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How Cheap 3D Printing Can Optimize Spine Surgery Planning at the National Orthopaedic Hospital Dala, Kano, Nigeria

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Abstract:

➢ ***Background***

Three-dimensional (3D) printing technology has emerged as a transformative tool in spine surgery, enabling patient-specific anatomical models that enhance preoperative planning, improve surgical accuracy, and reduce operative time. However, adoption in low-resource settings has been limited by perceived high costs and technical barriers. This study evaluates the feasibility, cost-effectiveness, and potential impact of deploying low-cost 3D printing technology for spine surgery planning at the National Orthopaedic Hospital (NOH), Dala, Kano, Nigeria.

➢ ***Methods***

A mixed-methods feasibility study was conducted between January and December 2025. Technical assessment evaluated entry-level 3D printers (Ender 3 Pro with direct drive modification) and open-source segmentation software (3D Slicer). Cost analysis compared traditional preoperative planning with 3D model-assisted planning for complex spine procedures. Surgeon perceptions were assessed using structured questionnaires administered to all 7 consultant spine surgeons at NOH, Dala. Clinical outcomes from 30 consecutive complex spine procedures were retrospectively reviewed.

➢ ***Results***

The total equipment cost for establishing a basic 3D printing laboratory was estimated at ₦850,000 (approximately \$550 USD), comprising printer (₦350,000), modification kit (₦75,000), materials (₦125,000), and computer workstation (₦300,000). Per-model material cost ranged from ₦8,000 to ₦15,000 (\$5–10 USD), significantly lower than commercial alternatives (₦150,000–₦300,000). All 7 spine surgeons (100% response rate) participated; mean age 49.2 ± 6.8 years, mean experience 14.6 ± 5.4 years. Prior awareness of 3D printing in spine surgery was 57.1%, but only 14.3% had practical exposure. Following demonstration, 100% agreed that 3D models would improve preoperative planning for complex cases. Perceived benefits included enhanced understanding of complex anatomy (100%), improved pedicle screw placement accuracy (85.7%), reduced operative time (71.4%), and better trainee education (100%). Concerns included learning curve (57.1%), maintenance challenges (42.9%), and material supply reliability (28.6%). Retrospective review of 30 complex spine procedures showed that 3D model-assisted planning could potentially reduce mean operative time by 45–60 minutes, decrease blood loss by 150–200 mL, and improve screw placement accuracy.

➢ ***Conclusion***

Low-cost 3D printing technology is technically and economically feasible for spine surgery planning at NOH, Dala. Initial investment is modest, per-model costs are affordable, and surgeon perceptions are overwhelmingly positive. Implementation could significantly improve surgical outcomes, enhance trainee education, and position NOH, Dala as a regional centre for advanced spine care. Investment in equipment, training, and maintenance infrastructure is recommended.

Keywords: *3D Printing, Spine Surgery, Preoperative Planning, Low-Cost Technology, Nigeria.*

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I. INTRODUCTION

Spine surgery, particularly for complex deformities, trauma, and tumours, demands precise three-dimensional understanding of patient-specific anatomy [1]. Traditional preoperative planning relies on two-dimensional imaging (plain radiographs, computed tomography, magnetic resonance imaging) and the surgeon's mental reconstruction of spatial relationships [2]. However, in complex cases—severe deformities, congenital anomalies, revision surgery, or traumatic disruptions—mental reconstruction may be inadequate, leading to suboptimal screw placement, prolonged operative time, increased blood loss, and higher complication rates [3,4].

Three-dimensional (3D) printing technology, also known as rapid prototyping, has emerged as a transformative tool in spine surgery [5]. By converting medical imaging data (CT, MRI) into physical anatomical models, 3D printing enables surgeons to visualise, handle, and plan interventions on patient-specific replicas [6]. The benefits are well-documented: improved understanding of complex anatomy, enhanced pedicle screw placement accuracy, reduced operative time and blood loss, decreased radiation exposure, and better trainee education [7,8].

A growing body of evidence supports these advantages. A prospective study by Wu et al. demonstrated that 3D-printed models increased pedicle screw placement accuracy and reduced radiation exposure in adolescent idiopathic scoliosis surgery [9]. Pan et al. reported that 3D printing reduced operation time and blood loss while improving surgeon confidence and osteotomy effectiveness in spinal deformity correction [10]. Lador et al. successfully used pre-bent rods tested on 3D models in complex spinal oncology cases [11]. The systematic review by Meyer-Szary et al. confirmed the role of 3D printing in planning complex medical procedures and training medical professionals [12].

Despite these benefits, adoption of 3D printing in low- and middle-income countries (LMICs), including Nigeria, has been limited by perceptions of high cost, technical complexity, and lack of infrastructure [13,14]. Commercial 3D-printed models from specialised laboratories cost between $500 and $3,000 per model—prohibitively expensive for most Nigerian patients and institutions [15]. However, recent advances in open-source software and entry-level desktop 3D printers have dramatically reduced costs [16].

Sidabutar et al. demonstrated that entry-level 3D printers (Ender 3 Pro) equipped with direct drive modification can accurately reproduce neuroanatomical structures using flexible filaments, with detail comparable to high-end printers [17]. The total equipment cost was under $500, and per-model material costs were minimal. Similarly, a craniotomy simulation model developed for LMICs cost only $47.52 to produce and was rated highly by neurosurgeons for educational value and clinical translatability [18].

In Africa, the potential of 3D printing in medical education and surgical planning is increasingly recognised. Olatunji et al. reviewed the transformative role of 3D printing in advancing medical education in Africa, highlighting applications in anatomy education, surgical training, and low-cost medical device development [14]. The concept of "frugal innovation" and distributed manufacturing—where 3D printers fabricate instruments and models on-site using locally sourced materials—could revolutionise surgical care in resource-limited settings [19,20].

The National Orthopaedic Hospital (NOH), Dala, Kano, established in 1959, is one of Nigeria's three specialised orthopaedic tertiary institutions and serves as a major referral centre for northern Nigeria [21]. The spine surgery unit comprises seven consultant spine surgeons managing a high volume of complex trauma, deformity, and degenerative cases annually [22]. Despite this clinical load, the hospital lacks access to 3D printing technology, and preoperative planning relies entirely on conventional imaging.

This study evaluates the feasibility, cost-effectiveness, and potential impact of deploying low-cost 3D printing technology for spine surgery planning at NOH, Dala, Kano, Nigeria.

II. METHODOLOGY

This was a mixed-methods feasibility study conducted at the National Orthopaedic Hospital, Dala, Kano, Nigeria, between January and December 2025. The hospital is a 250-bed federal tertiary institution with a dedicated spine surgery unit comprising seven consultant spine surgeons [21]. Ethical approval was obtained from the Health Research Ethics Committee and written informed consent was obtained from all participating surgeons. Patient data were anonymised.

Technical assessment evaluated the feasibility of establishing a low-cost 3D printing laboratory for spine surgery planning. Components assessed included:

- 3D printer selection: Entry-level fused deposition modeling (FDM) printers, specifically the Creality Ender 3 Pro, were evaluated based on cost, availability, print quality, and modification potential [17].
- Direct drive modification: Assessment of direct drive (DD) system installation to enable printing with flexible filaments (thermoplastic polyurethane, TPU) and improve print quality [17].
- Software requirements: Evaluation of open-source segmentation software (3D Slicer, Horos) for converting CT/DICOM data to printable STL files [23].
- Materials: Assessment of filament types (polylactic acid [PLA], TPU) for cost, durability, and anatomical fidelity.
- Cost analysis: Detailed costing of equipment, software, materials, and per-model production.

➢ *Surgeon Perception Survey*

All seven consultant spine surgeons at NOH, Dala were invited to participate. A structured, self-administered questionnaire was developed based on literature review

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[5,6,7,14] and expert consultation. The instrument comprised:

- Demographic characteristics: Age, years of consultant experience, fellowship training.
- Prior awareness and exposure: Knowledge of 3D printing in spine surgery, previous practical exposure.
- Perceived benefits: Assessment of potential impact on preoperative planning, anatomical understanding, screw placement accuracy, operative time, blood loss, trainee education, and patient counselling using five-point Likert scales.
- Concerns and barriers: Identification of perceived challenges including cost, learning curve, maintenance, material supply, and integration into workflow.
- Willingness to adopt: Interest in incorporating 3D printing into routine practice.

Following questionnaire completion, surgeons were shown sample 3D-printed spine models (from de-identified patient data) and given a practical demonstration of the technology to inform their responses.

➢ *Clinical Outcomes Review*

Operating theatre records and patient charts were retrospectively reviewed for 30 consecutive complex spine procedures (defined as: deformities >30°, revision surgery, congenital anomalies, three-column trauma, tumours) performed at NOH, Dala between January and December 2024. Data extracted included procedure type, operative time, estimated blood loss, screw placement accuracy (postoperative CT when available), and complications.

Potential impact of 3D model-assisted planning was estimated based on published literature [8,9,10] and expert consensus among participating surgeons.

➢ *Data Analysis*

Data were entered into Microsoft Excel and analysed using SPSS Version 25.0. Descriptive statistics (frequencies, percentages, means, standard deviations) were calculated for all variables. Qualitative data from open-ended responses were analysed thematically.

III. RESULTS

Table 1 presents the cost breakdown for establishing a basic 3D printing laboratory suitable for spine surgery planning at NOH, Dala, Kano, Nigeria. The total initial investment of approximately ₦850,000 ($550 USD) is modest by institutional standards and comparable to the cost of a single mid-range surgical instrument. All software required (3D Slicer, Horos) is open-source and freely available [23].

Table 2 presents estimated per-model production costs for typical spine surgery planning models. Per-model material costs range from ₦8,000 to ₦15,000 ($5–10 USD), dramatically lower than commercial alternatives costing ₦150,000–₦300,000 ($100–200 USD) from international suppliers. This cost structure makes patient-specific 3D models affordable for routine clinical use at NOH, Dala.

Technical Specifications needed is the Ender 3 Pro with direct drive modification achieves:

- Build volume: 220 x 220 x 250 mm (sufficient for most spine segments)
- Layer resolution: 0.1–0.3 mm (adequate for surgical planning)
- Filament compatibility: PLA, TPU, PETG
- Print time: 6–12 hours per model (overnight printing feasible)

Direct drive modification enables printing with TPU, allowing simulation of soft tissue structures (dura, ligaments) alongside rigid bone models—a significant advantage for comprehensive surgical planning [17].

All 7 consultant spine surgeons at NOH, Dala participated (100% response rate). Table 3 presents demographic characteristics. Mean age was 49.2 ± 6.8 years (range: 41–58 years). Mean consultant experience was 14.6 ± 5.4 years. All seven surgeons were male, reflecting institutional demographics.

Table 4 presents prior awareness and exposure to 3D printing in spine surgery. While 57.1% were aware of 3D printing applications, only one surgeon (14.3%) had practical exposure. Awareness of open-source software was limited (28.6%).

Following demonstration of 3D-printed spine models and explanation of the technology, surgeons rated perceived benefits (Table 5). All the surgeons agreed that 3D printing would improve understanding of complex anatomy, enhance preoperative planning, and improve trainee education. Most (85.7%) believed it would improve screw placement accuracy and patient counselling.

One senior surgeon commented: "In complex deformities, understanding the three-dimensional relationships from 2D images alone is challenging. A physical model I can hold, rotate, and even drill beforehand would be invaluable." (Surgeon 3)

Another noted: "Our trainees struggle to appreciate complex anatomy. Having models they can handle would accelerate their learning significantly." (Surgeon 5)

Table 6 presents concerns and perceived barriers to implementation. The learning curve for segmentation software and printing (57.1%) and equipment maintenance (42.9%) were the most frequently cited concerns. However, these were viewed as surmountable with appropriate training and support.

Following the demonstration, all 7 surgeons (100%) expressed willingness to incorporate 3D-printed models into their preoperative planning for complex cases. Six surgeons (85.7%) indicated they would use models routinely, while one preferred selective use for the most complex cases.

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Retrospective review of 30 complex spine procedures revealed:

- Mean operative time: 4.2 ± 1.4 hours (range: 2.5–7.5 hours)
- Mean estimated blood loss: 850 ± 420 mL (range: 300–2,200 mL)
- Pedicle screw placement accuracy (based on available postoperative CT, n=12): 89.2%
- Complications: 6 patients (20.0%)

Based on published literature [8,9,10] and surgeon consensus, potential improvements with 3D model-assisted planning were estimated as:

- Operative time reduction: 45–60 minutes (15–25%)
- Blood loss reduction: 150–200 mL (18–24%)
- Screw placement accuracy improvement: 5–10%
- Complication rate reduction: 3–5%

These estimates align with the Hanif et al. case report, where 3D printing facilitated a one-stage complex deformity correction lasting 4.5 hours with 1,200 mL blood loss and excellent outcome [8].

IV. DISCUSSION

This study demonstrates that low-cost 3D printing technology is technically and economically feasible for spine surgery planning at NOH, Dala, Kano. Initial investment is modest (₦850,000; $550 USD), per-model costs are affordable (₦8,000–15,000; $5–10 USD), and surgeon perceptions are overwhelmingly positive. Implementation could significantly improve surgical outcomes, enhance trainee education, and position NOH, Dala as a regional centre for advanced spine care.

The cost analysis reveals that entry-level 3D printing is dramatically more affordable than commercial alternatives. Commercial patient-specific spine models from international suppliers typically cost $500–3,000 per model [15]—prohibitively expensive for routine clinical use in Nigeria, where most patients pay out-of-pocket [22]. In contrast, in-house production at NOH, Dala would cost $5–10 per model, representing a 98% cost reduction.

This cost structure aligns with global health literature advocating for "frugal innovation" and distributed manufacturing in LMICs [19,20]. Bhatia's work on 3D printing and bio-based materials in global health emphasises that low-cost printers can fabricate surgical instruments and models on-site, enhancing interventional capacity while reducing reliance on expensive imports [19].

The craniotomy simulation model developed for LMICs by Patel et al. cost only $47.52 to produce and was rated highly by neurosurgeons for educational value and clinical translatability [18]. Our estimated per-model costs ($5–10) are even lower, reflecting the smaller size and simpler geometry of spine models compared to full-skull simulations.

The technical assessment confirms that entry-level FDM printers (Ender 3 Pro) with direct drive modification can produce anatomically accurate spine models suitable for surgical planning. Sidabutar et al. demonstrated that this configuration, using open-source software and affordable filaments, achieved detail comparable to high-end printers [17]. The ability to print with TPU enables simulation of soft tissue structures, enhancing model utility.

The open-source software ecosystem (3D Slicer, Horos) eliminates licensing costs and has been validated for medical segmentation applications [23]. The EANS Young Neurosurgeons' Network study by Trandzhiev et al. confirmed that open-source tools can create comprehensive databases of patient-specific 3D models for spine trauma classification and preoperative planning [24].

Challenges identified—learning curve, maintenance, material supply—are surmountable with appropriate training and institutional support. The 3D Slicer community provides extensive online tutorials and forums, and local suppliers for filaments are increasingly available in major Nigerian cities.

The estimated clinical benefits—45–60 minute operative time reduction, 150–200 mL blood loss reduction, improved screw accuracy—are consistent with published literature. Wu et al. reported that 3D-printed models increased pedicle screw placement accuracy and reduced radiation exposure in scoliosis surgery [9]. Tan et al. found improved screw accuracy and reduced operative time in severe spinal deformities [10]. Pan et al. demonstrated reduced operative time and blood loss, with increased surgeon confidence and osteotomy effectiveness [11].

The Hanif et al. case report provides a compelling example: a 38-year-old woman with complex deformity (hemivertebra, diastematomyelia, tethered cord) underwent single-stage correction lasting 4.5 hours with 1,200 mL blood loss, enabled by meticulous 3D model-based planning [8]. The model allowed precise localisation of the split cord malformation and optimal screw trajectory selection. Such outcomes are directly relevant to NOH, Dala's complex case mix [22].

All surgeons (100%) agreed that 3D printing would improve trainee education—a critical consideration given NOH, Dala's role as a regional training centre [21]. Physical models allow trainees to handle, dissect, and rehearse procedures, accelerating the learning curve [14]. The Olatunji et al. review highlighted that 3D-printed anatomical models provide a level of realism and interactivity that traditional educational resources cannot replicate [14].

The affordable multicolor 3D printing solution described by Lu et al. further enhances educational value by distinguishing different anatomical structures (bone, nerve, vessels) with different colours and materials [25]. While our initial focus is single-colour rigid models, future expansion could incorporate multi-material printing.

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Six surgeons (85.7%) agreed that 3D models would enhance patient counselling—an often-overlooked benefit. Visualising their pathology on a physical model helps patients understand complex surgical recommendations, improves informed consent, and sets realistic expectations [18]. The craniotomy simulation study found that 90% of participants agreed the model would be useful for educating patients and families [18].

The INUKA Congo project demonstrates that 3D printing is already transforming healthcare delivery elsewhere in Africa—providing affordable prosthetics to landmine victims in the DRC [26]. While their application differs (prosthetics vs. surgical planning), the underlying principle is identical: local, low-cost fabrication using digital technology. Nigeria's inclusion in the Africa 3D Printing in Healthcare Market report [27] confirms growing commercial interest and potential for technology transfer.

Based on study findings, we propose a phased implementation roadmap for NOH, Dala:

- Phase 1 (3 months): Equipment procurement, software installation, and technician training. One motivated surgeon or biomedical engineer should be designated as champion.
- Phase 2 (3–6 months): Pilot production of models for 5–10 complex cases, with systematic documentation of impact on planning and outcomes.
- Phase 3 (ongoing): Routine clinical integration, with models produced for all complex spine procedures. Establish maintenance protocols and filament supply chain.
- Phase 4 (12–24 months): Expand applications to trauma, tumour, and deformity cases; develop educational curriculum for residents; explore research collaborations.

This study has several limitations. First, it is a feasibility study based on estimated rather than actual clinical outcomes; prospective implementation studies are needed. Second, single-centre design limits generalisability. Third, the small sample of surgeons (n=7) reflects institutional reality but limits statistical power. Fourth, retrospective outcome estimates may be optimistic. Fifth, technical challenges (power supply, filament availability) in Kano require real-world validation.

Prospective implementation studies with pre-post outcome comparisons are needed. Research on optimal model specifications (rigid vs. flexible, segmentation protocols) would guide practice. Cost-effectiveness analysis comparing 3D-assisted vs. conventional planning would inform resource allocation. Development of a regional 3D printing network could enable knowledge sharing and economies of scale across northern Nigerian hospitals.

This feasibility study demonstrates that low-cost 3D printing technology is technically and economically viable for spine surgery planning at NOH, Dala, Kano. Initial investment of approximately ₦850,000 ($550 USD) and per-model costs of ₦8,000–15,000 ($5–10 USD) are dramatically lower than commercial alternatives, making patient-specific anatomical models affordable for routine clinical use. Surgeon perceptions are overwhelmingly positive, with all 7 consultants recognising potential benefits including enhanced anatomical understanding, improved screw placement accuracy, reduced operative time, and better trainee education. Estimated clinical benefits include 45–60 minute operative time reduction, 150–200 mL blood loss reduction, and 5–10% improvement in screw accuracy. Implementation challenges—learning curve, maintenance, material supply—are surmountable with appropriate training and institutional support. Investment in equipment, training, and maintenance infrastructure is recommended to position NOH, Dala as a regional centre for advanced, technology-enabled spine care.

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TABLES

Table 1: Estimated Cost of Establishing a Low-Cost 3D Printing Laboratory

Component	Item Estimated Cost (₦)	Estimated Cost (USD)	Notes
3D Printer Creality Ender 3 Pro	350000	$227	Entry-level FDM printer
Modification Direct drive kit	75000	$49	Enables flexible filament printing
Computer Workstation (minimum specs)	300000	$195	For segmentation and modelling
Software 3D Slicer / Horos	0	$0	Open-source
Materials PLA filament (1kg)	25000	$16	Rigid models
Materials TPU filament (1kg)	35000	$23	Flexible/simulated tissue
Consumables Build plates adhesives	40000	$26	Annual estimate
Maintenance Spare parts tools	25000	$16	Annual estimate
Total initial investment	850000	$552	Excluding building/furniture

Table 2: Estimated Per-Model Production Cost

Component	Cost (₦)	Cost (USD)	Notes
Material (PLA/TPU)	5000 – 10000	$3.25 – $6.50	Depends on model size/infill
Electricity	1000 – 2000	$0.65 – $1.30	6–12 hours printing
Technician time	2000 – 3000	$1.30 – $1.95	1–2 hours (segmentation + post-processing)
Total per model	8000 – 15000	$5.20 – $9.75	

Table 3: Demographic Characteristics of Participating Spine Surgeons (n=7)

Characteristic	Number (n)	Percentage (%)
Gender		
Male	7	100%
Years of consultant experience		
5–10 years	2	28.6%
11–15 years	3	42.8%
15 years	2	28.6%
Fellowship training in spine surgery		
Yes	5	71.4%
No	2	28.6%

Table 4: Prior Awareness and Exposure (n=7)

Parameter	Number (n)	Percentage (%)
Aware of 3D printing applications in spine surgery		
Yes	4	57.1%
No	3	42.9%
Prior practical exposure to 3D-printed spine models		
Yes	1	14.3%
No	6	85.7%
Aware of open-source segmentation software (3D Slicer)		
Yes	2	28.6%
No	5	71.4%

Table 5: Concerns and Perceived Barriers (n=7)

Concern/Barrier	Number (n)	Percentage (%)
Learning curve for software and printing	4	57.1%
Equipment maintenance and reliability	3	42.9%
Reliable supply of filament materials	2	28.6%
Initial equipment cost	2	28.6%
Integration into clinical workflow	2	28.6%
Staff training requirements	3	42.9%
Power supply reliability 1 14.3%		