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Innovations in paediatric orthopaedics: a narrative review of precision, personalisation, and biological restoration

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Abstract

Paediatric orthopaedics is currently witnessing a profound evolution, transitioning from traditional mechanical fixation toward a future defined by biological restoration and digital precision. The dynamic nature of the growing skeleton necessitates a "growth-aware" surgical philosophy to mitigate the lifelong burden on the child. This narrative review synthesises advancements across pivotal domains: advanced 3D imaging, virtual surgical planning, regenerative biotechnology (the "Diamond Concept"), and smart implant design, based on a rigorous analysis of 76 contemporary sources verified against Medline/PubMed databases. Innovations such as the EOS imaging system and AI-driven diagnostics have significantly reduced cumulative radiation exposure and inter-observer variability. The integration of 3D-printed patient-specific instrumentation and robotic assistance has elevated surgical fidelity in complex spinal and pelvic reconstructions. In the biological realm, the synergy of mesenchymal stem cells, BMPs, and bioactive scaffolds is providing solutions for recalcitrant defects. Furthermore, the advent of bioabsorbable magnesium alloys and internal motorized lengthening nails is effectively eliminating the need for secondary surgeries. The convergence of the "Digital Twin" paradigm with regenerative medicine offers a personalised trajectory for paediatric care. By embracing these advancements, clinicians can restore function while rigorously minimising the physical and psychological burden on the developing child.

Keywords

paediatric orthopaedics, diamond concept, 3D printing, EOS imaging, bioabsorbable implants, Digital Twin, artificial intelligence

Introduction

The discipline of paediatric orthopaedics represents a sophisticated subspecialty primarily dedicated to the complex diagnosis and management of musculoskeletal conditions across the developmental spectrum—from the neonate to the adolescent. It is imperative to acknowledge that the paediatric skeleton is not merely a diminutive version of its adult counterpart; rather, it is a dynamic biological entity defined by the presence of open growth plates (physes), heightened bone turnover, and an extraordinary capacity for spontaneous remodelling [1]. These intrinsic biological attributes necessitate a “growth-aware” therapeutic philosophy, as any clinical intervention must meticulously account for the child’s remaining longitudinal growth potential while simultaneously mitigating the peril of iatrogenic physeal injury [2, 3].

Over the preceding decade, the field has been the subject of a profound transformation, propelled by rapid technological evolutions that have redefined the heretofore accepted boundaries of diagnostic precision [4]. Nascent efforts in global collaboration have further refined this through multinational expert Delphi consensus [5]. The integration of artificial intelligence (AI), high-fidelity three-dimensional (3D) modelling, and regenerative biotechnology is currently facilitating a historical shift—transitioning from a tradition of purely mechanical stabilisation toward a future of biological restoration.

Moreover, contemporary innovations are increasingly preoccupied with the alleviation of the cumulative ‘surgical burden’—the total number of invasive procedures and anaesthetic exposures a child is subjected to throughout their skeletal maturation [6]. Acknowledging this, the present review synthesises evidence from 76 contemporary sources to provide a structured overview of the key technological domains reshaping the specialty, with a focus on translational relevance for the practising paediatric orthopaedic and trauma surgeon.

Review methodology

This article is a narrative review. Sources were identified through targeted searches of PubMed and Google Scholar using terms related to paediatric orthopaedics, imaging, regenerative medicine, implant design, and digital technologies. Additional references were identified through citation tracking of key articles. No formal systematic screening, risk-of-bias assessment, or meta-analytic synthesis was performed, consistent with the narrative review methodology. Where applicable, levels of evidence were assigned according to the Oxford Centre for Evidence-Based Medicine framework.

Advanced imaging and diagnostics: addressing the challenge of early detection

Diagnostic challenges in the growing skeleton

The paediatric skeleton presents a formidable “moving target” for the contemporary clinician. The ubiquitous presence of cartilaginous precursors and open physes implies that conventional radiography frequently fails to reveal the true magnitude of a deformity or the subtlety of an injury [7]. In the context of developmental dysplasia of the hip (DDH), the Graf method of ultrasonography has rightfully ascended to the status of the gold standard for early diagnostic screening, offering a rigorous and standardised anatomical classification [8]. Meticulous assessment of limb alignment remains a cornerstone of preoperative planning, particularly when addressing deviations in the mechanical axis [9]. The complexity of imaging interpretation in the growing child demands awareness of specific pitfalls unique to this population [10, 11]. Published studies report only moderate inter-observer reproducibility for key paediatric radiographic measurements, with most kappa and ICC values falling within the mid-range depending on the parameter and measurement technique.

Low-dose 3D imaging (EOS)

For children requiring serial radiographic monitoring, such as those with adolescent idiopathic scoliosis (AIS), the cumulative burden of ionizing radiation is a significant epidemiological concern regarding long-term oncogenic potential (Table 1) [12]. The low-dose 3D imaging system (EOS) has addressed this by providing biplanar radiographs with a radiation dose up to 90% lower than conventional radiography (Table 1) [13–16].

Table 1. Clinical challenges, technological solutions, and levels of evidence.

Clinical challenge	Technological solutions	Level of evidence	Key reference
Radiation accumulation	Low-dose 3D EOS Imaging	Level 2	[13]
Subjective DDH screening	Standardized Human Expertise & Certified Personnel	Level 2	[5]
Complex deformities	3D VSP and PSI Guides	Level 3	[14]
Repeat distractions	MCGR	Level 2	[15]
Global diagnostics	Portable US/Telemedicine	Level 4	[16]

DDH: developmental dysplasia of the hip; EOS: low-dose 3D imaging system; MCGR: magnetically controlled growing rods; PSI: patient-specific instrumentation; US: ultrasound; VSP: virtual surgical planning.

Virtual and augmented reality in training

Immersive virtual reality (VR) has demonstrated profound efficacy in the acquisition of complex orthopaedic surgical skills [17, 18]. Augmented reality (AR) takes this further by providing digital overlays during active surgery, revolutionising the safety of spinal navigation [19, 20].

Artificial intelligence in radiographic interpretation

AI is actively automating the most laborious tasks, such as the measurement of Cobb angles in spinal deformity [21]. Deep learning models have achieved diagnostic sensitivities in detecting fractures that rival human observers [22, 23]. Beyond detection, machine learning models are being employed to predict the risk of deformity progression in AIS, allowing for a more bespoke approach to bracing [24]. AI applications now span a broad range of domains in paediatric orthopaedics, including outcome prediction, surgical planning, and image classification [25–29]. While AI-based tools show promising accuracy, most models remain trained on limited, single-centre datasets and require external validation before routine clinical adoption in paediatric populations.

Advanced MRI and ultrasound sequences

The evolution of MRI has transitioned from anatomical to biochemical evaluation. Advanced sequences such as dGEMRIC allow for the molecular evaluation of cartilage health [30, 31]. Furthermore, ultrashort echo time (UTE) MRI has proven invaluable for the detailed visualisation of the osteochondral junction [32]. Point-of-care ultrasound (POCUS) has emerged as a validated, radiation-free modality for paediatric fracture diagnosis and physeal assessment [33–35].

Surgical planning and navigation: overcoming the limits of precision

3D modelling and patient-specific instrumentation (PSI)

Rigorous radiation-reduction protocols are essential in preoperative planning for the growing child, where the cumulative dose from repeated imaging studies carries long-term oncogenic risk [36]. Virtual surgical planning (VSP) leverages CT or MRI data to construct patient-specific anatomical models that provide the surgeon with precise spatial understanding of pathological anatomy prior to any incision [37–39]. Three-dimensional bioprinting has further extended these capabilities by enabling the fabrication of patient-specific scaffolds and surgical guides from biocompatible materials with remarkable geometric fidelity [40].

The culmination of this digital planning workflow is patient-specific instrumentation (PSI)—individually designed 3D-printed cutting and positioning guides that conform to the patient's unique skeletal anatomy with sub-millimetre accuracy, minimising intraoperative decision-making and reducing total procedure time [38, 41]. Despite their precision, traditional growth-friendly instrumentation strategies, such as growing rods, carry inherent hardware-related complication profiles over multi-year distraction periods [42]. To overcome these historical limitations, modern implementations are increasingly coupled with robotic-assisted navigation systems to secure complex anatomical trajectories, particularly for pelvic instrumentation in severe neuromuscular spinal deformities (Table 2) [43].

Table 2. Key innovations and clinical impact.

Innovation	Clinical impact and benefits	Key references
Low-dose EOS imaging	Reduces lifetime cancer risk; provides accurate 3D alignment	[2, 13]
AI-driven diagnostics	Increases screening accuracy; reduces inter-observer variability	[21–29]
3D VSP/PSI	Higher surgical precision; reduces operative time and complications	[14, 41]
Magnetic growing rods	Eliminates repeated surgeries; reduces psychological burden	[6, 15]

EOS: low-dose 3D imaging system; PSI: patient-specific instrumentation; VSP: virtual surgical planning.

Computer-assisted navigation and robotics

Computer-assisted navigation systems have fundamentally transformed the accuracy of implant placement across a spectrum of paediatric procedures, providing real-time three-dimensional spatial feedback that substantially reduces the risk of neurovascular injury [44–46]. Given that repeated intraoperative imaging remains a necessity in these complex spinal contexts, mitigating cumulative radiation exposure represents an uncompromised priority for the safety of the pediatric patient [47].

Robotic platforms have further elevated surgical precision by providing a mechanically stabilised and tremor-free arm for pedicle screw placement in complex paediatric spinal deformity surgery, with published data demonstrating significantly reduced rates of cortical breach and intraoperative radiation exposure compared with conventional freehand techniques [48–51]. Early applications of robotic assistance in paediatric trauma are also emerging, with preliminary data supporting its potential for achieving high-fidelity fracture reduction in complex periarticular injuries [51, 52].

Biologic and regenerative technologies

Biological challenges and growth modulation

Biological restoration is the current frontier of paediatric orthopaedic innovation, offering solutions that transcend the limitations of purely mechanical constructs. The inherent plasticity of the growing skeleton, while a remarkable biological asset, also predisposes it to a spectrum of pathological processes that conventional implants are ill-equipped to address. Among the most transformative departures from surgical dogma is vertebral body tethering (VBT), which represents a fundamental rethinking of the surgical correction of AIS. Rather than achieving correction through rigid fusion, VBT leverages the very principle of asymmetric growth modulation—applying a flexible cord under tension to the convex side of the scoliotic curve and harnessing the Hueter-Volkmann principle to guide corrective growth over time.

This dynamic, fusionless approach preserves segmental spinal mobility and avoids the long-term biomechanical consequences of solid fusion in a young spine, including adjacent segment disease and the “flatback” deformity [53]. Current VBT evidence is limited by relatively short follow-up, reoperation rates, and ongoing debate regarding optimal patient selection and timing of intervention.

Stem-cell and biologic augmentation

Clinicians are increasingly turning to mesenchymal stem cells (MSCs) and platelet-rich plasma (PRP) as autologous biological augments for bone regeneration, offering the theoretical advantage of stimulating healing through the patient’s own reparative machinery without donor-site morbidity [54]. Recombinant bone morphogenetic proteins—BMP-2 and BMP-7—offer potent, well-characterised osteoinductive signals for recalcitrant non-unions and critical-size defects, with a substantial and growing body of evidence supporting their judicious use in complex paediatric skeletal defects where conventional grafting is insufficient [55].

The diamond concept and 3D-printed biologic scaffolds

The "Diamond Concept" integrates cells, signals, scaffolds, and stability into a unified framework for bone tissue engineering (Table 3) [56–58]. 3D-printed bioactive scaffolds mimic the architecture of the bone matrix, promoting rapid vascularization and cellular ingrowth [59–61].

Table 3. Pillars of the diamond concept in bone tissue engineering.

Pillar	Biological/mechanical role	Key references
Osteogenic cells	Provision of MSCs/osteoblasts	[54]
Osteoinductive signals	Growth factors for differentiation	[55]
Osteoconductive scaffold	Porous structural template	[62]
Mechanical stability	Rigorous internal fixation	[63]

BMP: bone morphogenetic protein; MSCs: mesenchymal stem cells; 3D: three-dimensional.

Implant design innovations: solving growth-related limitations

The theoretical foundation laid by the Diamond Concept provides the biological blueprint for advanced bone tissue engineering, where scaffolds seamlessly interface with cellular signaling networks to accelerate osteogenesis [64]. Mechanobiologically optimized porous structures enhance bone regeneration in critical-size defects, demonstrating that mechanical environment and design geometry are fundamentally linked during structural remodeling [65]. These biologic advancements are particularly critical in periarticular trauma, where managing complex bone healing requires a strategic integration of tissue repair mechanisms [66]. Furthermore, tracking long-term structural integrity and physical rehabilitation outcomes is now facilitated by continuous gait kinematics dana collected through modern biosensors [67].

In the clinical management of complex pediatric non-unions, applying these optimized bioengineering frameworks ensures that biological bone restoration can be achieved even in highly compromised mechanical environments [68]. Minimizing the high rate of diagnostic inter-observer and intra-observer variability in long-bone deformity measurements is an absolute prerequisite to properly calculating these patient-specific stabilization forces [69]. Finally, long-term safety profiles established over the past 15 years confirm that modern cellular and structural materials cause no adversarial systemic responses in the developing child [70].

Challenges with traditional implants and growth-sparing systems

Titanium implants have become the material of choice in paediatric fracture management, offering optimal biocompatibility and growth compatibility [71]. The unique biomechanical environment of the growing child requires implants that can adapt to rapid skeletal changes. The development of growth-modulating biological therapies has further expanded the armamentarium available to the paediatric orthopaedic surgeon. Magnetically controlled growing rods (MCGR) now permit non-invasive distraction in an outpatient setting, markedly reducing the frequency of general anaesthesia and the psychological trauma of repeated hospitalisations [6, 15]. These systems exemplify the "growth-aware" philosophy, where the implant serves as a temporary scaffolding for a biological process. Despite their advantages, MCGR systems remain associated with complications such as distraction failure ("stalling"), rod fracture, and high implant cost.

Intramedullary fixation and the refinement of guided growth

Elastic stable intramedullary nailing (ESIN) remains the gold standard for many long-bone fractures, as it respects the biological integrity of the physis [72, 73]. For older adolescents, rigid intramedullary nails utilizing a lateral entry point have effectively eliminated the risk of femoral head necrosis, which was a devastating complication of older piriformis-entry designs [74, 75]. In the management of angular deformities, the 'eight-plate' concept for guided growth has revolutionised clinical outcomes by providing a reversible and mechanically reliable method for correction [76].

Bioabsorbable materials and the advent of internal distraction

The most transformative innovation in hardware is the move toward bioabsorbable materials, such as poly-L-lactide (PLLA) and advanced magnesium alloys, which dissolve after union is achieved. These materials are instrumental in minimising the lifetime surgical burden for children. For limb lengthening, internal motorized nails provide precise distraction while eliminating the risk of pin-site infections characteristic of external fixators. For magnesium-based implants, precise control of degradation kinetics and gas formation remains a key challenge, particularly in small paediatric bones. A comparison of traditional implants with innovative implants and materials is presented in Table 4.

Table 4. Comparison of traditional vs. innovative implants and materials.

Category	Traditional approach	Innovative solution	Key advantage
Bone healing	Autologous bone grafting	BMP, MSCs, 3D scaffolds	Eliminates donor-site morbidity
Limb lengthening	External fixators	Internal motorized nails	Eliminates pin-site infections
Growth modulation	Blount staples; epiphysiodesis	Tension band plates; VBT	Reversibility; physis preservation
Scoliosis management	Traditional growing rods	MCGR	Reduced general anaesthesia
Fixation materials	Permanent titanium/steel	Bioabsorbable (magnesium)	No secondary removal surgery
Intramedullary nailing	Piriform-entry rigid nails	ESIN; lateral-entry nails	Preserves femoral head vascularity

BMP: bone morphogenetic protein; ESIN: elastic stable intramedullary nailing; MCGR: magnetically controlled growing rods; MSCs: mesenchymal stem cells; VBT: vertebral body tethering.

Digital orthopaedics and the “Digital Twin”

Systemic challenges and precision modelling

The digital revolution in orthopaedics extends well beyond imaging and navigation, encompassing an entirely new paradigm for patient-specific care. Eradicating inter-observer variability in radiographic measurements is a fundamental prerequisite for evidence-based care, yet remains an unsolved challenge. Discrepancies in the measurement of pelvic obliquity or Cobb angles lead to inconsistent surgical decisions, with clinically significant variation reported between experienced surgeons [12]. The emergence of the “Digital Twin”—a high-fidelity, patient-specific computational replica of a child’s unique anatomy, physiology, and biomechanics—represents a paradigm shift of profound significance.

By integrating multimodal imaging data, patient-specific material properties derived from quantitative MRI, and real-time motion capture, the Digital Twin enables unparalleled preoperative simulation and implant design optimisation. Surgeons can rehearse complex procedures, test alternative fixation strategies, and objectively predict postoperative alignment without a single incision, thereby transforming the subjective art of surgical planning into a rigorous, evidence-based science [38]. Implementation of Digital Twin platforms requires substantial computational infrastructure, specialised personnel, and integration with hospital IT systems, which currently restricts their use to highly specialised centres.

Wearable sensors and telemedicine

Wearable sensors provide continuous joint kinematics data from the patient’s natural milieu, offering a more ecologically valid, objective, and representative profile of functional movement than periodic clinical snapshots obtained under artificial laboratory conditions [67]. “Smart casts” with integrated pressure sensors now enable real-time monitoring of compartment pressures to prevent the devastating complication of compartment syndrome. Telemedicine platforms further ensure that specialist expert counsel is a global utility, vital for surgeons working in underserved, resource-limited, and geographically remote regions [16].

Paediatric trauma innovations: minimising the burden

Accelerating osteogenesis and the role of LIPUS

Contemporary trauma management focuses on accelerating biological healing while minimising the cumulative procedural burden. The paediatric skeleton’s extraordinary healing capacity is, paradoxically, both its greatest advantage and a source of clinical complexity, as rapid but disordered healing can result in malunion with growth-related consequences. Low-intensity pulsed ultrasound (LIPUS) has emerged as a formidable non-invasive adjunct for augmenting bone healing, demonstrating profound immunomodulatory and anti-inflammatory potential in preclinical and clinical models of complex fractures [66]. By mechanically stimulating transmembrane integrins and activating downstream osteoblastic signalling cascades—including the Wnt and BMP pathways—LIPUS significantly reduces the incidence of delayed union and shortens the period of immobilisation, translating directly into a reduced duration of the child's absence from school and daily activities [68, 69].

Bioabsorbable fixation in periarticular trauma

The philosophical shift toward bioabsorbable materials is particularly consequential in periarticular trauma, where hardware removal surgery entails significant psychological distress and a non-trivial risk of iatrogenic physeal injury. Advanced magnesium-based alloys represent the current vanguard of this field, offering mechanical stability broadly comparable to titanium during the critical period of fracture healing, while degrading predictably through controlled corrosion to harmless inorganic by-products, thereby obviating the need for a secondary operative procedure entirely [71]. The optimisation of degradation kinetics—ensuring the implant maintains sufficient structural integrity during the entire healing phase before dissolving—remains an active area of materials science research with direct translational relevance to the paediatric orthopaedic and trauma surgeon.

Global health and low-resource innovations

Diagnostic democratisation

A significant and often-overlooked dimension of orthopaedic innovation is the imperative to translate technological advances into globally accessible tools. In high-income settings, MRI, robotics, and digital planning represent the standard of care; in low- and middle-income countries, the absence of basic diagnostic infrastructure results in late-presenting deformities and preventable long-term disability. POCUS has transformed the clinical landscape in resource-limited settings by providing a portable, radiation-free, and cost-effective alternative for screening DDH and triaging fractures in remote regions [16]. Deployed by trained health workers, POCUS programmes have demonstrated feasibility and accuracy comparable to hospital-based imaging, enabling early diagnosis at the community level.

Technological sustainability

Solar-powered diagnostic devices and low-cost 3D printing are actively reshaping the delivery of orthopaedic care in regions with unstable infrastructure, ensuring that high-fidelity surgical planning is not restricted by geography or economics. Telemedicine platforms now connect remote surgeons with subspecialty paediatric orthopaedic expertise, enabling real-time case consultation that would previously have required international travel [16]. Crucially, the global scalability of AI-driven decision support tools—which can be deployed on low-cost mobile hardware—offers a realistic pathway to democratising the diagnostic precision currently available only in tertiary referral centres [28, 29]. These innovations collectively advance the ethical imperative of ensuring that every child, regardless of birth geography, has equitable access to evidence-based musculoskeletal care (Table 5).

Table 5. Global innovations and impact on healthcare equity.

Global innovation	Impact on healthcare equity	Key reference
Portable ultrasound	Expands diagnostic access in rural and low-resource settings	[16]
Telemedicine	Connects local surgeons with global paediatric specialists	[16]
Low-cost 3D printing	Provides affordable anatomical models for surgical training	[37]
Solar-powered devices	Supports healthcare delivery in regions with unstable power	[16]

The global burden of paediatric musculoskeletal conditions is disproportionately concentrated in low- and middle-income countries, where delayed diagnosis and limited access to specialist care frequently result in preventable disability. Scaling POCUS, telemedicine, and low-cost 3D printing requires not only technology but also structured training programmes, sustainable financing models, and integration into existing health systems. Future work should prioritise cost-effectiveness analyses and implementation research in resource-limited settings.

Discussion

The synthesis of the 76 contemporary studies reviewed herein illuminates a decisive and accelerating shift in paediatric orthopaedics—from a discipline of mechanical stabilisation toward one defined by biological intelligence, digital precision, and equity of access. Several overarching themes emerge with clarity. First, the philosophy of minimising the "surgical burden"—operationalised through non-invasive distraction, bioabsorbable implants, guided growth, and POCUS—has evolved from a peripheral aspiration to a central organising principle. Second, the convergence of AI, 3D modelling, robotics, and the Digital Twin framework is systematically dismantling the technical limitations that previously constrained surgical precision in complex paediatric deformities. Third, the Diamond Concept has provided a robust and clinically validated framework for biological bone restoration, with its four pillars—cells, signals, scaffolds, and stability—now underpinning not only fracture management but the entire domain of paediatric bone tissue engineering.

However, several important limitations temper uncritical enthusiasm. Many innovations reviewed here—particularly AI-based diagnostic models, Digital Twin platforms, and growth-modulating biologics—remain at the proof-of-concept or early clinical trial stage, with limited long-term paediatric follow-up data. The generalisability of findings from adult or mixed-age cohorts to the uniquely dynamic paediatric skeleton remains an open question requiring dedicated investigation. Furthermore, the risk of exacerbating existing global health inequities through the uncritical adoption of high-cost technologies demands that future research explicitly address cost-effectiveness and scalability in low-resource settings. Looking forward, the integration of real-world wearable sensor data with Digital Twin models, combined with AI-driven personalised outcome prediction, will likely define the next generation of "growth-aware" precision medicine in paediatric orthopaedics [38, 72].

The technologies discussed in this review span a spectrum of maturity: EOS imaging, ESIN, guided growth, MCGR, and bioabsorbable polymers are already integrated into routine paediatric practice, whereas Digital Twin platforms, advanced bioprinting, AI-based predictive models, and many stem-cell-based interventions remain investigational with limited paediatric validation.

Conclusion

Technological innovation is profoundly re-authoring the narrative of paediatric orthopaedics. From the sophisticated elegance of the Diamond Concept to the transformative predictive power of the Digital Twin, the field is transitioning toward a future defined by personalised care, biological restoration, and a radical reduction in the surgical burden. The innovations reviewed herein—spanning advanced low-dose imaging, AI-driven diagnostics, VSP, PSI, regenerative biotechnology, smart implant design, and global health equity tools—collectively represent a coherent and accelerating paradigm shift.

Critically, these advances are not isolated breakthroughs but are most powerful when integrated: the Digital Twin informed by wearable sensor data, the Diamond Concept augmented by AI-optimised scaffold design, and MCGR-guided distraction monitored by telemedicine platforms. By embracing these advancements while remaining steadfastly "growth-aware" and committed to global accessibility, the modern paediatric orthopaedic surgeon can ensure that every child—regardless of geography or resources—achieves their full skeletal potential with the minimum possible physical, psychological, and social burden. The ultimate aspiration of this discipline remains constant: not merely technical excellence, but the optimization of functional outcomes and quality of life in childhood.

Abbreviations

AI: artificial intelligence

AIS: adolescent idiopathic scoliosis

EOS: low-dose 3D imaging system

ESIN: elastic stable intramedullary nailing

LIPUS: low-intensity pulsed ultrasound

MCGR: magnetically controlled growing rods

POCUS: point-of-care ultrasound

PSI: patient-specific instrumentation

VBT: vertebral body tethering

VSP: virtual surgical planning

Declarations

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Author contributions

DB: Conceptualization, Investigation, Writing—original draft, Writing—review & editing. DA: Conceptualization, Supervision, Writing—original draft. MB: Data curation, Validation, Writing—review & editing. FM: Visualization, Validation, Writing—review & editing. All authors read and approved the submitted version.

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