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ROLE OF ARTIFICIAL INTELLIGENCE IN PREDICTING MUSCULOSKELETAL AND ORTHOPAEDIC OUTCOMES AFTER PAEDIATRIC SURGERY

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ABSTRACT Artificial Intelligence (AI) is revolutionizing the field of paediatric orthopaedic surgery by offering transformative solutions for predictive diagnostics, outcome forecasting, and clinical decision-making. With the integration of machine learning (ML), deep learning (DL), and clinical decision support systems (CDSS), AI enables highly individualized assessments of musculoskeletal outcomes following paediatric surgery. These technologies enhance accuracy in diagnosing congenital anomalies, anticipate growth-related complications, and refine surgical planning through data-driven insights. Importantly, collaboration between orthopaedic surgeons and paediatric surgical teams plays a pivotal role in interpreting AI-generated predictions and implementing them effectively. This review delves into the current and emerging roles of AI in paediatric musculoskeletal care, emphasizing global trends, unique challenges in the Indian healthcare context, and the need for robust ethical frameworks and clinician training. It also highlights future directions for integrating AI into everyday clinical practice to improve surgical precision, reduce complications, and optimize long-term functional outcomes in children.

KEYWORDS : Artificial Intelligence, Paediatric surgery, Orthopaedics, Predictive Modelling, Clinical Decision Support Systems

INTRODUCTION

Artificial intelligence (AI) is rapidly revolutionizing healthcare, emerging as a groundbreaking tool across diverse medical specialties, including orthopaedics and paediatric surgery. Its ability to harness vast datasets through predictive analytics, enhance imaging interpretation, and forecast surgical outcomes is particularly transformative in paediatric musculoskeletal care. The unique challenges posed by the dynamic nature of growth, anatomical variability, and evolving surgical responses in children demand precision and adaptability that AI uniquely offers. By enabling personalized treatment strategies, AI promises to improve decision-making, minimize complications, and optimize long-term results for young patients. As highlighted in recent studies [1, 9, 22, 35], integrating AI into paediatric orthopaedics and surgery holds immense potential to reshape clinical pathways and elevate standards of care, driving a future where innovation and compassion work hand in hand.

Predictive Role of AI In Paediatric Musculoskeletal Outcomes

Artificial intelligence (AI) harnesses the power of machine learning (ML) and deep learning (DL) algorithms to process complex clinical datasets and identify patterns that elude conventional statistical tools. In the paediatric population—especially neonates and young children—unique challenges such as developmental variability, rapidly changing anatomy, and heterogeneous surgical indications complicate outcome prediction. AI addresses this by enabling personalized risk stratification and more precise forecasting of postoperative outcomes, including infection rates, implant loosening, deformity recurrence, and complications arising from skeletal growth.

A landmark study by Cooper et al. [2] introduced a superlearning model that significantly outperformed traditional mortality prediction tools in neonatal surgical patients, demonstrating AI's potential in high-stakes paediatric care. Similarly, Yang et al. [3] validated the SORG ML algorithm in an international cohort, revealing strong predictive accuracy for 90-day and one-year survival in spine metastasis cases—laying the groundwork for adapting these tools to paediatric spine surgeries. In orthopaedics, Pierce et al. [15] showed that the ACS-NSQIP machine-learning risk calculator effectively predicted complications following adult spinal deformity correction, suggesting its future utility in paediatric cases where variables like implant longevity, skeletal immaturity, and growth modulation require tailored algorithms for precise outcome prediction.

AI in Paediatric Imaging and Diagnosis

Diagnostic imaging plays a pivotal role in evaluating musculoskeletal conditions in children, where early detection and timely intervention are crucial. Artificial intelligence (AI), particularly through deep learning (DL), is transforming the landscape of paediatric radiology by improving diagnostic speed, accuracy, and reproducibility. Advanced DL algorithms can now detect subtle fractures often missed by human observers, with tools like BoneView demonstrating high sensitivity in paediatric emergency settings [31]. Similarly, AI-based systems like BoneXpert provide automated bone age assessment and cortical bone health quantification, offering reliable metrics across diverse ethnic groups [30, 33, 40].

In developmental dysplasia of the hip (DDH), early and accurate diagnosis is critical. AI models trained on large radiographic datasets now assist in detecting DDH with higher consistency, as shown by studies leveraging deep transfer learning [17]. Moreover, digital X-ray radiogrammetry has emerged as a potential alternative to dual-energy X-ray absorptiometry in assessing bone quality in children with suspected DDH or low bone mass [29]. Offiah [19] and Messina et al. [39] have highlighted how AI can reduce variability in radiological interpretation. Innovations such as 3D-printed navigation templates, derived from AI-analyzed imaging data, are also being used to improve surgical planning in complex DDH cases [26].

Integration of Orthopaedicians and Paediatric Surgeons

The successful application of artificial intelligence (AI) in predicting paediatric musculoskeletal outcomes hinges on seamless collaboration between paediatric surgeons and orthopaedicians. In India, where patient volumes are high and specialized expertise is often concentrated in tertiary centres, a multidisciplinary approach can bridge diagnostic and therapeutic gaps. Paediatric surgeons, who often manage congenital anomalies and perform early interventions, must work in tandem with orthopaedicians skilled in long-term musculoskeletal management, including deformity correction, implant monitoring, and growth modulation.

Joint preoperative planning, informed by AI tools, is particularly valuable in complex cases. For instance, in rare conditions like large scapular osteochondromas associated with congenital diaphyseal aclasia, Tam et al. [24] demonstrated how 3D models derived from AI-analyzed imaging data facilitated precise surgical execution. Similarly, in procedures such as proximal femoral osteotomy for DDH, 3D-printed navigation templates based on AI-generated segmentation have improved intraoperative accuracy and outcomes [26].

In the Indian context, integrated care models could be promoted through regional paediatric musculoskeletal clinics where both specialties consult simultaneously. AI-assisted case boards, where imaging, growth predictions, and surgical simulations are reviewed by multidisciplinary teams, can streamline decision-making. Moreover, involving biomedical engineers in these teams can enhance the practical deployment of AI tools in real-time surgical planning. Training modules and joint CMEs (Continuing Medical Education) focusing on AI literacy can empower both paediatric and orthopaedic surgeons to co-lead this technological transition, ensuring AI predictions are ethically and effectively translated into comprehensive perioperative strategies tailored to the paediatric population.

Current Trends in AI Utilization

The integration of artificial intelligence (AI) across paediatric musculoskeletal care is expanding rapidly, driven by innovations in imaging, robotics, and data analytics. In diagnostic imaging, AI-based computer-aided detection tools such as those tested by Helm et al. [18] have demonstrated up to 90% sensitivity in identifying pulmonary nodules in paediatric oncology patients. Similarly, texture-based AI classification models using PET/CT imaging have shown promising results in differentiating benign from malignant nodules, with accuracies exceeding 85% [41].

Robotics-assisted surgeries are also gaining traction, particularly in spine deformity corrections. Gonzalez et al. [20] evaluated 40 paediatric cases using robotic-assisted pedicle screw placement, reporting improved accuracy and reduced intraoperative time. Furthermore, 3D planning tools based on AI segmentation—such as those used in complex forearm malunion surgeries—have been shown to enhance preoperative precision [21], while 3D MRI-based printing models are improving surgical outcomes in congenital musculoskeletal anomalies [38].

In non-orthopaedic paediatric surgery, machine learning (ML) models have demonstrated up to 94% accuracy in diagnosing acute appendicitis [7] and have reliably predicted recurrent intussusception [10]. The integration of wearable sensor data with AI is being explored for real-time rehabilitation monitoring, with sensors capturing over 10,000 data points daily [5]. Meanwhile, platforms like Rayyan [11] and quality assessment tools such as QUADAS-2 [6] support evidence-based AI research by streamlining systematic reviews and enhancing diagnostic study validation.

Table 1 Current Trends in AI Utilization in Paediatric Musculoskeletal and Surgical Care

AI Application Area	Key Reference (s)	Use Case	Reported Outcome / Accuracy
Imaging Diagnostics (Pulmonary Nodules)	Helm et al. [18]	Computer-aided detection in paediatric oncology	Sensitivity up to 90%
PET/CT Radio-genomics	Chen et al. [41]	AI-based texture classification of solitary pulmonary nodules	Diagnostic accuracy >85%
Robotic Spine Surgery	Gonzalez et al. [20]	Pedicle screw placement with AI + stealth navigation	Increased precision, reduced intra-op time (first 40 cases)
3D Planning Tools (Forearm Malunion)	Storelli et al. [21]	AI-assisted 3D modeling for deformity correction	Improved surgical planning and alignment
MRI-based 3D Printing	Partha-sarathy et al. [38]	Personalized surgical models in congenital deformities	Enhanced anatomic visualization, reduced intra-op error
Wearable Sensors + AI	Huang et al. [5]	Gait monitoring and rehab feedback via sensor data	Over 10,000 data points/day analyzed for movement prediction
Acute Appendicitis Prediction	Aydin et al. [7]	ML algorithm for pre-op diagnosis in children	Accuracy up to 94%
Recurrent Intussusception Prediction	Guo & Qian [10]	ML-based post-enema recurrence prediction	Statistically significant prediction accuracy
Systematic Review Support	Ouzzani et al. [11]	Rayyan web/app tool for AI-assisted screening	Cuts screening time by over 30% in systematic reviews
Diagnostic Study Validation	Whiting et al. [6]	QUADAS-2 for bias assessment in AI diagnostic tools	Widely adopted, improves study quality transparency

Indian Perspective

In India, the incorporation of artificial intelligence into paediatric orthopaedic surgery remains in an early developmental stage. A significant barrier to widespread adoption is the lack of standardized digital datasets specific to the Indian paediatric population. This is compounded by infrastructural disparities between urban tertiary centers and rural hospitals, making nationwide AI implementation challenging. Additionally, the scarcity of AI tools tailored for Indian paediatric anatomy and conditions further restricts clinical utility.

Nevertheless, progress is underway. Several academic institutions and hospitals have started adopting AI-powered diagnostic imaging platforms, with a growing interest in clinical applications. Amisha et al. [22] emphasized the importance of clinician-centric AI education and the creation of indigenous datasets to enhance tool relevance in the Indian context. Al-Rumaih et al. [1] and Han et al. [35] also highlighted the need for interdisciplinary collaboration and regulatory support to scale AI-driven interventions.

A practical example of innovation comes from Parthasarathy et al. [38], who demonstrated the application of MRI-integrated 3D printing for surgical planning in paediatric musculoskeletal deformities. This technology, although in its infancy in India, holds immense promise for tertiary care centers lacking advanced navigation tools. With government-backed digital health initiatives and AI research funding gaining momentum, India is poised to bridge this technological gap in paediatric orthopaedics.

Integrating artificial intelligence (AI) into paediatric general surgery and orthopaedic surgery involves multiple practical and systemic challenges that impact both paediatric general surgeons and orthopaedic specialists. One of the primary obstacles is the limited availability of large, standardized paediatric datasets. As Schaefer et al. [32] highlighted, the scarcity and heterogeneity of data in paediatric populations restrict the robustness and generalizability of AI algorithms. This is particularly problematic for rare or complex musculoskeletal disorders, where insufficient data can lead to biased or inaccurate predictions, limiting the clinical utility of AI models.

Ethical considerations also play a critical role in AI implementation, especially in vulnerable groups such as children. According to Loh et al. [14] and Sutton et al. [36], AI-driven clinical decision support systems (CDSS) must maintain transparency and interpretability to ensure accountability. It is essential that both surgeons and families comprehend the rationale behind AI recommendations, as this fosters trust and informed decision-making in paediatric care. Without clear explanation of AI outputs, there is a risk of misunderstanding or misapplication of technology in sensitive clinical contexts.

Clinically, a significant barrier lies in the limited familiarity and trust among surgeons regarding AI tools, particularly in resource-constrained settings. Knake [9] and Wang et al. [28] observed that many clinicians remain skeptical due to insufficient training, lack of standardized workflows, and concerns about reliability. This skepticism affects both paediatric surgeons, who manage acute congenital conditions, and orthopaedic surgeons, who focus on long-term skeletal growth and corrective procedures. The disconnect between these specialties can impede effective interdisciplinary collaboration necessary for comprehensive AI integration.

Furthermore, infrastructural limitations are a major challenge, especially in India. Many healthcare facilities lack electronic health records, advanced imaging systems, or high-performance computing capabilities required to deploy AI solutions effectively. Gödeke et al. [4] emphasized the translational gap between promising AI research and its practical application in paediatric surgical settings. Overcoming this gap demands systemic reforms, including investment in digital infrastructure and dedicated interdisciplinary training programs, to facilitate smooth adoption and optimize patient outcomes.

Future Goals and How to Achieve Them

a. Development of Paediatric-specific Algorithms

AI models tailored specifically for children's unique musculoskeletal development are critical. Unlike adult datasets, paediatric data must account for dynamic growth patterns, variable healing rates, and evolving anatomy. Establishing national paediatric orthopaedic registries that systematically capture surgical outcomes, growth metrics, and complication profiles will be invaluable. Collaborative networks across India's leading children's hospitals can facilitate large-scale data sharing, enabling algorithms to learn from diverse populations and pathologies [30, 40]. Joint efforts between paediatric surgeons and orthopaedicians are essential to define relevant clinical parameters and ensure comprehensive datasets.

b. Training and Collaboration

Incorporating AI literacy into paediatric orthopaedic and surgical training programs will build essential skills. Hands-on interdisciplinary fellowships, where trainees rotate between surgical units and AI research labs, can promote practical understanding. Encouraging team-based case discussions integrating AI predictions will nurture trust and clinical adoption [1, 22]. Such collaboration also bridges the knowledge gap, allowing paediatric surgeons to better understand long-term musculoskeletal implications and orthopaedicians to appreciate early surgical considerations.

c. Public-private Partnerships

Partnerships between Indian medical institutions and technology firms can develop cost-effective AI tools adapted to resource-limited settings. These partnerships could focus on modular AI platforms for diagnostics, risk prediction, and surgical planning, optimized for Indian healthcare infrastructure [25, 35]. FDA-cleared systems like OrthoNext [42] demonstrate scalable models that could be localized for Indian hospitals, especially government-run centers.

d. Emphasis on Explainable AI

Explainable AI (XAI) will be pivotal in building clinician and patient confidence. Transparent AI systems allow surgeons to interpret the basis of predictions, facilitating shared decision-making with families, which is especially important in paediatrics where treatment consequences affect long-term growth [14].

e. Ethical and Regulatory Oversight

India must establish clear regulatory frameworks addressing data privacy, ethical use, and clinical responsibility in AI applications. Drawing from global guidelines, national policies should mandate rigorous validation and continuous monitoring of AI tools used in children [34, 36].

f. Community and Rural Outreach

AI can bridge healthcare disparities by enabling teleradiology consultations, mobile diagnostic units, and remote surgical planning, expanding access to paediatric orthopaedic expertise in rural India [1, 28, 31]. Training local healthcare workers to utilize AI-supported tools will enhance early diagnosis and timely referrals, creating a robust care continuum.

CONCLUSION

Artificial intelligence promises to revolutionize paediatric orthopaedic surgery by improving the accuracy of predictions, enabling personalized treatment plans, and reducing postoperative complications. While AI adoption in imaging, surgical planning, and risk assessment is advancing rapidly worldwide, India faces unique challenges, including scarce paediatric-specific datasets, limited infrastructure, and gaps in clinician training. Key to overcoming these barriers is a close collaboration between paediatric general surgeons and orthopaedicians, blending early surgical intervention expertise with long-term musculoskeletal care to fully harness AI's potential. Establishing national registries, promoting interdisciplinary training programs, and developing customized, explainable AI solutions suited to India's diverse healthcare landscape will be crucial steps forward. Additionally, strong ethical frameworks and expanded public-private partnerships can help widen access, particularly in rural and underserved areas. By integrating clinical experience with innovative AI technologies, India is well-positioned to lead a new era in precision paediatric orthopaedics—offering each child individualized, compassionate, and data-driven care throughout their growth and development.

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