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Artificial intelligence in orthopaedic surgery: A comprehensive review of current innovations and future directions

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ABSTRACT

This review explores the integration of Artificial Intelligence (AI) within orthopaedic surgery and its potential role across pre-surgical planning, intraoperative assistance, and post-surgical rehabilitation phases. By examining current applications, this review identifies challenges impeding AI's full adoption in orthopaedics such as data privacy concerns, the need for robust predictive models, and integration with existing medical systems. The review proposes potential solutions and research directions to address these challenges.

1. Introduction

The medical field is witnessing transformative changes with the adoption of artificial intelligence which brings a new era of healthcare with its advanced processing power and specialised software [1]. These technological advancements have the potential to improve diagnostic precision, enable personalised treatment plans, and streamline administrative tasks [1].

Artificial Intelligence includes a range of technologies (as shown in Fig. 1) that enable machines to mimic human abilities, analyse large data sets, and offer insights or recommendations. This field includes the use of machine learning for predictive analysis, natural language processing for interpreting and generating text and computer vision for image analysis [2]. In healthcare, these capabilities can enable faster and more accurate decision-making and improve patient care and outcomes [3]. This is especially important in specialities like orthopaedic surgery where precision is crucial [4].

Orthopaedic surgery is dedicated to addressing issues of the bones, joints, and adjacent connective tissues through invasive and non-invasive approaches. These areas are highly sensitive and demand considerable precision during medical procedures [4].

AI has the potential to improve the field of orthopaedics, a domain where surgeries are among the most frequently performed medical procedures. This prevalence underscores the broad impact that AI can have, not only in optimising surgical techniques but also in improving overall patient care on a large scale [5,6]. Additionally, the nature of these surgeries requires planning and precision [7], areas where AI excels by generating precise surgical plans, and ensure both predictability and successful surgical outcomes. From a financial perspective, AI has the potential ability to reduce long-term costs by minimising human errors, shortening hospital stays, and expediting recovery times [8]. Also, the precision of AI-assisted robotic systems in procedures that involve the placement of implants and bone alignments, directly correlates with improved surgical success rates [9]. Beyond the operating room, AI can potentially extend its benefits to post-surgical care and rehabilitation by learning from past patient data to predict and personalise recovery plans to ensure patients can return to their normal lives rapidly [10].

2. Literature review

2.1. The emergence of AI as a trend

With the introduction of ChatGPT in November 2022 (an AI chatbot able to generate text, write essays and solve complex mathematical

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problems), AI has become widely accessible to the public and quickly turned into a trend. This innovation has captured the attention of investors who are now willing to allocate funds to AI ventures. Consulting group McKinsey has reported that AI utilisation in businesses worldwide has increased from 20 % to over half in 2017 [11]. In the UK, adoption rates are even higher among larger businesses nearing 70 % according to the latest government report [11].

Industries such as financial services, technology, and telecommunications are at the forefront of incorporating AI into their strategic processes. For instance, BT recently announced that AI will replace more than 10,000 jobs by the end of the decade [11]. Additionally, Statista predicts that the global market for AI will reach almost $2 trillion by 2030 [11].

However, this adoption comes with high expectations that can be overestimated. A study by Jones-Jang and Jin Park (2023), which investigated public reactions to AI failures, suggests that people often place full confidence in AI, sometimes even more than in their own abilities [12].

2.2. AI in pre-operative planning and simulation of surgical procedures

AI in orthopaedic simulation is the application of artificial intelligence technologies to create and manage virtual environments and tools that replicate orthopaedic surgical procedures for training, skill assessment, and preoperative planning [13]. This technology can allow a detailed and interactive representation of human anatomy and surgical techniques which enable surgeons to practice and improve their skills in a risk-free setting and to visualise and assess the potential outcomes of different approaches before making decisions [14].

This adoption has demonstrated positive results as studies have shown that AI-driven simulation can lead to better-prepared surgeons and more predictable surgical outcomes [15]. A study funded by the National Institutes of Health revealed that these simulators increased training exercise pass rates from 4 % to 31 %, a significant improvement that confirms their substantial impact on medical training excellence [16].

AI in orthopaedic preoperative planning can help to enhance the precision and personalisation of surgical strategies particularly in complex procedures like total knee arthroplasty [17]. By analysing large datasets and previous surgical outcomes, AI models can generate detailed and patient-specific plans that have the potential to improve surgical efficiency and reduce the need for intraoperative adjustments [17]. A study by Lambrechts et al. (2022) demonstrated that AI planning improves outcomes by reducing manual plan corrections by 39.71 % on average and up to 47.95 % for those requiring adjustments [17]. Zhou et al. (2023) demonstrated that the implementation of 3D preoperative planning can improve the precision of orthopaedic surgeries by up to 44.7 % [18]. These results demonstrate that AI has the potential to improve preoperative planning accuracy compared to manual methods.

Integration of AI-driven simulators with existing healthcare systems and surgical equipment is essential for seamless workflow and practical utility during surgeries [19]. However, this integration faces challenges including the real-life surgical environment's complexity and the lack of validated assessment criteria for AI algorithms. A neurosurgical group at McGill University developed a machine-learning algorithm for a VR-based task. However, the notable limitation identified in their study is the challenge of correlating the assessment of surgical skills in a simulated environment with actual performance in the operating room [19].

Another challenge of AI in orthopaedic simulations is the need for high-quality/diverse datasets. Effective AI models in this field require not only large datasets but also a dataset that truly represents the varied patient demographics encountered in orthopaedics to ensure the models are accurate, reliable, and unbiased [20].

Integrating AI into preoperative planning for orthopaedics also may face challenges such as aligning AI predictions with individual surgeon preferences and improving the accuracy of implant size forecasts [18].

Future advancements in orthopaedic simulation could utilise 3D printing technologies to integrate patient-specific data and create models that accurately reflect each patient's unique anatomical and pathological features. This method would potentially improve surgical precision and lead to better outcomes, such as quicker bone healing, less pain, and more effective rehabilitation [21]. Personalised 3D-printed models and tools would allow surgeons to adapt their techniques to the specific requirements of each patient, which may result in more efficient surgeries with less blood loss and shorter operation times [21]. This customisation could benefit medical education by offering tailored models for training and learning [21].

Additionally, future work can focus on leveraging extended reality (XR) technologies such as augmented reality (AR) and mixed reality (MR). A notable example is the Department of Orthopaedic Surgery at Massachusetts General Hospital, which is incorporating the PrecisionOS virtual reality (VR) system into its training for medical students and residents [22]. This reflects a wider trend in medical education towards adopting extended reality technologies. Similarly, the U.S. Army Medical Research and Development Command is using AR for training simulations, employing tools like the PerSim VR system and the AUGMED extended reality training tool, which provide realistic medical intervention scenarios [23]. The AR and VR market in healthcare is anticipated to grow with an expected compound annual growth rate of 22.5 % from 2023 to 2027 [22].

Future work in the field of AI in preoperative planning in orthopaedics could explore the incorporation of online learning models to enhance the adaptability and precision of surgical plans over time [18]. This approach would allow AI systems to evolve with surgical techniques and patient-specific considerations. Another promising direction involves leveraging comprehensive 3D bone models through advanced machine learning techniques, such as graph convolutional neural networks to automate the extraction of clinical features and improve the customisation of surgical plans [18].

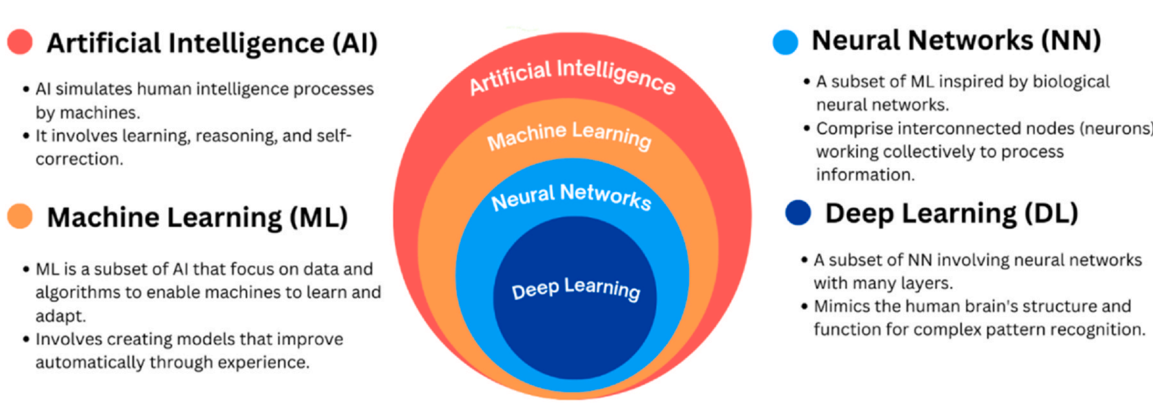

Fig. 1. Visualising the Relationships Between AI, ML, DL, and NN.

2.3. AI in surgical guidance

The integration of AI into the surgical field particularly in orthopaedics has marked the beginning of a revolutionary era by improving surgical precision [24].

AI-powered tools including robots are leading this change by offering a helping hand during surgeries and guiding surgeons in real time to ensure accuracy. In surgeries where joints are replaced, these systems help by optimising component position and have shown remarkable potential in orthopaedic surgical procedures [24]. The Mako Robotic-Arm Assisted Technology, for example, is a surgical assistance system developed by Stryker designed to assist orthopaedic surgeons in performing precise and minimally invasive knee and hip replacements [25]. It uses a robotic arm which operates with specialised software that processes 3D imaging data. This software is integral to the system's function and enables personalised pre-operative planning by constructing a detailed 3D model of the patient's anatomy from Computed Tomography (CT) scans [25]. During surgery, the system provides real-time feedback to the surgeon and ensures that the procedure adheres closely to the surgical plan. A study conducted by Nam et al. (2022) demonstrated that the MAKO robot-assisted system improved the accuracy of knee surgery by 32.14 % compared to traditional methods and resulted in better alignment of the knee components [26]. Another study by Seidenstein et al. (2021) showed that a new robotic system for knee surgery was more precise in achieving the correct knee alignment compared to traditional tools, as the robotic group hit the target alignment in 100 % of cases within a 3° range, and 93 % within a 2° range, while the traditional group only managed 75 % and 60 % respectively [27].

While AI-powered tools and robotic systems have marked a transformative change in orthopaedic surgeries, there are existing limitations and challenges that need addressing. The high cost of implementation and maintenance of such advanced technologies is a challenge as they limit access to well-funded medical institutions and potentially widen the healthcare access gap. According to the His-replacement.info website (2023), the Mako robot itself is priced at $1.25 million with an annual $100,000 service contract and $1000 in disposable equipment per case, the implant is estimated at $5500 and the optional addition of X-ray technology with an initial cost of $75,000 and an annual service contract of $50,000. The total cost is around $3 million for setup and an additional $1 million annually for maintenance and service [28].

This high implementation cost may deepen existing inequalities in healthcare access. Small rural hospitals and less-funded healthcare institutions often cannot afford these technologies given that they are already struggling to stay financially viable [29]. This discrepancy may keep AI tools primarily accessible to patients in affluent areas, thereby potentially widening the gap between well-resourced and under-resourced hospitals [29].

Research by the Nuffield Trust (2020) shows that England's rural hospital trusts face financial difficulties, with 25 % of the £ 1 billion shortfall across NHS organisations attributable to the six smallest and most remote hospital trusts [30]. Similarly, in the United States, over 450 rural hospitals are at risk of closure due to financial instability, as reported by the Chartis Center for Rural Health in 2020 [31].

Globally, the disparity is even more pronounced, as wealthy first-world nations have greater access to AI technologies compared to their less affluent counterparts [32]. Consequently, patients in developed countries may benefit from improved medical outcomes through AI, while those in poorer regions will remain at a disadvantage which further amplify global health inequalities [32]. According to the Commonwealth Fund's 2022 report, wealthy nations can prioritise healthcare in their budgets due to well-established health insurance systems that offer broad coverage and access to diverse medical services. In contrast, low-income countries struggle to allocate sufficient funds to healthcare due to limited tax revenues and competing financial demands which impacts their ability to provide comprehensive healthcare services [33]. For example, in high-income OECD countries, the average health expenditure can be as high as USD 6651 annually per capita, whereas in some of the poorest parts of the world, healthcare spending can be less than USD 50 per person per year [33].

Addressing these inequities requires deliberate policies and initiatives that ensure AI technologies are accessible to all healthcare institutions, regardless of their financial status. This can include funding support for under-resourced hospitals and international aid for low-income countries to adopt and implement AI tools [34]. Without such measures, the AI revolution in healthcare risks widening the existing gaps between the "haves" and the "have-nots" both within and between countries.

Another challenge is that robotic systems follow preplanned trajectories based on CT-based preoperative plans. As seen in total knee arthroplasty (TKA), this approach ensures precision and safety but also presents limitations in terms of intraoperative flexibility [35]. The preprogrammed path of the robot may restrict the surgeon's capacity to make on-the-fly adjustments during the procedure and this is particularly challenging when encountering unforeseen anatomical variations or complications [35]. Consequently, this could affect the surgeon's ability to customise the surgery to each patient's unique requirements, especially in complex or non-standard cases where deviating from the initial plan may be advantageous [35].

Another notable challenge is establishing trust in robotics within orthopaedics, as in many other healthcare fields. For example, in the field of dental health, a study revealed that about one-third of dental patients are hesitant to trust a robot with routine procedures like tooth cleaning and this apprehension increases significantly with more complex procedures, such as root canal treatments where two-thirds of patients express hesitation [36]. Moreover, research by Torrent-Sellens et al. (2021) indicates that only around 11 % of individuals in the UK are comfortable with the idea of receiving medical advice from robots [37]. This statistic highlights a substantial lack of confidence in robotic assistance in healthcare and demonstrates the need for further efforts to build trust and acceptance among patients [37].

Future work in the field is to adopt augmented reality (AR) which represents a promising avenue for AI-powered surgical guidance as it offers real-time data visualisation and enhances the surgeon’s awareness. Studies have demonstrated that AR can improve accuracy in surgical navigation and reduce surgical time [38]. A study by Elmi-Terander et al. (2019) demonstrated that using augmented reality (AR) technology in surgery resulted in high accuracy for screw placement. Specifically, 98 % of the over 200 screws placed were classified within the top two categories of the grading system [39]. Additionally, a study in a comparative analysis of augmented reality (AR) versus conventional techniques in spinal surgery demonstrated an improvement in screw placement accuracy with the use of AR, particularly for novice surgeons, the implementation of AR technology resulted in a reduction in procedural errors from approximately 7 % to 2 % [40].

To effectively adopt AR technologies in surgery, it is needed to address issues related to the accuracy of image overlay, user interface design, and the potential for information overload [41]. To address these challenges, investment in advanced imaging technologies and smarter algorithms is necessary for seamless integration. Equally important is the design of the user interface, which must be intuitive to minimise the cognitive burden on surgeons. Moreover, to prevent information overload, which can cause confusion and delay, the implementation of customisable AR displays would be beneficial [42]. These displays can enable surgeons to access the most pertinent information at the right time during surgery [42].

2.4. AI in rehabilitation

Orthopaedic rehabilitation is a therapeutic approach that helps patients recover from musculoskeletal injuries or surgeries. It involves a series of treatments and exercises designed to restore strength, mobility, and function while managing pain and preventing disability. This process is important for patients to regain their ability to perform daily activities and return to their daily routines [43].

AI systems have become useful in post-surgical rehabilitation as they can offer precise and actionable information that helps in tracking patient recovery [43]. For example, wearable sensors and computer vision are revolutionising how rehabilitation is monitored which offers objective insights into the patient's functional capabilities and adherence to prescribed exercises [44].

However, the accuracy of these tools relies on the quality of the sensors and algorithms used, sometimes missing the mark in capturing the full range of motion or misinterpreting activities can lead to potential inaccuracies [45]. For example, Wearable fitness trackers like Fitbits aim to detect early signs of COVID-19 by monitoring spikes in heart rate and temperature. However, these symptoms are not unique to COVID-19 and could also indicate common flu which potentially leads to false alerts and potential misallocation of medical resources [45].

Another challenge lies in ensuring patients consistently use these devices and correctly perform their exercises [46]. A study conducted by Argent et al. (2018) to investigate the concern of patient non-compliance showed that nonadherence rates ranged from 30 % to 50 % among musculoskeletal patient groups [47].

In the future, machine learning models should be trained on robust datasets to improve the precision of sensors and algorithms for a more precise interpretation of complex movements and thereby decrease the errors [48]. Additionally, AI can be leveraged to create engaging and interactive rehabilitation programs that motivate patients to stick to their exercise plans with feedback loops to provide real-time corrections and guidance and to ensure exercises are done correctly [49]. AI systems can also filter vast amounts of patient data to customise exercise prescriptions, adapt treatment plans based on progress and even predict potential complications [49].

2.5. AI in predictive analytics

AI in predictive analytics within orthopaedics refers to the application of artificial intelligence methods to analyse patient data to predict surgery/treatment outcomes and risk of complications. This helps orthopaedic specialists to make data-driven decisions, customise patient care plans and improve overall treatment strategies. Studies have demonstrated the efficacy of AI models in assessing risks and predicting outcomes with high accuracy, outperforming traditional risk calculators in some cases [50]. For example, IBM's Watson is an AI system that rapidly processes data and offers insights in various fields using natural language processing and machine learning [51]. In healthcare, Watson has been reported to diagnose lung cancer with a 90 % success rate compared to the 50 % rate achieved by human doctors [52].

However, the accuracy of these predictive models depends heavily on both the quality and quantity of the available data. Inconsistencies in data entry along with the lack of standardisation in medical records pose challenges [53]. According to a study by Batko and Ślęzak (2022), about 47.58 % of Polish medical centres use structured data and about 23.35 % report irregularities in data recording. These irregularities have the potential to significantly compromise the accuracy of AI predictive models [53].

Another study by the UK's Drug Safety Research Unit (2020) found that batch numbers for medicines were recorded only 38 % to 58 % of the time, and adverse drug reaction reports often lacked essential information such as brand names and batch numbers. This lack of documentation can impact data quality and quantity [54].

Moreover, it is important to recognise that disease diagnosis, management, and patient outcomes can depend on patient demographics. This means that certain ethnicities may be underdiagnosed or undertreated for specific diseases. For example, women and ethnic minorities are often underdiagnosed due to historical biases in medical research [55].

Research by Hall et al. (2020) indicates that Black, Hispanic, and Native American patients often do not trust their healthcare providers due to a history of mistreatment and implicit biases [56]. Another study by Oxtoby (2020) shows that Black and Minority Ethnic (BME) patients undergoing orthopaedic procedures in the UK, are often undertreated for pain compared to their white counterparts [57]. This disparity is due to stereotypes and biases about pain tolerance among different racial groups, which can influence clinical judgment and lead to inadequate pain management [57].

Women also have been misdiagnosed due to historical instances of untreated or ignored medical conditions as they were either denied access to healthcare or accused of inflating their medical problems. For instance, conditions like autoimmune diseases in women have historically been misattributed to psychological causes rather than recognised as physical conditions [58].

According to Celi et al. (2022), Electronic Health Records (EHR) data often lack diversity, which lead to models that do not generalise well to underrepresented groups [59]. The study also found that predictive models, such as those used to assess cardiovascular risk, perform well for Caucasian patients but not for African American patients. This discrepancy can lead to unequal distribution of medical care. Thus, even if datasets include appropriate proportions of men, women, and various ethnic groups, if a disease is underdiagnosed in a specific group, the AI model will continue to underdiagnose that group [59].

Addressing these issues requires a multifaceted approach that include strategies to standardise data entry practices and improve the quality of medical records. There is also a need to invest in the development of more interpretable AI models and ensure that their workings are transparent and comprehensible to end-users [60].

In the future, AI can help in identifying the likelihood of complications after surgery and help in better decision-making for both surgeons and patients [61]. The efficiency of healthcare services can improve as AI predicts the demand for orthopaedic care and ensures resources are allocated where they are needed most [62]. Early detection of conditions like osteoporosis will become more accurate allowing for earlier and more effective treatment [62].

2.6. AI in transforming operating theatre efficiency in orthopaedic surgery

In the light of surgical scheduling, artificial intelligence (AI) systems can integrate a variety of elements including the availability of surgeons, the unique requirements of each patient, and the use of medical equipment. This integration can lead to fewer delays, lower expenses, and more efficient processes in the operating room [63,64]. For example, an AI algorithm developed by researchers at Duke University Hospital has demonstrated a 13 % increase in accuracy in predicting surgical time required in the operating room compared to human schedulers [65]. This reduction in scheduling errors not only can streamline clinical workflow but also can solve cost over time. The same research found that decreasing the overtime hours for cases extending beyond regular working hours in both inpatient and ambulatory operating rooms could potentially cut overtime labour costs by approximately $79,000 across four months [65].

However, the efficacy of AI in this area is linked to the quality and completeness of the input data and any inaccuracies or gaps in data can result in suboptimal scheduling. The complexity of the algorithms also plays a crucial role — while simplistic algorithms may fail to capture the intricate details of scheduling, overly complex ones could result in computational burdens and delayed outputs [64]. There are also challenges related to change management and user adoption, as integrating AI into existing workflows necessitates a cultural shift and training for the involved personnel. Ethical and legal considerations pose a challenge as well, particularly regarding patient privacy and data security [65,66].

AI also proves to be invaluable in managing and optimising surgical instruments, equipment, and supplies which reduces waste and improve resource allocation efficiency [67]. This technology fosters more efficient and cost-effective operating environments, helping to improve performance in the operating theatre [68]. However, for AI to make an impact in this domain, it is important to provide accurate and comprehensive data regarding inventory levels, equipment usage patterns, and supply lifecycles. The algorithms used must also be advanced enough to analyse this data and make recommendations, yet simple enough to be adopted seamlessly into existing hospital systems [69].

Regarding staff allocation, it is important to properly distribute staff members across different surgical procedures. AI holds significant potential in this aspect, as it can efficiently align the skills and availability of personnel with the specific requirements of surgical tasks [69]. This capability of AI will help to address staffing shortages and reduce delays [70].

The successful implementation of AI in staff allocation depends on the availability of accurate and up-to-date data regarding staff schedules, skill sets, and the specific needs of each surgical procedure. Additionally, the algorithms used must be adept enough to make quick and precise matching decisions [71].

The real-time monitoring capabilities of AI systems can provide invaluable insights into equipment usage, interactions among staff and patient outcomes which can enable the quick identification and addressing of any inefficiencies or issues [72]. Additionally, AI's predictive maintenance capabilities will potentially be able to minimise the equipment downtime further improving operational efficiency [72].

As we look to bring AI into operating rooms for live monitoring, it is critical to prioritise the protection and privacy of sensitive patient information and work details. The AI's effectiveness is related to the quality and accuracy of the data it processes [73]. It is equally important to ensure that medical staff are well-trained and comfortable with using AI, as any hesitation could slow its successful adoption [73]. When it comes to using AI for patient care decisions, it is also essential to have clear rules and know who is responsible those decisions [73]. Moreover, AI must adhere to all healthcare regulations and standards to prevent legal issues and preserve its good standing [73]. Addressing these challenges requires a well-rounded strategy that includes robust data security measures, comprehensive training for medical personnel and ongoing evaluation of how AI affects patient care and the efficiency of operations [73] [74].

The following figure summarises some of the points previously mentioned and illustrates where AI is currently being used in orthopaedics (Fig. 2).

3. Analysis

AI has the potential to revolutionise the field of orthopaedic but full integration is challenging.

Fig. 3 is a structured representation of a Force Field Analysis concerning the adoption of AI in orthopaedics. Force Field Analysis is a decision-making tool used to analyse the pressures for and against a change initiative [75].

The figure breaks down the factors into two opposing sets of forces: those driving the change towards AI adoption (on the left in blue) and those resisting it (on the right in red). Driving Forces are positive factors that advocate for the implementation of AI in orthopaedics. This section highlights the potential benefits such as improved planning and simulation through AI, improved surgical precision, personalised rehabilitation plans and reduced cost.

Restricting Forces are negative factors that impede the adoption of AI in orthopaedics. The main challenge as shown above is the high implementation costs. As discussed in Section 2.3, the high cost of AI adoption limits its access to only well-funded medical institutions. Such financial constraints not only impede the widespread integration of AI in healthcare practice but also restrict the scope of research as lesser-funded entities may lack the resources to engage in AI-related studies. Another major obstacle is assembling a sufficiently large and diverse dataset as many medical institutions are not proficient at recording and storing data [76]. There is also a risk of perpetuating existing medical biases, as creating a completely unbiased dataset is challenging. All these data challenges can lead to missing or incorrect information which may result in AI models producing biased and unreliable outcomes.

Integrating AI into orthopaedics reflects the challenges faced by the integration of any new system within pre-existing frameworks, like healthcare. One of the primary challenges is ensuring that AI systems align seamlessly with existing medical infrastructures, a process that necessitates substantial staff training. Another barrier is the hesitancy of medical staff which stems largely from concerns over job security. A 2023 Freelance Writing Jobs survey revealed that nearly half (44 %) of healthcare workers fear AI might replace their roles [77].

Moving forward, addressing all these different challenges requires balanced approaches. To address the high cost of implementing AI in orthopaedics, the following strategies could be beneficial:

- Shifting the perspective of AI from being a costly expense to an investment that will yield long-term savings.
- Exploring public funding options could provide practical financial support.
- Using open-source AI platforms and tools which are available for free and can significantly reduce software expenses, this ensures a balance between affordability and the maintenance of high-quality AI integration in the field.
- Using telehealth services to provide remote consultations and access to specialist care, particularly in regions where travel to healthcare facilities is challenging like rural areas.
- Establishing partnerships between governments, private sector entities, and NGOs to provide financial and technical support for deploying AI technologies in rural hospitals.
- Deploying mobile health clinics to offer cost-effective healthcare services directly to rural populations to reduce infrastructure costs and improving access.

Addressing the issue of limited data can involve the following strategies:

- Fostering collaborations between healthcare institutions by sharing data, these partnerships can create more comprehensive and diverse datasets.
- Facilitating the contribution of data from a broader range of sources including smaller clinics. This approach helps to capture a wide array of patient demographics, conditions, and treatment outcomes.
- Investing in advanced data collection and processing technologies that can efficiently handle large volumes of data and extract meaningful insights from them.
- Implementing robust data governance and ethical guidelines is also very important to ensure that the data collection process respects patient privacy and consent. However, the lack of reliable methods for making patient data anonymous presents a hurdle and can delay projects for months. In the best-case scenarios, this is a major obstacle, but in less favourable circumstances, it can completely halt innovative projects. Healthcare professionals often hesitate to share patient data due to the time-consuming and potentially risky process of encrypting the data. To overcome these challenges, simplifying the process of anonymisation the data to something as easy as a single click would facilitate the sharing of data.
- Regularly monitor AI outputs for signs of bias by comparing outcomes across different demographic groups and update the data every time.
- Use bias correction algorithms that can adjust data or model outputs to reduce disparities.
- Incorporate diverse expertise not only from the medical and tech fields to ensure a well-rounded approach to AI development. This can help identify potential bias in AI applications before they are implemented.

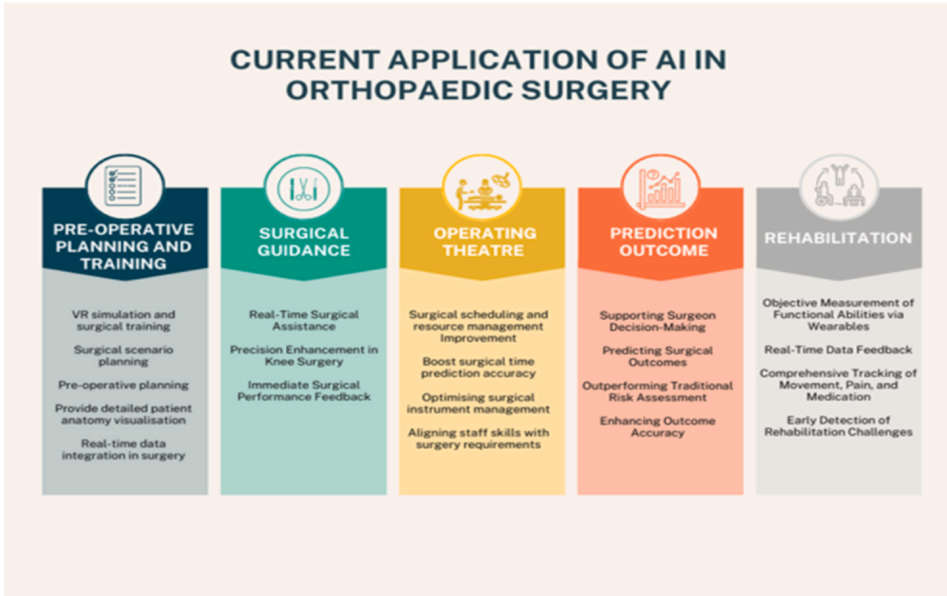

Fig. 2. Current Application of AI in Orthopaedic Surgery.

Raise awareness among all stakeholders about the potential biases in AI applications and their consequences.

To address ethical concerns:

Well-informed patients, about the importance of AI and the use of their data.
Maintaining transparency in how AI systems make decisions is equally important and can be achieved by involving the public, patients, and other stakeholders in discussions about AI in healthcare. This can help in understanding societal concerns and expectations and in formulating policies that are in line with public values.
Openly discussing the AI's decision-making process helps build trust among healthcare professionals and patients.
Implementing robust data security measures to protect sensitive patient information from unauthorised access or breaches and following the laws to make the data secure and protected is the most important step in the development of any AI system.
Develop clear protocols to obtain informed consent from patients by ensuring they understand how their data will be used in AI systems. This should include information about data collection, processing, and the potential risks and benefits of AI-driven treatments.

To address the problem of integration, it can be beneficial to:

Develop AI systems that are customisable as this will allow healthcare providers to tailor them to their specific needs and existing workflows. It also needs to ensure that AI applications have intuitive interfaces and are user-friendly. The less disruptive and easier the technology is to use, the more readily it will be accepted and integrated into daily medical practice.

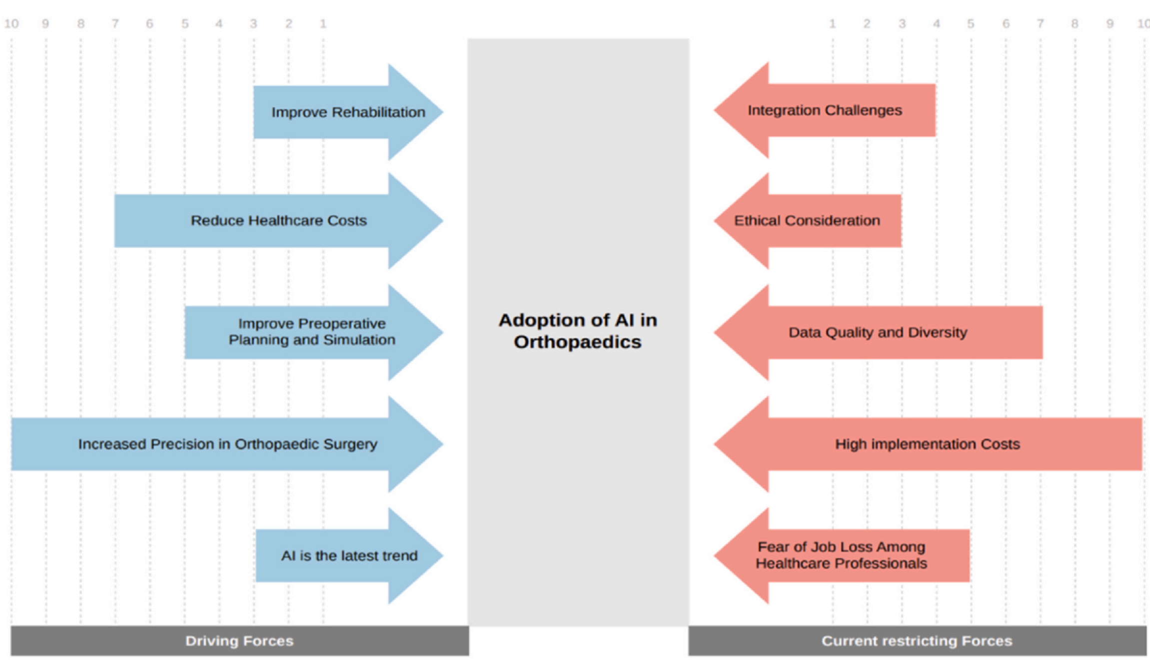

Fig. 3. Force Field Analysis for AI Adoption in Orthopaedics.

Engage healthcare professionals in the development and implementation process. Their insights can guide the creation of AI tools that fit naturally into their daily routines and address practical challenges.
Provide comprehensive training programs for healthcare staff to familiarise them with the new AI tools. Continuous education about updates and best practices is also crucial to ensure smooth operation and integration.
Offer technical support and maintenance services to address any technical issues immediately to ensure that AI systems function smoothly and reduces downtime.
Design AI solutions to be scalable to adapt to the growing and changing needs of the healthcare facility.

To boost confidence in AI adoption, it is important to:

Reassure people that AI attempts to assist not replace them and this can be achieved by openly and transparently communicating with healthcare staff about AI's purpose, benefits, and limitations.
Provide reassurances about job security by highlighting the growing demand for healthcare services and the need for skilled professionals and explaining how AI implementation can lead to job evolution rather than elimination with new roles and opportunities emerging in the field.

4. Conclusion

Integrating AI into orthopaedics offers a promising future where technology can improve patient outcomes and care. However, achieving this vision requires addressing several challenges. The true success of AI in orthopaedics lies not just in its technological complexity, but in its capacity to improve patient care and adhere to the fundamental principles of medicine: compassion, accuracy, and continuous improvement.

CRediT authorship contribution statement

Wissem Tafat: Writing – original draft, Writing – review & editing, Methodology. **Marcin Budka:** Supervision. **David McDonald:** Supervision, Writing – review & editing. **Thomas W. Wainwright:** Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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