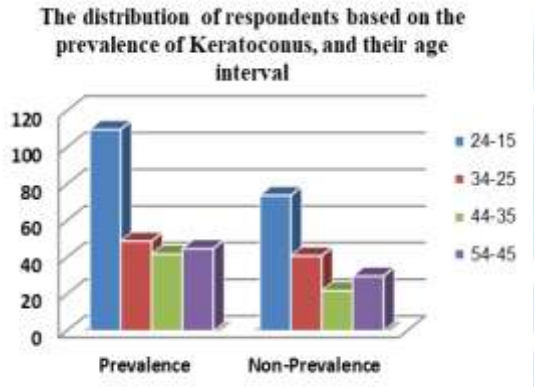

Fig (18): The distribution of respondents based on the prevalence of Keratoconus, and their age interval.

Table (12): It seems that; at (α=0.05) there is no statistically significant differences of the relationship between the age interval of the respondent and the prevalence of Keratoconus, whereas (Chi-square = 1.965), and P-value (0.580) > 0.05.

Table (12): Chi-square test:

	Value	d.f.	Asymp. Sig. (2-sided)
Pearson Chi-Squar	1.965	3	0.580

Table (13): The distribution of the Prevalence of Keratoconus, and the Corneal Thickness:

Corneal Thickness		Keratoconus	Total
> 500		< 500	
170	**Prevalence**	76	246
127	**Non-Prevalence**	40	167
297	**Total**	116	413

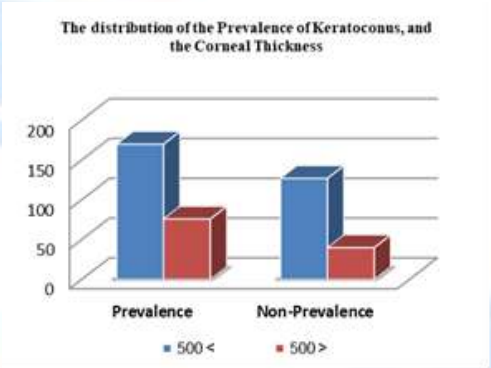

Fig (19): The distribution of the Prevalence of Keratoconus, and the Corneal Thickness.

Table (13), and Figure (19): Display the amount of prevalence of Keratoconus with > 500 Corneal Thickness is 170, and the amount of prevalence of Keratoconus with < 500 Corneal Thickness is 76. However, the number of non- prevalence of Keratoconus with > 500 Corneal Thickness is 127, and the number of non-prevalence of Keratoconus with < 500 Corneal Thickness is 40.

Table (14): It seems that; at (a=0.05) there is no statistically significant differences of the relationship between the Corneal Thickness of the respondent and the prevalence of Keratoconus, whereas (Chi-square = 2.373), and P-value (0.123) > 0.05.

Table (15), and Figure (20): Display the amount of prevalence of Keratoconus and Regular Astigmatism is 10, and the amount of prevalence of Keratoconus and Irregular Astigmatism is 236. However, the number of non-prevalence of Keratoconus regular Astigmatism is 159, and the number of non-prevalence of Keratoconus and Irregular Astigmatism is 8.

Table (14): Chi-square test:

	Value	d.f.	Asymp. Sig.
Pearson Chi-Square	2.373	1	0.123

Table (15): The distribution of the Prevalence of Keratoconus, and the Astigmatism:

Keratoconus	Astigmatism		Total
	Regular	Irregular	
Prevalence	10	236	246
Non-Prevalence	159	8	167
Total	169	244	413

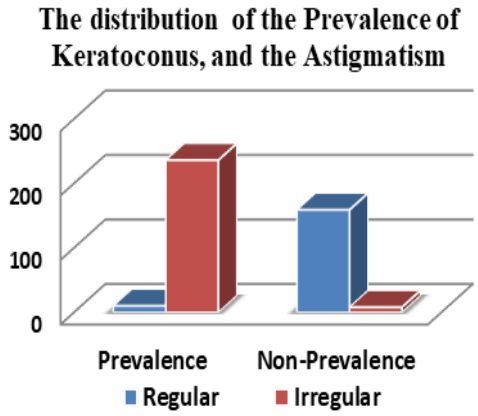

Fig (20): The distribution of the Prevalence of Keratoconus, and the Astigmatism.

Table (16): Chi-square test.

	Value	d.f.	Asymp. Sig. (2-sided)
Pearson Chi-Square	341.811	1	0.000

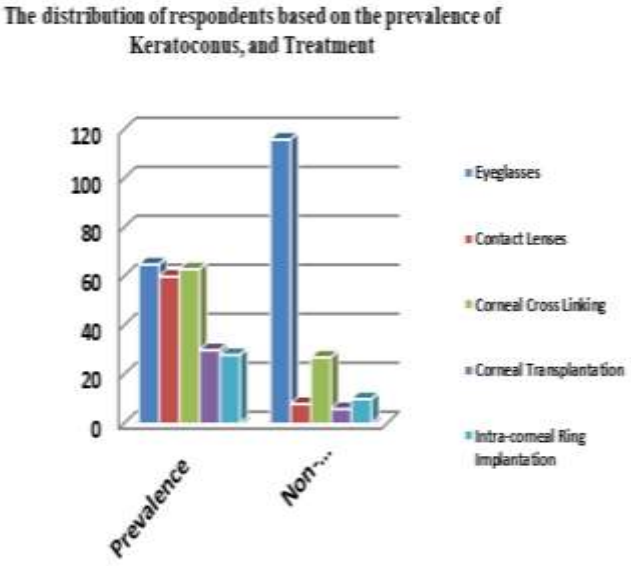

Fig (21): The distribution of respondents based on the prevalence of Keratoconus, and Treatment.

Table (15): It seems that; at (a=0.05) there are statistically significant differences of the relationship between the Astigmatism of the respondent and the prevalence of Keratoconus, whereas (Chi-square = 341.811), and P-value (0.000) < 0.05.

Table (16), and Figure (21): Display the amount of prevalence of keratoconus and eyeglasses treatment, which was 65, followed by the amount of prevalence of keratoconus and contact lenses treatment, which was 60; then the amount of prevalence of keratoconus and corneal cross-linking treatment 63; then the amount of prevalence of keratoconus and corneal transplantation 30; and lastly the amount of prevalence of intra- corneal ring implantation treatment was 28.

According to Table (17), the number of non-prevalence of keratoconus and eyeglasses treatment was 116, followed by the number of non-prevalence of keratoconus and contact lens treatment, which was 8, then the number of non-prevalence of keratoconus and corneal cross-linking treatment was 27; then number of non-prevalence of keratoconus and corneal transplantation was 6; and lastly, the number of non-prevalence of keratoconus and intra-corneal ring implantation treatment was 10.

Table (17): The distribution of respondents based on the prevalence of Keratoconus, and Treatment:

Keratoconus	Treatment					Total
	Eyeglasses	Contact Lenses	Corneal Cross Linking	Corneal Transplantation	Intra-corneal Ring Implantation	
Prevalence	65	60	63	30	28	246
Non-Prevalence	116	8	27	6	10	167
Total	181	68	90	36	38	413

Table (18): It seems that; at (α=0.05) there are statistically significant differences of the relationship between the Treatment of the respondent and the prevalence of Keratoconus, whereas (Chi-square = 80.910), and P-value (0.000) < 0.05.

Table (18): Chi-square test:

	Value	d.f.	Sig. (2- sided)
Pearson Chi-Square	80.910	4	0.000

V. DISSCUSSIONS

"Keratoconus has been found to affect all ethnicities, although the prevalence and incidence are higher among South Asians and Middle Easterners compared with those of European ancestry." (Kanski, 2015). The intent of this study was to investigate the probability of keratoconus among patients attend visit Delta Optics Center and Benghazi Teaching Hospital for Ophthalmology, as well as any potential correlations between the condition and clinical and demographic factors**.**
The result shows that keratoconus affected about 59.6% of patients, indicating a relatively significant disease burden in this area. Despite statistical analysis using the chi-square test showing no significant association between gender and keratoconus prevalence (p = 0.146), males had a slightly higher prevalence of keratoconus (53.3%)

than females. In contrast higher prevalence of KC in this study compared to study reported in kenya, Denmark**.**

Also, a Saudi Arabia study demonstrate that majority of middle east countries had higher prevalence KC (Kennedy, 2000; Assiri, 2005). Opposite to this a study by Aly Rashid *et al*.,2021) Kenyan study where female had higher prevalence of keratoconus over male, while some studies shown no difference between gender (Gomes,2022), in compatible with this study by Aly Rashid Z, H et al. where prevalence of KC was not significantly associated with gender (p = 0.80). (Aly Rashid,2023)**.**

However, estimated prevalence of KC to be 7.9% in Africa a meta-analysis of a finite number of studies by Akowuah (Akowuah *et al.*, 2021), as consider lower when compared to this study.

Also, a lower prevalence of KC ranges from 1.4 to 4.8% In Turkey, India and the Middle East (Salman A,2022; Özalp O,2021; Jonas,2009; Torres Netto,2018)**.** Concerning the age of participants as found, the 15–24 age group had the highest prevalence (44.7%), which is consistent with research demonstrating keratoconus often begins in adolescence or early adulthood. Even if younger people are more impacted, age by itself may not be a predictive element in this group also, relationship between 34 Statistically, age groups and the prevalence of keratoconus were not significant (p = 0.580). This suggests that other variables like heredity, environmental exposures, or eye habits may be more important predicting elements for keratoconus than age alone.

Similarly, a study by Kenyan authors Aly Rashid and colleagues found non-significant association between frequency of keratoconus and age (Aly Rashid *et al*., 2025). By contrast in a cross-sectional study in Sweden, where prevalence was higher in the age group of 21 to 30 years (Binder, 2020), implying that regional

variance may be explained by variations in population characteristics, environmental conditions, and genetic predisposition. Age and gender alone cannot be regarded a deciding factor. The variances seen between several studies draw attention to the impact of genetic and environmental variation between populations.

In this study about 71.9% of the participants had a thickness greater than 500 microns, also, however still the correlation between corneal thickness and keratoconus prevalence found not significant ($p = 0.123$). This might indicate that although corneal thinning is a characteristic of keratoconus, it is not the only factor that determines early diagnosis or detection in this disease.

A statistically significant association was remarkably noted between keratoconus and astigmatism ($p < 0.001$). In 95.9% of patients with keratoconus had irregular astigmatism, which is consistent with the disease's known clinical profile. This result demonstrated how crucial comprehensive screening for astigmatism is in detecting possible cases of keratoconus as discussed before in theoretical part.

Eventually, as marked in the results a significant relationship was found between the type of treatment used and keratoconus prevalence ($p < 0.001$). Contact lenses, corneal cross-linking, and surgical procedures like corneal transplantation and intracorneal ring implantation were more common among keratoconus patients, even though eyeglasses were still the most popular treatment for all groups.

Also, in Sweden Kenyan study had found majority of the respondents prescribed spectacles in mild cases of keratoconus fewer patients where on for contact lenses and CXL and surgery treatment (Aly Rashid ,2025; Aly Rashid, 2023; Binder J.T,2020). Overall, the relatively higher prevalence incident reflects “the prevalence of KC appears 35 to be higher in countries with hot and dry climates compared to cooler climates” (Santodomingo-Rubido, 2022).

This distribution reflects both the severity and progression of the disease in those affected. This finding only represents patients in Benghazi and is not entirely conclusive because it only applies to one hospital and clinic and does not represent the entire Libyan population.

CONCLUSION

Keratoconus is relatively common among patients visiting ophthalmology centers in Benghazi, particularly among young people. While gender, age, and corneal thickness were not significantly associated with the disease, irregular astigmatism had a strong and statistically significant relationship. Furthermore, the treatment options for keratoconus and non-keratoconus patients differed significantly, with the former receiving more advanced interventions.

This result represents the population in Benghazi not the entire country of Libya. Additionally, furthermore studies required in despite sample size, because the majority of participants come from a single hospital and clinic, cause sampling locations are not diverse. As noted, this study emphasizes the need for early screening for astigmatism in young people to help with early diagnosis and treatment. The study also supports the idea that treatment should be different for each patient based on disease degree and condition.

RECOMMENDATIONS

1. Encourage younger adults for early screenings regarding keratoconus specially for patients with irregular astigmatism, for early diagnosis and treatment, and emphasize them for continuous follow-up as irregular astigmatism consider related to keratoconus.
2. Increase population awareness through learning courses and programs regarding keratoconus signs and symptoms, risk factor so as to promote early diagnosis and treatment.
3. Improve the education of the eye care providers through training learning sessions about modern optical techniques and how to keep up with modernity about keratoconus.
4. Emphasize the important of conduct continuous studies related to keratoconus in Libya, address the updated concerning the risk factors, causes of disease.
5. Offer in public health care institutions updated diagnostic instruments and treatment options.

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Diagnosis of Common Refractive Errors in Children Using Non-Surgical Techniques

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الملخص:
الخلفية: تُعدّ عيوب الانكسار من أهمّ جوانب ضعف البصر لدى الأطفال، وتمثّل مشكلة صحية عامة هامة، لا سيما في الدول النامية. قد تؤثر عيوب الانكسار سلبًا على نموّ الأطفال في جميع جوانبه، وقد تؤدي إلى إعاقة بصرية دائمة إذا لم يتمّ اكتشافها مبكرًا. هدفت هذه الدراسة إلى تقييم مدى انتشار عيوب الانكسار وأنماطها بين الأطفال المراجعين لعيادة ومستشفى طب العيون في بنغازي، ليبيا. المنهجية: أُجريت الدراسة في مرافق الرعاية الصحية المختارة لطب العيون. تمّ إجراء دراسة مقطعية، حيث جُمعت البيانات الديموغرافية أولًا، ثمّ أُجري فحص سريري للعين، شمل تقييم حدّة البصر، وقياس الانكسار، وتقييم أجزاء العين (الأمامية والخلفية)، وسُجّلت جميع البيانات المُجمّعة. النتائج: أظهر الأطفال في هذه الدراسة انتشارًا أعلى لضعف البصر. تُعدّ عيوب الانكسار السبب الرئيسي لضعف البصر (قصر النظر وطول النظر)، يليها الحول والغمش. كانت نسبة ضعف البصر أعلى لدى الفئة العمرية الأكبر سنًا مقارنةً بالفئات الأصغر سنًا. كانت الإناث يترددن على المستشفى أكثر من الذكور وقت إجراء الدراسة، وقد استُخدمت أكثر من تقنية تشخيصية واحدة. أظهر الأطفال في سن المدرسة معدلًا أعلى من عيوب الانكسار مقارنةً بالفئات العمرية الأصغر. ويُعدّ تصحيح النظر (باستخدام النظارات) الطريقة العلاجية الأكثر شيوعًا. الخلاصة: شاع ضعف البصر بين الأطفال في سن المدرسة في بنغازي، ويعود ذلك أساسًا إلى عيوب الانكسار غير المصححة، مثل قصر النظر، والاستجماتيزم، وطول النظر. تُبرز هذه النتائج الحاجة إلى تحسين برامج الكشف المبكر والفحص، ونهج العلاج لدى الأطفال للحد من عيوب الانكسار التي يُمكن الوقاية منها في مرحلة الطفولة، وتأثيرها طويل الأمد.

الكلمات المفتاحية: عيوب الانكسار؛ ضعف البصر لدى الأطفال؛ طب العيون للأطفال؛ قصر النظر؛ الحول؛ أمراض العيون؛ طول النظر

Abstract: Background: Refractive errors consider the main aspect of Visual impairment in childhood represent a significant public health issue, particularly in developing countries. Refractive errors may adversely affect children development in all aspect and can lead to permanent visual disability if not discovered early. This study aimed to assess the prevalence and pattern of refractive errors among children attending ophthalmology clinic and hospital in Benghazi, Libya. Method: The study conducted in the selected health care facilities for ophthalmology. A cross-sectional study performed, first colleting demographic data, second clinical ophthalmic examination were performed, including acuity assessment, refraction, and segment evaluation (anterior and posterior), all data collected was recorder. Results: Children in this study exhibit a higher prevalence of visual impairment. Refractive errors are the main cause of visual impairment (myopia and hyperopia), followed by strabismus and amblyopia. The older age group had a higher visual impairment than the younger groups. Female participants were attending the hospital more often than males at the time of the study more than one diagnostic technique had been used. School-aged children showed a higher burden of refractive errors compared to younger age groups. Correction of vision (glasses) is the most

common management method used. Conclusion: Among school-aged children in Benghazi visual impairments were common, primarily due to uncorrected refractive errors such as myopia, astigmatism, and hyperopia. These findings highlight the need for improve early detection and screening program, treatment of approach in children to reduce preventable childhood refractive errors and its long-term impact.

Keywords: Refractive Errors; Childhood visual impairment; Pediatric ophthalmology; Myopia; Strabismus; Eye diseases; Hyperopia.

I. INTRODUCTION

"Vision is critical for daily activities, and visual impairment is one of the most serious disabilities. Visual impairment at birth or during childhood can affect learning, communication, employment, health, and quality of life, and the effects are often life-long. (Brown *et al.*, 2003). Although the proportion of infants and school-aged children with visual impairment is less than 5%, children with visual impairment account for 20% of individuals with visual impairment worldwide, after adjustment for disability-adjusted life years (Sun, 2000). The control of visual impairment and blindness in children is a priority of the World Health Organization's VISION 2020 program. (Gilbert & Foster, 2001). Uncorrected refractive error is one of the most common causes of visual impairment in children. Increasing evidence indicates that uncorrected refractive error is a main cause of avoidable blindness in many regions, including Chile, Africa, and Malaysia" (Ellwein *et al.*, 2000; Naidoo *et al*., 2003; Goh *et al.*, 2005).

Minor decline in vision (<6/12 or just below the driving standard) has increasing the risk of death and physical, social, and intellectual issues in humans older than 50 years (Taylor *et al.*, 2003). The worldwide monetary effect of uncorrected refractive mistakes is an anticipated 268.eight billion worldwide dollars, primarily based totally on population The global economic impact of uncorrected refractive error is an estimated 268.8 billion international dollars, based on population and economic data combined with a meta-analysis of prevalence studies (Smith *et al*., 2009).

In Libya particularly in Benghazi, their limited studies published regarding prevalence of refractive errors, diagnoses approach among school aged children, to identify these factors as necessary to improve and development of children vision screening programs, treatments, and pediatric eye care approaches.

1.2 The Aim to Accomplish:

This study aimed to assess the prevalence of refractive errors, as well as the non-invasive diagnostic approaches used among school-aged children attending Al-Sabri Polyclinic and Al-Nahr Central Hospital in Benghazi Libya.

II. GROWTH AND DEVELOPMENT OF CHILD'S EYE

The eye growth and development of hid many challenging anatomical and physiological alterations starting from the intrauterine life until the early puberty. After the early puberty, the axial duration of eye, this is defined due to the fact the anterior posterior diameter of the eye, remains unaltered in healthy subjects. The eye refractive status still to change in adults due to aging processes. The eye development starts in the 3-week embryo, from the optic vesicles. The preliminary three years of existence is the vital duration for eye development, and fast growth in. Clear vision is mandatory for the development of visual cortex in this critical period. It is well-known that everyday person viuale capability develops at three years of age (Fredrick, 2004).

The coordinated boom of eye's refractive additives to attain a plano refraction is known as emmetropization. If any failure takes place on this process, refractive mistakes develop. The axial period is both too short, inflicting hypermetropia, or too long, inflicting myopia. Astigmatism is because of extraordinary shapes in cornea. Very high degrees of hypermetropia (>5D) are not normal in newborns. The cornea and lens can also additionally flatten generally inside years; however, the axial period regularly pauses behind. This reasons everlasting hyperopia, that is referred to as nanophthalmos. Generally, eyes with hyperopia of extra than five diopters have little hazard of emmetropization (Mutti, 1992).

2.1. The cornea:

Is an avascular, obvious tissue that lets in mild transmission into the eye. The cornea performs a vital

function withinside the refraction of the eye; it really works as a concave-convex lens in contact with the aqueous and the tear film (AAO, 2009). The cornea outer aspect has an oval configuration with an average horizontal diameter of 12.6 mm and an average vertical diameter of 11.7mm. The outer surface of the cornea is the main refractive element of the eye contributing with approximately +48 diopters to the convergence of the light in the retina (Colina, 2000).

Refractive Index (nn*n*): While ~1.376 is the standard, it varies by layer (epithelium ≈is approximately equal to ≈ 1.401, stroma ≈is approximately equal to ≈ 1.369).

Total Power: Roughly 40–45 D (anterior surface is +48.8 D, posterior is -5.8 D).

❖ Reason of Cornea Transparency:

- Collagen fibers are arranged uniformly and regularly in the stroma, reducing light scattering.
- lack of blood vessels, which stops light from being absorbed and dispersed.
- The corneal endothelium uses active ion pumps to maintain controlled hydration.
- Collagen fibrils have a uniform diameter and spacing, which facilitates effective light transmission.
- non-keratinized epithelium that preserves optical clarity.

2.2. Refractive Errors (Ametropia):

Refractive errors are existed while the attention fails to convey parallel light (remote objects) to cognizance at the retina. Ametropia, that is described because the presence of any of the refractive disorders, is the maximum generally diagnosed ailment of the human eye. Ametropia includes the hyperopia (Farsightedness), myopia (Nearsightedness) and astigmatism (abnormal curvature of the cornea). The most common refractive error in the pediatric population is myopia (near sight). The World Health Organization estimates refractive disorders to be 2-10%worldwide. The incidence is discovered to be lots better withinside the Far East. The occurrence of astigmatism of one diopter or extra is 50% in infancy. The occurrence decreases swiftly at some stage in the system of emmetropization. Only few youngsters increase astigmatism extra than 1 diopter via way of means of 6 years of age (Maida *et al.*, 2008).

2.2.1. Myopia:

Is (short-sighted) eye, distant objects are brought to focus in front of the retina. This can be due to the fact the eyeball is just too long (axial myopia) or the refractive factors of the attention too powerful (refractive myopia), (Johnstone, 2008).

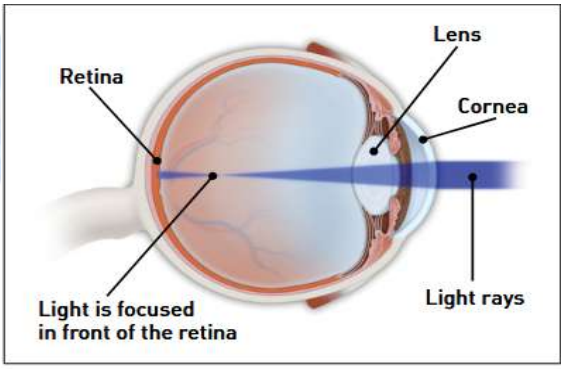

Fig.1: Myopic Eye.

Sub-categorizing the classification of myopia:

1. Axial myopia: A refractive state that can be attributed to excessive axial elongation.
2. Refractive myopia: A refractive state that can be attributed to changes in the structure or location of the image forming structures of the eye, Ex (the cornea and/or lens).
3. Curvature myopia: The lens or cornea is more curved than usual (steeper cornea), (Flitcroft *et al.*, 2019).
4. Index myopia: Is because of an extrade withinside the refractive index of the internal optical media of the eye (lens, aqueous humor or vitreous). Changes in index myopia are not unusualplace in diabetics and may arise in avitaminosis A and D.
5. Positional myopia: Is produced via way of means of anterior placement of crystalline lens withinside the eye.

2.2.2. Hypermetropia (Hyperopia):

Is (long-sighted) eye, distant objects are brought to focus behind the retina. This can be due to the fact the eyeball is simply too short (axial hypermetropia) or the refractive factors of the attention are inadequate (refractive hypermetropia), (Johnstone, 2008).

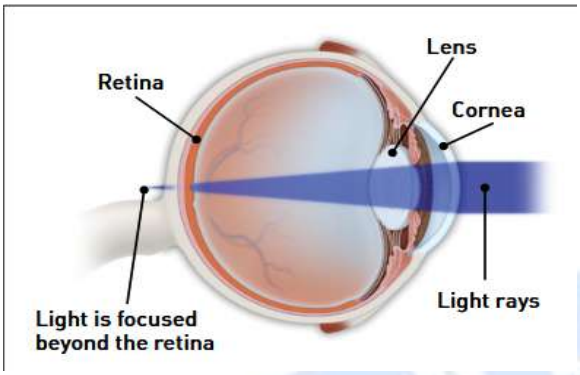

Fig.2: Hyperopic Eye.

2.2.3. In astigmatism:

Astigmatism that causes blurred vision due either to the irregular shape of the cornea, or on occasion the curvature of the lens. The eye had varied refractive power depending on which meridian light enters the eye. If those meridia lie at 90° to every apart from everyday astigmatism is stated to exist. If the meridia lie at 90° to every different however now no longer always withinside the horizontal or vertical meridia, that is termed 'indirect astigmatism'. If the meridia do now no longer lie at 90° to every aside from that is termed 'abnormal astigmatism' and is difficult to correct with lenses (Johnstone**,** 2008).

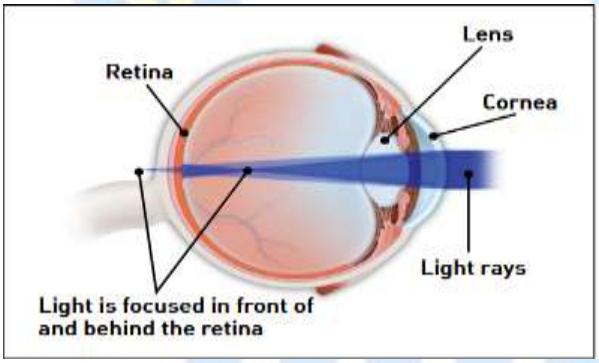

Fig.3: Astigmatism Eye.

2.2.4. Amblyopia:

Amblyopia is the blend of two Greek words; amblyos – blunt and opia –vision. The parents commonly use the lazy eye terminology instead of ambloypia. Due to the suppression of the blurred imaginative and prescient from the diseased eye, the hazard of improvement of unilateral Amblyopia is a lot better than the threat of bilateral amblyopia. Congenital cataracts are one of the critical etiologies for amblyopia, even as senile cataracts are the maximum not unusualplace treatable reason of imaginative and prescient loss the various elderly. Any pathology that outcomes in strange visible revel in in a single or eyes earlier than the important duration of seen development might also result in amblyopia. The important length typically ends at 6-eight years of age (Morishita & Hensch, 2008).

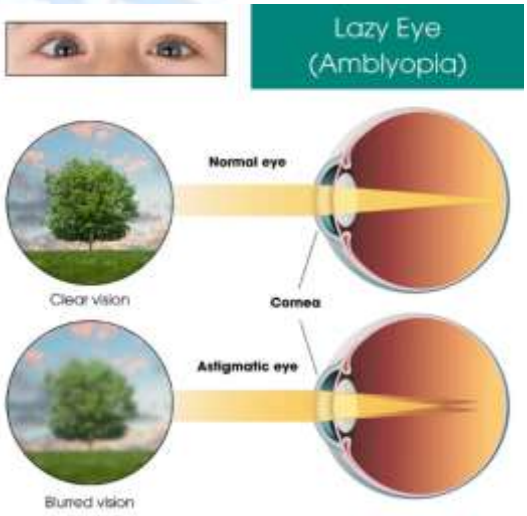

Fig.4: Amblyopia.

2.2.5. Strabismus:

Strabismus (Squint) is a misalignment of the eyes, which compromises the capacity to attention each eye at the identical target. This misalignment is due to an imbalance some of the extraocular rectus muscles. Strabismus is some of the maximum not unusualplace pediatric ocular pathologies, taking place in more or less 2–4% of children (Williams *et al*., 2008; Greenberg *et al*., 2007). It can be gift at beginning, particularly in untimely or low beginning weight deliveries (Connor *et al*., 2002) Or be obtained all through childhood, regularly withinside the placing of comorbid illnesses inclusive of imaginative and prescient deprivation, cataracts, or retinoblastoma (Abramson *et al*., 1998; Weakley *et al*., 2001). Prolonged strabismus and the resultant visible discordance may also disrupt the brain's visible machine because it develops, making it A major purpose of amblyopia. It can also be averse to the development of binocular vision (Wright *et al*., 2003).

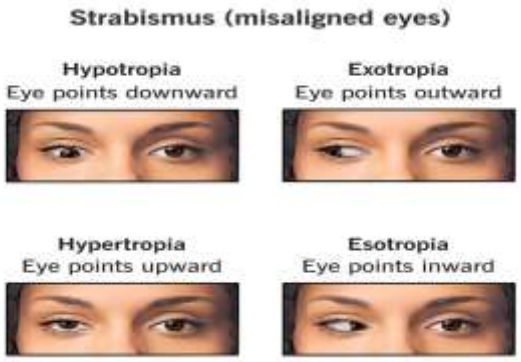

Fig.5: Strabismus (Squint)

2.2.6. Congenital Cataract (Infantile):

Cataract is an n opacification of the crystalline lens. Are occurred within the first year of life. (Shiels & Hejtmancik, 2017). The majority of bilateral congenital or infantile cataracts now no longer related to a syndrome haven't any identifiable cause.

Causes:

1. Genetic mutation is likely the most common cause. Over fifteen genes worried in cataract formation had been identified, and the inheritance is most customarily autosomal dominant even though it is able to be X-connected or autosomal recessive. (Reddy, 2004). Within the equal pedigree, there may be enormous morphologic variation.
2. Systemic associations include metabolic disorders such as galactosemia, Wilson disease, hypocalcemia and diabetes. Cataracts may be a part of a number of syndromes, the most now no longer unusual place being trisomy 21. Intrauterine infections such as rubella, herpes simplex, toxoplasmosis, varicella and syphilis are some other causes. (Reddy, 2004).

2.3. Diagnosis:

2.3.1. Clinical examination (Visual Acuity):

The evaluation of the visible acuity (VA) is with the aid of using some distance the maximum typically finished take a look at in ophthalmology. Its objectives to degree the spatial decision of the eye - or better - the visible system. A regular VA calls for intact optics (clean cornea and lens, and glasses if needed), a regular function of the relevant retina (fovea) and optic nerve, and intact visible pathways past the optic nerve (chiasm, optic tract, Thalamus, optic radiation, and seen cortex). Herman Snellen, a Dutch ophthalmologist, is taken into consideration the inventor of this test. (Jansonius, 2010).

2.3.1.1. Visual acuity chart: layout and usage:

Figure (6), (right panel) presents a modern VA chart. It includes five optotypes consistent with row (’line’). The spacing among the traces equals the scale of the optotypes under the spacing. The duration modifications a number of the lines with an issue of 1.26, that is, 0.1 log units. This implies 0. three log devices with 3 lines, that is, a doubling or halving of the size (1.263 = 2, 1.26-three = 0.5). Next to every line various is given: the denominator of Snellen, or D. This variety shows the not unusual place distance at which a healthful eye is truly able to treatment the corresponding optotypes. (Jansonius, 2010).

2.3.1.2. Optotype size and minimal angle of resolution:

Optotypes are designed on a 5x5 grid. A VA of 1.0 corresponds to an optotype top of 5 arcmin and a gap duration of 1 arcmin, (Figure (6), that is, the standard spatial resolution (consistent with the Raleigh criterion) of the visible device is 1 arcmin. The hole length is likewise known as the minimum attitude of resolution (MAR), and an opportunity manner for expressing visible acuity is the logMAR, in which the bottom of the logarithm is 10 and MAR in arcmin (Jansonius, 2010).

Fig.6: Snellen Chart.

2.3.2. Diagnostic Devices:

2.3.2.1. Autorefractometer:

An autorefractor or automatic refractor is a computer-controlled tool used withinside the direction of an eye fixed examination to provide an objective size of a person's refractive mistakes and prescription for glasses or touch lenses. This is done with the aid of using measuring how light is modified because it enters a person's eye (Medina, 2015). The majority of autorefractors calculate the vision correction an affected character needs (refraction) with the useful resource of the use of using sensors that come upon the reflections from a cone of infrared light (Medina, 2015). Cycloplegic refraction is often recommended in children to eliminate the effect of accommodation and obtain accurate refractive measurements, particularly in cases of hyperopia or suspected amblyopia (kanski, 2022).

Fig.7: Autorefractometer.

2.3.2.2. Retinoscopy:

Is an examination method that objectively measures the refractive blunders of the eye. This is carried out with the aid of using searching through an optical device known as a retinoscope to look at the motion of reflected light in a patient's pupil (Hollis *et al.*, 2022). This goal evaluation lets in the examiner to evaluate refractive blunders without subjective enter from the patient, making it A beneficial device for comparing infants, younger children, adults with developmental delays, and others who might not otherwise Be capable of cooperate for subjective refraction (American Association for Pediatric Ophthalmology and Strabismus, 2023). Retinoscopy can also be used to assess accommodative characteristic and to evaluate for ocular floor and media pathologies which include cataracts (Elliott, 2020).

Fig.8: Retinoscopy.

2.3.2.3. Slit lamp examination:

Its biomicroscope that give a focused beam of light with variable height, width, and angle. This particular tool allows three-dimensional visualization and dimension of the quality anatomy of the adnexa and anterior phase of the eye. Able to detect dry eye, corneal abnormalities, and eyelid disorders (Davison *et al*., 2005).

Fig. 9: Slit lamp examination.

2.3.2.4. Fundus examination (Fundoscopy):

Known as clinical procedure used to evaluate the posterior segment of the eye, including the Retina, Optic Disc, Macula, Retinal Blood Vessels, and Choroid. It is an essential diagnostic technique for detecting and

monitoring a wide range of ocular and systemic diseases that affect the eye. The examination is commonly performed using direct or indirect ophthalmoscopy, fundus photography, or advanced imaging modalities such as optical coherence tomography. (American Academy of Ophthalmology, 2022).

Fig.10: Fundus examination (Fundoscopy).

2.4. Management:

2.4.1. Refractive Errors Management (Optical Correction):

Spectacles, contact lenses, refractive surgery, intraocular lenses and clear lens extraction are the modern-day techniques of refractive correction (kanski, 2011). Spectacles are the simplest, safest, and most cost-effective way to correct refractive error. In resource rich countries spectacles are used to correct about two thirds of refractive errors. (Webber, 2007). Many low-income settings services and spectacles may be unavailable or unaffordable for most of the population, contact lenses (Evans & Rowlands, 2004; Gilbert *et al.*, 2008). A minority of the population with refractive errors makes use of corrective contact lenses, which are used either daily or for extended wear (overnight weekly/monthly), (Webber, 2007).

2.4.2. Amblyopia Management:

The preliminary step withinside the control is the correction of the underlying etiology, if possible. Surgical treatment of the strabismus, or the congenital cataract, correction of the refractive errors thru glasses or contact Lenses are the principal remedy modalities for the correction of the maximum not unusual place reasons of amblyopia. In a few pathologies, which include nystagmus, retinoblastoma, it isn't always feasible to take away the underlying reason of blurred vision totally (Matta *et al.*, 2010).

3. **2.4.3. Strabismus Management:**

Abnormal eye actions are often related to pediatric eye deviations and they could impact the control of the cases. Accommodative styles of esotropias can be absolutely cured with spectacles. Surgical correction is determined in line with the perspective of deviation, if the deviation isn't always corrected via way of means of the spectacles all through follow-up (Hughes, 2000).

III. METHODOLOGY

3.1. Study design:

This a cross-sectional descriptive study was conducted to assess children's vision and prevalence of eye disorders and other corresponded approaches (diagnosis, and treatment) among school-aged children attended Al-Sabri Polyclinic and Al-Nahr Central Hospital in Benghazi, Libya. The study conducted from the first of September to the end of November 2025.

3.2. Sample Size:

A total of (447) children were included in the study, all collected questionnaires were complete. valid responses were obtained from all participants. Study population composed from school aged children between (6 -16 years old) who attended the selected hospitals during study period.

3.3. Data Collection Tool and Assembling Methods:

A structured questionnaire was used, specifically designed for the purpose of this study approved from department of optometry and vision science. Composed from seven main sections in addition to demographic data. These sections included:

Demographic data: Contain age, gender, and nationality.

- First section: Medical history and complaints: focusing on ocular history of participants, genetic diseases and also, with presenting visual complaints.
- Second section: The clinical examination:

Assessment of visual acuity and ocular health used (Snellen chart for both eyes).
Autorefractor to examine refractive errors.
(Retinoscopy and Cycloplegic) refraction.
Slit lamp examination to assess anterior segment abnormalities.
Assessment for both eye for difference in visual acuity.

- Third section: Examination conclusion: recording the finding.
- Fourth section: Screening practices and barriers: information related to vision screening frequency, available equipment, and challenges.
- Fifth sections: Knowledge and attitudes: assessment of eithers their awareness regarding early detection of eye disorders.
- Six sections: Treatment: documentation of prescribed or recommended treatment options for each patient.
- Seventh section: (Recommendations and suggestions).

3.4. Data Analysis:

The Statistical Package for the Social Sciences (SPSS) version 23 was used to evaluate the data. Descriptive data described as frequencies, percentages mean, and standard deviations.

3.5. Ethical Approval:

The study was approved from Medical Technology college - Optometry &Vision Science department, ethical guidelines used prior research procedures and consent was taken for each patient in the research. The data keep it confidential and only for research purpose. Also was permitted form Benghazi Teaching Hospital for Ophthalmology.

IV. RESULTS

4.1. Descriptive Results:

Section one: The Demographic Data of participants:
A total of 447 questionnaires were received, all were valid. As noted, 276 were females (61.7%), and 171 were males (38.3%), presenting higher females' participation in the study in Table (1) and Figure (11).

Table 1: Distribution of participants according to Child's Gender:

Gender	no.	%
Male	171	38.3
Female	276	61.7
Total	447	100

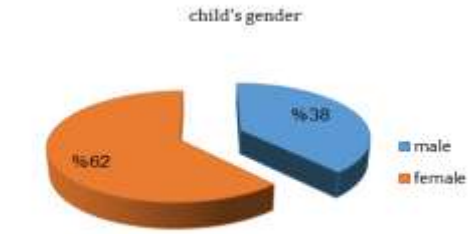

Fig.11: Distribution of participants according to Child's Gender.

Table (2), and Figure (12) represent that, the majority of participants were Libyan nationals (74.5%), while (25.5%) were non-Libyan, indicating that the study sample was predominantly Libyan.

Table 2: Distribution of participants according to Child's Nationality:

Nationality	no.	%
Libyan	333	74.5
Non-Libyan	114	25.5
Total	447	100

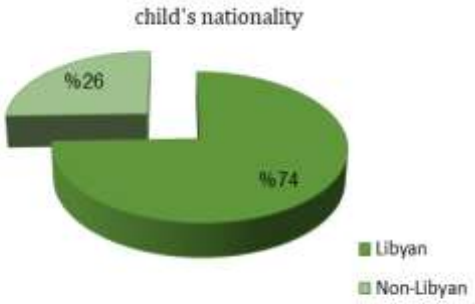

Fig.12: Distribution of participants according to Child's Nationality.

As seen in Table (3), and Figure (13), The participants' ages ranged from 6 to 16 years. The largest age group was [9–11] years (31.1%), followed closely by [12–14] years (30.4%). The [6–8] years group included (17.7%), and the [15–16] years group comprised (20.8%).

Table 3: Distribution of participants according to Child's Age:

Age	no.	%
6 – 8	79	17.7
9 – 11	139	31.1
12 – 14	136	30.4
15 - 16	93	20.8
Total	447	100

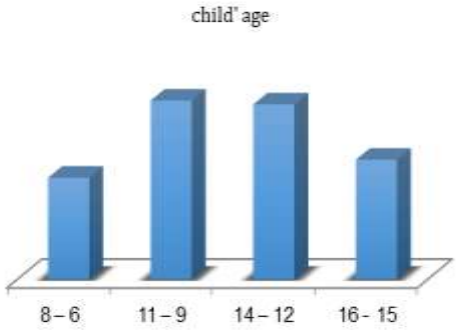

Fig.13: Distribution of participants according to Child's Age.

From Table (4), and Figure (14) all participants (447, 100%) were recruited from hospitals, while no participants were recruited from clinics, schools, camps, or different settings.

Table 4: Distribution of participants according to place of examination:

Place	No.	%
Hospital	447	100
Clinic	-	-
School	-	-
Camp	-	-
Other	-	-
Total	447	100

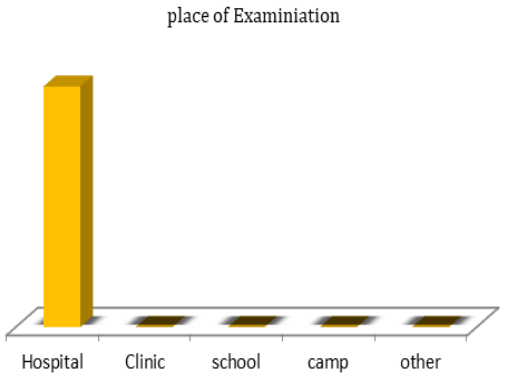

Fig.14: Distribution of participants according to place of examination.

Section Two: Medical History and Complaints:

The Table (5), Figure (15), and Figure (16) show the distribution of participants according to the presence of visual problems. The majority of participants reported having at least one visual problem, accounting for (88.3%) of the total sample, while (11.6%) reported no visual problems. The most frequently reported condition was Hazy Vision (27.3%), followed by no specific visual problem (15.9%), and Blurred Vision (12.3%). Other visual complaints included Blurred Vision with Headache (5.6%), Distance Vision Problems (4.0%), Near Vision Problems (3.1%), and Double Vision (3.6%). Refractive Errors were reported by (6.7%) of participants, whereas Severe Visual Impairment was the least common condition (1.8%). Overall, the results indicate a high prevalence of visual problems among the studied sample, with varying types and frequencies of visual complaints.

Table 5: Distribution of participants according to visual problems:

Response		No Specific Visual Problem	Hazy Vision	Blurred Vision	Blurred Vision, And Headache	Distance Vision Problems	Near Vision Problems	Double Vision	Refractive Errors	Severe Visual Impairment	Other Ocular Conditions	Total
Yes	No.	71	122	55	25	18	14	16	30	8	36	395
	%	15.9	27.3	12.3	5.6	4.0	3.1	3.6	6.7	1.8	8.1	88.3
No	No.	-	-	-	-	-	-	-	-	-	-	52
	%	-	-	-	-	-	-	-	-	-	-	11.6
Total	No.	-	-	-	-	-	-	-	-	-	-	447
	%	-	-	-	-	-	-	-	-	-	-	100

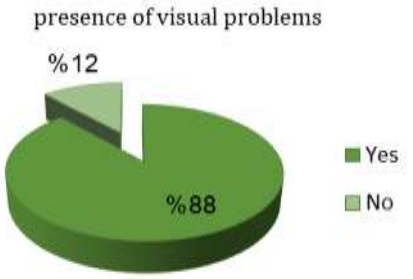

Fig.15: Presence of Visual Problems.

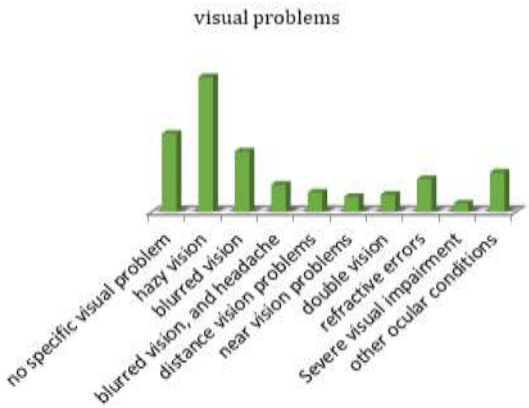

Fig.16: Visual Problems.

The multiple response analysis shown in Table (6), and Figure (17) 72.8% of cases experienced the most often reported symptom, Trouble Seeing Far Objects, followed by Frequent Headaches, seen in 68.6% of participants. Common too was trouble seeing nearby objects, noted by 57.7% of cases. Additional signs included 29.1% of recurrent eye rubbing or itching, 22.3% of learning or attention challenges at school, and 14.9% of head tilting or closing one eye while reading. Only (3.5%) of participants reported less frequent symptoms of drooping eyelid/squint. Participants' capacity to pick more than one symptom led the overall proportion of cases to go above (100%). The findings generally show that among the sample under study, especially those linked to distance vision and migraines, visual-related symptoms are rather prevalent.

Table 6: Prevalence of Visual Symptoms Based on Multiple Response Analysis:

Symptoms	no.	%
Difficulty seeing distant	313	27.1
Difficulty seeing near objects	248	21.5
frequent eye rubbing or itching	125	10.8
head titling/closing one eye while reading	64	5.5
Learning or attention difficulties at school	96	8.3
frequent headaches	295	25.5
drooping eyelid/squint	15	1.3
Total	447	100

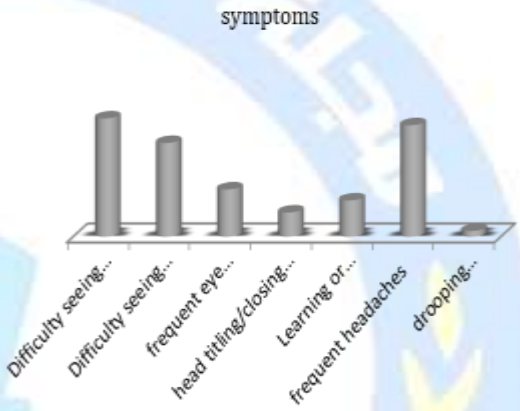

Fig.17: Distribution of participants in line to the symptoms

The Table (7), and figures (18), and Figure (19) show that the majority of participants (95.8%) reported no previous family history of eye diseases. Only a small proportion of the sample reported a positive family history, mainly related to genetic eye conditions, with low percent of responses. Glaucoma was reported by only one participant (0.2%). Overall, the findings indicate that a family history of eye diseases was uncommon among the studied sample.

Table 7: Distribution of children according to previous family eye diseases:

Response		Genetic	Glaucoma	No Specific Disease	Total
Yes	No.	9	1	9	19
	%	2.0	0.22	2.0	4.22
No	No.	-	-	-	428
	%	-	-	-	95.8
Total	No.	-	-	-	447
	%	-	-	-	100

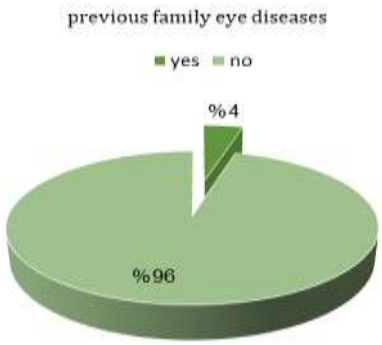

Fig.18: Previous family eye diseases.

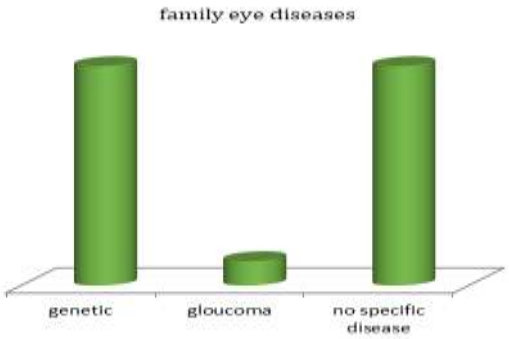

Fig.19: Family Eye Diseases.

The Table (8), and Figure (20) show the participants' responses regarding whether the child had previously been unable or unwilling to wear glasses. The majority of children (98%) did not experience any difficulty, while only a small proportion (2%) had previously been unable or unwilling to put on glasses to put on glasses. These results indicate that non-compliance with wearing glasses was uncommon among the studied sample.

Table 8: Previous Inability or Unwillingness of the child to wear glasses:

Response	no.	%
Yes	9	2.0
No	438	98
Total	447	100

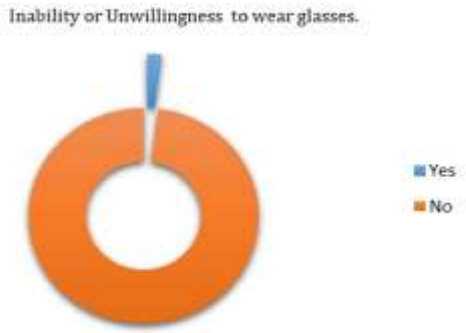

Fig.20: Previous Inability or Unwillingness of the child to wear glasses.

Section three: The Clinical Examination:

(A): Visual Acuity Evaluation:

The results of the visual acuity test are presented in the Table (9). The Mean visual acuity for the Right Eye was (0.49) with (SD = 0.464), with scores ranging from 0 to 3. For the Left Eye, the Mean visual acuity was slightly lower at (0.44) with (SD = 0.267), ratings additionally starting from zero to 3. These findings indicate that, on average, visual acuity was similar between both eyes, although the variability was higher in the right eye in compared to the left eye.

Table 9: Visual Acuity Test.

Acuity test	Mean	S.D	Minimum	maximum
Right	0.49	0.464	0	3
Left	0.44	0.267	0	3

The Table (10) presents the results of vision correction. The Mean correction for the Right Eye was (0.70) with (SD = 0.16), ranging from 0 to 1, while the Left Eye had a Mean of (0.73) with (SD = 0.30), with a range from 0 to 6. These results indicate that, on average, the degree of correction was slightly higher in the left eye, and there was greater variability in the left eye compared to the right eye.

Table 10: Visual Acuity with correction:

Correction	Mean	S.D	Minimum	Maximum
Right	0.70	0.16	0	1
Left	0.73	0.30	0	6

The Table (11), and Figure (21) show the presence of a difference of more than two lines between the right and left eyes on the Snellen chart. The majority of participants (71.6%) exhibited a difference greater than two lines, while (28.4%) did not show such a difference. These results indicate that interocular differences in visual acuity were common among the studied sample.

Table 11: Difference of More than two lines between two eyes on the Snellen chart:

Response	No.	%
Yes	320	71.6
No	127	28.4
Total	447	100

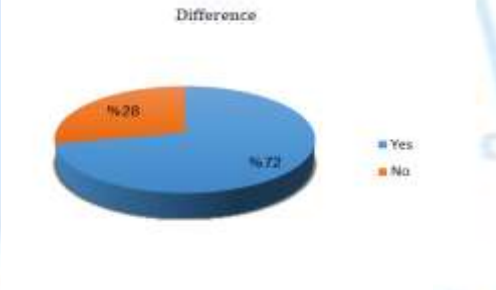

Fig.21: Difference of More than two lines between two eyes on the Snellen chart.

B) instrumental Examinations:

The Table (12), Figure (22) present the use of the Autorefractor among the children and the corresponding Mean and Standard Deviation of refractive parameters for both eyes. The vast majority of participants (99.1%) underwent Autorefractor measurement, while only (0.9%) did not. For the right eye (OD), the Mean axis was (2.98 ± 112.9), the Mean sphere (1.71 ± 3.2), and the Mean cylinder (0.99 ± 1.34). For the left eye (OS), the Mean axis was (3.0 ± 63.7), the Mean sphere (2.4 ± 3.5), and the mean cylinder (3.0 ± 58.2). These results indicate that almost all participants were assessed using the Autorefractor, providing reliable measurements for both eyes.

Table 12: Use of Autorefractor and Mean ± of Refraction Parameters (OD, and OS):

Response	No.	%	Mean ± S.D						
			OD Axi	OD Sph	OD Cyl	OS Axi	OS Sph	OS Cyl	OD Axi
Yes	443	99.1	2.98 ± 3.2	1.71±1.34	99.0±63.7	3.0±3.5	2.4±8.8	112.9±58.2	2.98 ± 3.2
No	4	0.9	-	-	-	-	-	-	-

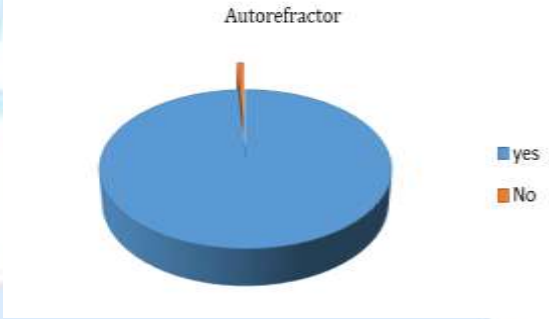

Fig.22: Use of Autorefractor.

From Table (13), and Figure (23), it seems that, only a small proportion of children (0.9%) underwent retinoscopy, while the majority (99.1%) did not. For those assessed, the mean values for the right eye (OD) were: axis (0.01 ± 0.88), sphere (0.004 ± 0.21), and cylinder (0.39 ± 0.07). For the left eye (OS), the Mean values were: axis (0.01 ± 5.98), sphere (0.007 ± 0.23), and cylinder (0.88 ± 11.3).

Table 13: Frequency of Retinoscopy Performance and Mean ± S.D of Refraction Parameters (OD, and OS):

Re	no.	%	Mean ± S.D					
			OD axi	OD sph	OD cyl	OS axi	OS sph	OS cyl
yes	17	99.1	0.01±0.21	0.004±0.07	0.39±5.98	0.01±0.23	0.007±0.09	0.88±11.3
No	430	0.9	-	-	-	-	-	-

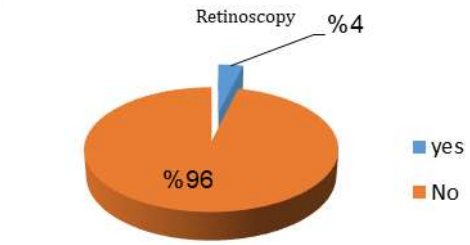

Fig.23: Retinoscopy Performed.

The Table (14), Figure (24) present the performance of Cycloplegic Refraction among the children. Cycloplegic refraction was performed in (24.2%) of the sample, while it was not performed in (75.8%). Among those who underwent Cycloplegic Refraction, the Mean refractive values for the right eye (OD) were (0.87 ± 2.11) for axis, (0.37 ± 0.93) for sphere, and (23.27 ± 54.31) for cylinder. For the left eye (OS), the corresponding Mean values were (0.89 ± 2.16), (0.40 ± 0.97), and (25.23 ± 55.68), respectively. Overall, Cycloplegic Refraction was performed in approximately one quarter of the study sample, with similar refractive measurements between both eyes.

Table 14: Frequency of Cycloplegic Refraction Performance and Mean ± of Refraction Parameters (OD, and OS):

Response	no.	%	Mean ± S.D					
			OD axi	OD sph	OD cyl	OS axi	OS sph	OS cyl
yes	108	24.2	0.87±2.11	0.37±0.93	23.27±54.31	0.89±2.16	0.40±0.97	25.23±55.68
No	339	75.8	-	-	-	-	-	-

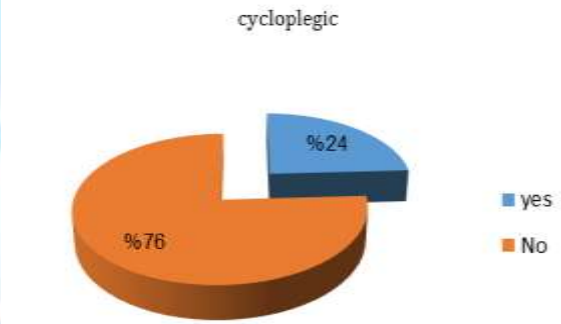

Fig.24: Frequency of Cycloplegic Refraction Performance.

The table (15), Figure (25), and Figure (26) summary Slit Lamp Examination findings among the children. In (6.94%) abnormal Slit Lamp were observed in children, while no abnormal findings were showed in majority of participants (93.06%). The most common abnormality was Dry Eye, reported in (3.6%). Other findings were infrequent an included Eyelid and Conjunctival Conditions, Atrophy (Optic/Ocular), Pupil abnormalities, Corneal Diseases (0.9%,0.4%,0.4%,0.22%). Overall, slit lamp examination results were predominantly normal, with a low prevalence of anterior segment abnormalities.

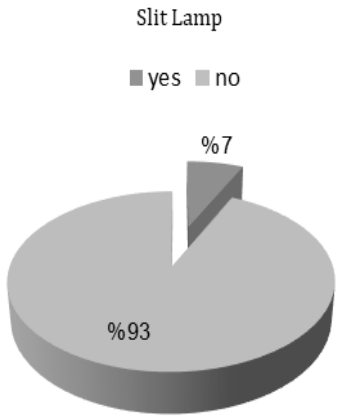

Fig.25: Slit Lamp Examination.

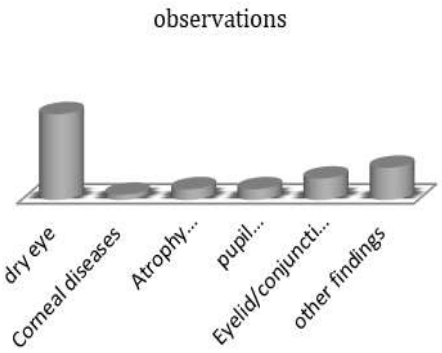

Fig.26: Observations of abnormal Slit Lamp.

C) Examination Conclusion:

The Table (16), and Figure (27). Based on several response analysis, whereby individuals were free to list more than one diagnosis. The most often mentioned diagnosis was myopia, or nearsightedness (35.9%), then astigmatism (28.2%), and Hyperopia, or farsightedness (22.7%).Less frequent diagnoses were amblyopia (lazy eye) at 7.6% and strabismus (squint) at 4.6%; just a very tiny fraction of cases revealed no significant refractive error (0.6%) or other disorders (0.4%).Generally speaking, the data suggest that among the sample under study refractive errors were the most often reported disorders.

Table 16: Most Probable Diagnosis (multiple responses analysis):

Diagnosis	no.	%
Myopia (Nearsightedness)	242	35.9
Hyperopia (Farsightedness)	153	22.7
Astigmatism	190	28.2
Amblyopia (Lazy Eye)	51	7.6
Strabismus (Squint)	31	4.6
No significant refractive error	4	0.6
Other	3	0.4

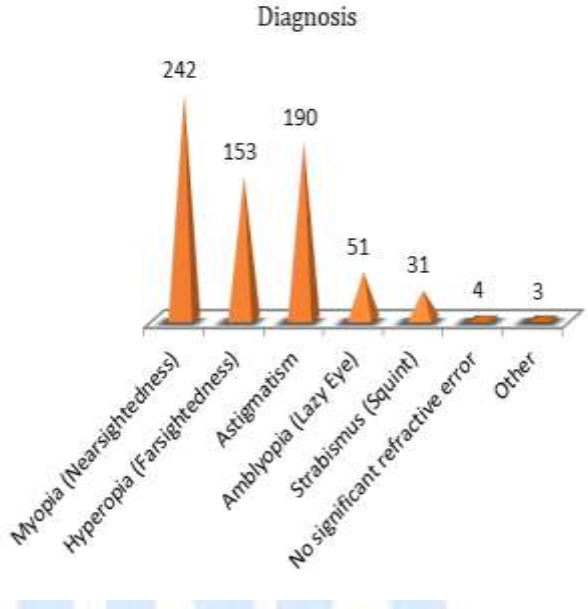

Fig.27: Most Probable Diagnosis.

Table 15: Slit Lamp Examination:

Response		Dry Eye	Corneal Diseases	Atrophy (Optic/Ocular)	Pupil Abnormalities	Eyelid/Conjunctival Conditions	Other Findings	Total
Yes	No.	16	1	2	2	4	6	31
	%	3.6	0.22	0.4	0.4	0.9	1.4	6.94
No	No.	-	-	-	-	-	-	416
	%	-	-	-	-	-	-	93.06
Total	No.	-	-	-	-	-	-	447
	%	-	-	-	-	-	-	100

The Table (17), and Figure (28) present data on whether the child was prescribed or advised to wear glasses. The majority of participants (94.6%) received a Prescription or Advice for glasses, while only a small proportion (5.4%) did not. Among those prescribed or advised, the Mean refractive values for the right eye (OD) were: axis (2.10 ± 2.35), sphere (1.11 ± 1.22), and cylinder (80.58 ± 70.94). For the left eye (OS), the Mean values were: axis (2.44 ± 4.55), sphere (1.31 ± 4.37), and cylinder (91.37 ± 71.37

Table 17: Prescription of glasses for the Child:

Response	no.	%	Mean ± S.D					
			OD axi	OD sph	OD cyl	OS axi	OS sph	OS cyl
yes	423	94.6	2.10±2.35	1.11±1.22	80.58±70.94	2.44±4.55	1.31±4.37	91.37±71.37
No	24	5.4	-	-	-	-	-	-

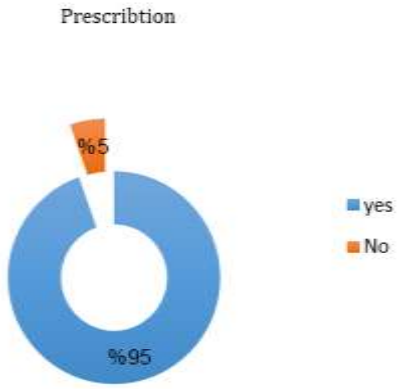

Fig. 28: Prescription of glasses for the Child

Section Four: Screening Practices and Barriers:

Table (18), and Figure (29) Multiple response analysis will help you to show the equipment availability at the screening locations, therefore enabling more than one item every site. The most often available tool was the Snellen Chart (28.0%), then the Autorefractor (27.8%), then the Slit Lamp (23.3%) and Cycloplegic Drops (19.4%). Retinoscope (1.2%), Direct Ophthalmoscope/Fundus Examination (0.1%), and other unknown tools (0.1%) were among less often available instruments. While more specialized equipment was scarce at the screening sites, these findings suggest that fundamental visual acuity and refractive evaluation methods were often accessible.

Table 18: Responses analysis:

Equipment	no.	%
Snellen Chart	447	28
Autorefractor	443	27.8
Retinoscope	19	1.2
Cycloplegic Drops	310	19.4
Slit Lamp	372	23.3
Direct Ophthalmoscope/Fundus Examination	2	0.1
other	1	0.1

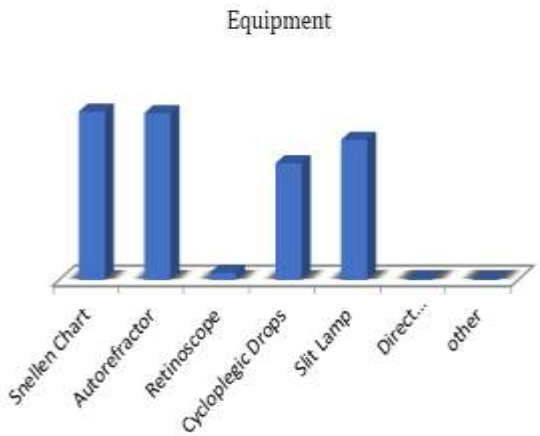

Fig.29: Available Equipment at the Screening Site.

Table (19), and Figure (30) explained the majority of children (86.8%) underwent Annual vision screenings, while (8.7%) were screened only at School. A smaller proportion of children were screened when visual complaints arise (2.9%) or under other unspecified circumstances (1.6%). These results indicate that annual vision screening is the standard practice at the facility.

Table 19: Children's vision screening frequency:

Vision Screening	No.	%
At School Enrollment	39	8.7
Annually	388	86.8
When Complaints Arise	13	2.9
Other	7	1.6
Total	447	100

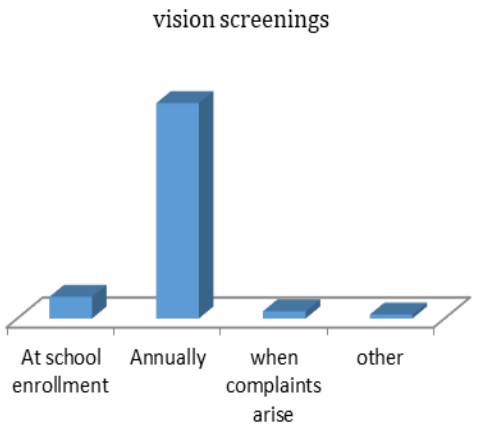

Fig.30: Children's vision screening frequency.

Table (20), and Figure (31) Based on a multiple response question, show the primary obstacles to early vision screening in the region; participants may choose more than one barrier. Limited Time in School (61.8%) was the most often cited obstacle, followed by Lack of Equipment (22.4%), and Parental Refusal or Lack of Awareness (12.2%). Less often noted obstacles were Distance or Accessibility (2.4%), Cost of Screening or Glasses (1.0%), and other considerations (0.2%). No participants mentioned Lack of Trained Staff as a hurdle. These findings imply that early eyesight screening in the region is mostly hampered by logistical limits inside schools.

Table 21: Main Barriers to Early Vision Screening in the Area (multiple responses analysis):

Main Barriers	no.	%
Lack of equipment	110	22,4
Lack of trained staff	0	0
Parental refusal/Lack of awareness	60	12.2
Cost of screening/glasses	5	1.0
distance/Accessibility	12	2.4
limited time is school	304	61.8
other	1	2

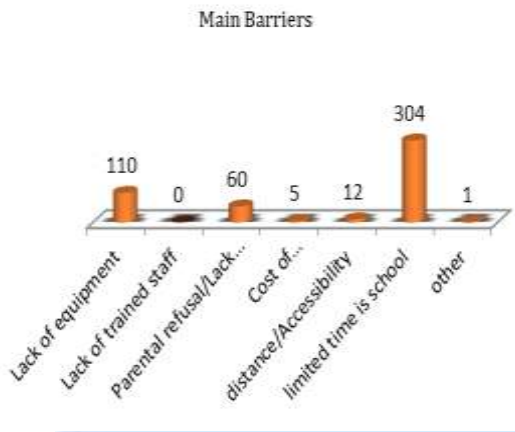

Fig.31: Main Barriers to Early Vision Screening in the Area

Section Five: Knowledge and Attitudes:

Table (21), and Figure (32) present that, all participants Strongly Agreed with the that early detection of refractive errors in children improves learning. While none of them choose any of the other responses options. As indicates a unanimous recognition among the respondents of the importance of early refractive error detection for enhancing children's educational outcomes.

Table 21: Early Detection or Refractive Errors:

Agreement Level	No.	%
Strongly Disagree	-	-
Disagree	-	-
Natural	-	-
Agree	-	-
Strongly Agree	447	100
Total	447	100

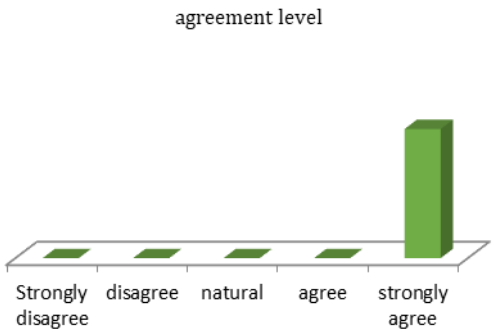

Fig. 32: Agreement level

From Table (22), and figure (33), Figure (34), (99.1%) of participants reported school screening programs are not sufficient, with the main reported barriers being lack of time in school (54.1%) and medical negligence to provide required medical equipment (26.4%).

Table 22: Evaluation of School Program Sufficiency:

Response		Lack Of Time Is School	Failure To Provide Required Medical Equipment	Unspecified/Other	Total
Yes	no.	-	-	-	4
	%	-	-	-	0.9
No	no.	242	118	83	443
	%	54.1	26.4	19.5	99.1
Total	no.	-	-	-	447
	%	-	-	-	100

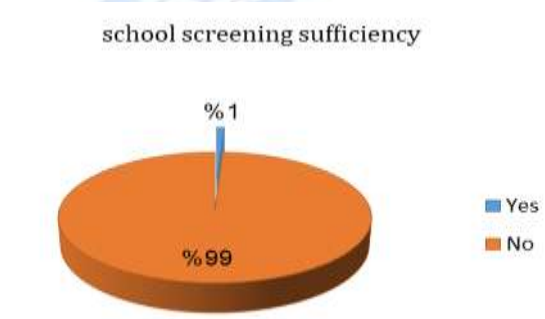

Fig.33: Evaluation of School Program Sufficiency.

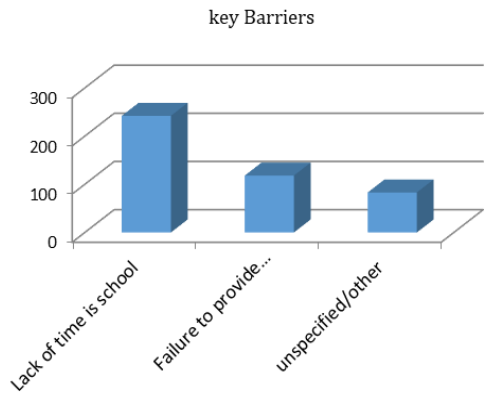

Fig. 34: Barriers to Implementing School Screening Programs.

Section Six: Treatment:

Table (23), and Figure (35), Participants were having freedom to choose more than one treatment option, therefore a multiple response analysis helps to show the distribution of treatment alternatives. As a result, the overall number of answers is more than the actual sample size. This helps to explain why the sum of frequencies is more than the number of people who took part in the study. With management mostly consisting of glasses and contact lenses reflecting the great incidence of refractive errors among the sample under study, the results reveal that therapy for Myopia was the most often reported (36.3%). After this, 29.2% of people were treated for Astigmatism, which was treated only with glasses, which shows that we still rely on glasses to fix this problem. Twenty-two-point three percent of recorded treatments involved hyperopia, which was also treated with glasses and contact lenses. Less often noted therapies included those for lazy eye (7.2%), in which glasses and occlusion therapy were used in addition to glasses, and Squint (5.0%), which was mostly treated with glasses. Generally, the findings show that spectacle correction is still the most common treatment for most visual problems found; more complex therapies were noted less often, with or without contact lenses.

Table 23: Treatment (Multiple response analysis):

Treatment	no.	%
Suquint → glasses	33	5
Lazy Eye → cover un cover test and glasses	48	7.2
Myopia → glasses and contact lenses	241	36.3
Hyperopia → glasses and contact lenses	148	22.3
Astigmatism → Treatment (only glasses)	194	29.2

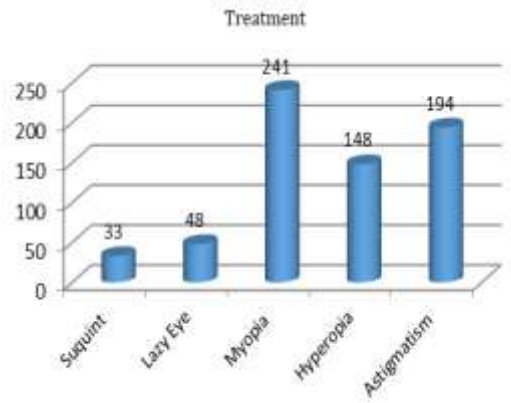

Fig.35: Treatment.

Section Seven: Recommendations and suggestions:

Table (24) participants were permit to pick many options; as shows the recommendations and advice found by them. The total number of answers therefore surpasses the sample size, and the percentages represent the proportion of whole responses rather than particular participants. Emphasizing the supposed need for greater public awareness of early vision screening and eye health, the most often recommended advice was raising awareness campaigns (28.2%). Supporting low-income families (25.5%) and training healthcare workers (25.2%) followed this quickly, therefore emphasizing worries regarding both service access and staff capacity. Many people also advised modern screening equipment (21.2%), therefore showing knowledge of the need of current technology in boosting screening accuracy and efficiency. Participants see awareness, social support, professional education, and technical resources as supplementary techniques vital for enhancing school-based vision screening programs.

Table 24: Recommendations and suggestions (Multiple Response analysis):

Suggestion	no.	%
Increase awareness campaigns	446	28.2
provide modern screening equipment	335	21.2
train healthcare staff	398	25.2
support how-income families	403	25.5

V. DISCUSSIONS

Uncorrected refractive errors are the main cause of moderate and severe visual impairment and account for 43% of the world's causes of visual impairment "(Nzuki, 2004). This study aimed to diagnosis of refractive errors among children attending health care facilities in Benghazi. Regarding demographic data, female participants exhibit higher proportion (61.7%) than male (38.3%) reflect more female children seeking hospitals for diagnosis and treatment at the time of study, it could be due differences in health-seeking behavior, parental awareness, or sociocultural factors may have contributes to higher female children presentation at hospitals setting. While in contrast at sub-Saharan countries study males (61.6%) participants were more than females (38.4%) (Saleh & Gaffer, 2023).

Also, predominantly the majority of participants in the study were Libyan nationality, as the study was done in Benghazi Libya. Higher incidence of visual impairment was noted in age group [9–11] years (31.1%), followed by [12–14] years (30.4%), and [15–16] years group (20.8%), the reason may due increase academic, higher work and teaching demands. While near to this result highest incident reported among age group between 6 to 10 years and age group 11 – 16 years (Saleh & Gaffer, 2023).

The study exhibits higher prevalence of visual impairment among children (88.3%), as at list with one visual impairment, and obviously hospital-based sample is not equal to a community-based sample. WHO in same context (WHO, 2019). Also, higher than Malaysian study (10.1%) (Gilbert & Foster, 2001), and a Chilean report (14.7%), (Maul, *et al.*, 2000) and South African study (1.2%), (Naidoo *et al.*, 2003). This desperation in prevalence of visual impairments between studies may related to difference in environmental, socioeconomic factors, and health care seeking.

The prevalent diagnosis among children was myopia (Nearsightedness) (35.9%), which could be related to pushy near vision tasks, and higher screen time. This finding is compatible with study as were myopia taken as the most common diagnosis among children by (Shah & Satani, 2023). In contrast Ethiopian study illustrate surface eyelid infections ocular allergies were common diagnosis among children attending Jimma University Hospital. (Demissie & Demissie, 2014). While Salman noted Allergic conjunctivitis as the most prevalent disease in his study (salman, 2010). Second diagnosis in this study was hyperopia (22.7%), in contrary to this expectation hyperopia exhibit only (3.25%), (Pi LH, *et al.*, 2012). This variation as result of contrast in diagnostic criteria, distribution of age in the study, and cycloplegic refraction use.

The prevalence of strabismus (squint) was (4.6%), near to the result of Chinese study (4.9%), and on the other hand of squint was (12%) in study conducted in Iraqi (Hnoosh, 2014) (1.6%) Kathmandu (Hornby *et al.*, 2002; Nepal *et al.*, 2003).

Difficulty seeing distant (27.1%), frequent headaches (25.5%), and difficulty seeing near objects (21.5%), were the most complain from participants. (4.2%) children had family history with eye disease. (98%) of children experience any difficulty wearing glasses, while only (2%) had. Furthermore, differences in visual acuity had been noticed between the right and left eyes are consistent with findings from clinical studies emphasizing the importance of monocular visual assessment in children (AAO, 2022), this reflects the need of early detection and diagnosis to avoid long term visual impairment, also this emphasizes the monocular eye assessment as visual impairment(unilateral) could remain undiscovered without single eye assessment.

Furthermore, (86.8%) underwent annual vision screenings, while (8.7%) were screened only at School, where the most frequent tools used among children Snellen Chart (28.0%), was also used Autorefractor, Slit Lamp, retinoscopy, Cycloplegic refraction. Which reflect the accessibility in routine clinical eye setting contribute to correct diagnosis, and comprehensive evaluation. Also, Gilbert and Foster and Resnikoff *et al.*, highlighting the use of different diagnostic methods and examination for eyes diseases lead to improve detection, reduce risk of misdiagnosis (Gilbert & Foster, 2001; Resnikoff *et al.*, 2004).

The study showed (94.6%) of children took a prescription or advice for glasses. Also, history of eye diseases was uncommon among children and glaucoma was the only diseased missioned, in visual acuity test was found interocular differences in children examined. In context of a study from Saudia Arabia described refractive errors as the main cause of visual impairment among school-aged children with high proportion of children treated with glasses (Alrasheed *et al.*, 2017).

The This study has some limitations that. First, design based only on hospital make it lose the generalizability to the general pediatric population, as attending hospitals are more likely due to visual complaints compared to those attend community. Further, disparity in diagnostic devices and examination methods may affect comparability with other studies.

Despite these, this study highlighted the afflict of refractive errors for children at Benghazi city, focusses on the need of regular eye screening, early detection, prompt intervention, and the awareness of the impact of long-term refractive errors of children general and educational life.

CONCLUSIONS

Uncorrected refractive errors such as myopia, astigmatism, and hyperopia were common, as the main cause of visual impairments among school-aged children in Benghazi. Discovered with multiple diagnostic methods. The majority of these children required optical correction. However, school vision screening programs were considered insufficient due to limitations in time and resources. These findings

highlight the need for early detection, improving screening programs, provide approachable treatments of visual problems for children and increasing parental awareness regarding long term refractive errors.

RECOMMENDATIONS

1. Routine screening for children at school, and allocated enough time to ensure each child get screening.
2. Give low-income families inexpensive or free eye exams and corrective tools.
3. Emphasize in providing corporation between health and education sectors to enhance the design, execution, and sustainability of school eyesight screening programs.
4. Increase awareness and provide eye health education for parents, and promotes the important of frequent and early eye checkup.
5. Provide modern appropriate screening and diagnostic tools.
6. Supporting and emphasize on improving training programs for eye care professional and screening staff.

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Biophysics and Consciousness: Between Determinism, Probability, and Understanding Unconscious Brain Activity

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الملخص: تستكشف هذه الورقة البحثية العلاقة المعقدة بين القوانين الفيزيائية والظواهر البيولوجية، مُدمجةً فهم نشاط الدماغ اللاواعي ضمن إطار احتمالي باستخدام التصوير بالرنين المغناطيسي الوظيفي (FMRI) والذكاء الاصطناعي (AI). يتمحور السؤال الرئيسي حول ما إذا كانت العمليات الحيوية والأنشطة العقلية تخضع لنفس الفرضيات الدقيقة التي تخضع لها المادة الجامدة، أم أن هناك فواصل نوعية وأحداثًا احتمالية تُحدد الحياة والوعي. تبدأ المناقشة بأمثلة فيزيائية دقيقة، تشمل تبديد الشحنة، والتأثير الكهروضوئي، وتوليد الأشعة السينية، مُسلطةً الضوء على أن الأحداث المجهرية النادرة يُمكن أن تُشكل أسسًا فيزيائية رئيسية. ثم تتوسع الورقة لتشمل العمليات البيولوجية، مثل نشاط البروتوبلازم، وانقسام الخلايا، والوراثة، مُؤكدةً أن الفرق الجوهري بين الأنظمة الحية وغير الحية يكمن في الفواصل والاحتمالات التي تسمح بظهور سلوكيات جديدة لا يُمكن اختزالها إلى قوانين متصلة فقط. علاوة على ذلك، يُظهر نشاط الدماغ اللاواعي خصائص احتمالية مماثلة، يمكن تحليلها والتنبؤ بها باستخدام التصوير بالرنين المغناطيسي الوظيفي ونماذج الذكاء الاصطناعي (Demertzi *et al.*, 2011; Laureys *et al.*, 2004).

الكلمات المفتاحية: الفيزياء الحيوية - الحتمية - الاحتمالية - الانقطاعات - أصل الحياة - الديناميكا الحرارية - الإرادة الحرة - المادة غير الحية - العقل اللاواعي - التصوير بالرنين المغناطيسي الوظيفي - الذكاء الاصطناعي.

Abstract: This paper explores the complex relationship between physical laws and biological phenomena, integrating the understanding of unconscious brain activity within a probabilistic framework using functional Magnetic Resonance Imaging (FMRI) and Artificial Intelligence (AI). The central question is whether living processes and mental activities are governed by the same precise hypotheses as inanimate matter, or if there exist qualitative discontinuities and probabilistic events that define life and consciousness. The discussion begins with precise physical examples, including charge dissipation, the photoelectric effect, and X-ray generation, highlighting that rare microscopic events can constitute major physical foundations. The paper then extends to biological processes, such as protoplasmic activity, cellular division, and inheritance, emphasizing that the critical difference between living and non-living systems lies in discontinuities and probabilities that allow the emergence of new behaviors not reducible to continuous laws alone. Furthermore, unconscious brain activity exhibits similar probabilistic characteristics, which can be analyzed and predicted using fMRI and AI models (Demertzi *et al.*, 2011; Laureys *et al.*, 2004).

Keywords: Biophysics – Determinism – Probability – Discontinuities – Origin of Life – Thermodynamics – Free Will – Non-living Matter – Unconscious Mind – Functional MRI – Artificial Intelligence.

I. INTRODUCTION

Since the emergence of modern physics, scientific laws have relied on determinism: knowing a system's initial state allows for precise prediction of its future. However, twentieth-century developments, especially in quantum theory and statistical thermodynamics, introduced probability as an intrinsic component of physics. This shift is particularly significant in studying biological

phenomena. While biological processes adhere to physical laws, they exhibit qualitative differences from inanimate matter. The central question arises: is life and consciousness a mere extension of the same laws, or do qualitative "discontinuities" exist that define living systems and mental processes? Recent research using fMRI and AI indicates that unconscious brain activity exhibits probabilistic patterns, reinforcing the importance of incorporating uncertainty and variability into our models of life and cognition (Schiff *et al*., 2007; Monti *et al.*, 2010).

II. DISCUSSIONS

Classical physics traditionally assumed that any unexpected change in the motion of objects would be regarded as a "miracle," thereby violating determinism. However, phenomena such as electrons spontaneously gaining or losing energy, or shifting their trajectories without apparent causes, reveal that probability constitutes a fundamental aspect of nature. A parallel is evident in unconscious mental processes, where unpredictable variations in brain activity emerge independently of prior brain states, as demonstrated in fMRI studies of emotional and cognitive responses (Demertzi *et al.*, 2011; Monti *et al*., 2010). Rare occurrences, whether in physics or neuroscience, often serve as foundational: the sparse presence of ions in the air, the emission of electrons under light, or the rare formation of X-rays are cornerstones of modern physics, just as rare unconscious neural events—such as spontaneous creative insights or unexpected emotional reactions—prove pivotal for higher-order mental functions.

These neural phenomena can now be quantified and analyzed through AI-based pattern recognition applied to fMRI data (Laureys et al., 2004; Owen *et al.*, 2006). Likewise, the notion of discontinuity is central to both biology and cognition. Cellular division, inheritance, and voluntary behavior are not merely predictable from prior states but instead follow multiple probabilistic pathways.
Unconscious neural activation in specific regions may thus generate cognitive or behavioral discontinuities that lead to unforeseen outcomes, which cannot be accounted for solely by sensory inputs (Demertzi *et al.*, 2011; Monti *et al*., 2010; Schiff *et al.*, 2007).

This understanding extends to questions of free will and intentionality, where voluntary actions and decisions transcend purely physical or biochemical chains of causation. Even though neural signaling can be traced, the spontaneity of thought and intention remains irreducible. Incorporating probabilistic frameworks with the study of unconscious brain activity through fMRI and AI enables a deeper capacity to model and anticipate these emergent processes (Laureys *et al.*, 2004; Monti *et al*., 2010).

Modern physics, from thermodynamics to quantum theory, confirms that probability is not a temporary approximation but a structurally fundamental principle. In the same way, biological mechanisms and unconscious mental dynamics can be interpreted as organized probabilistic outcomes shaped by both Internal physico-chemical states and external influences. Within this probabilistic paradigm, certain cognitive and psychological phenomena—such as psychophysiological healing—may plausibly exert influence on biological pathways (Laureys *et al.*, 2004; Monti *et al*., 2010; Schiff *et al.*, 2007).

CONCLUSIONS

Life and consciousness are not violations of physical laws but rather manifestations of inherent probabilistic properties and discontinuities. The fundamental distinction between living and non-living systems lies in structural arrangements and probabilistic patterns that enable the emergence of novel behaviors and distinct mental processes. Thus, incorporating probability into biophysics and the analysis of unconscious brain activity is essential for understanding cognition, inheritance, and cellular division. In contrast, excessive materialist reductionism may overlook genuine possibilities already

recognized by modern physics and neuroscience. Studying life and consciousness from a physical perspective cannot rely solely on classical determinism, since biological and mental phenomena are characterized by discontinuities and probabilistic behaviors that set them apart from non-living matter.

Therefore, integrating probabilistic frameworks and philosophical considerations, together with analyzing unconscious brain activity through functional MRI and artificial intelligence, is crucial for grasping the essence of life, will, and cognition. Life and consciousness are not mere "exceptions" to physical laws but extensions of these laws at higher levels of complexity, where physics, biology, neuroscience, and philosophy converge in a unified understanding of nature.

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