Capability of 3D Printed Part Used in Medical Surgery of Spine Bone Replacement

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***Abstract*— This research presents a study undertaken following the collaboration between specialists in two multidisciplinary fields, namely engineering and medicine. It was aimed at solving a practical problem by developing a spine bone for use in orthopedic surgery. Specific engineering tools, knowledge and processes, and methods were used for accomplishing this task. 3D Printer according to the surgeon's preferences for ensuring ergonomic use is an important criterion alongside functional and sterilization requirements, cost and manufacturing time, 3D printing represents a feasible manufacturing solution as this research proves. The research details the steps required to complete the final product: design, prototypes manufacturing, and testing. To perform the practical analysis that highlights the spine bone mechanical behavior, the finite element method was used in assessing different handle designs.**

***Index Terms*—Orthopedic, Practical Analysis, Spine Bone, 3D Printing, Material Characteristic.**

I. INTRODUCTION

3D printing, also known as additive manufacturing, is a revolutionary technology that creates physical objects directly from digital designs by building them layer by layer. It is widely used for rapid prototyping, product development, and even end-use parts. The process begins with a CAD (Computer-Aided Design) file, which is exported as an STL file and then processed by a slicer to generate G-code, the language that guides the printer's movements. Among the popular 3D printing methods are FDM (Fused Deposition Modeling), which extrudes melted filament like PLA or ABS; SLA (Stereolithography), which cures liquid resin with UV light; and SLS (Selective Laser Sintering), which fuses powdered materials using a laser. Other technologies include DLP, Binder Jetting, and Electron Beam Melting (EBM).

Common materials used in 3D printing include thermoplastics like PLA, ABS, PETG, and flexible TPU, as well as resins, nylon, and metal powders. During the printing process, settings such as layer height, infill, print speed, and support structures affect the quality and strength of the final product. Post-processing techniques like sanding, painting, or curing may be needed for a refined finish. Essential components of a printer include the extruder, nozzle, and heated bed, all of which must be properly calibrated to maintain dimensional accuracy and a high-quality surface finish. As digital fabrication continues to evolve, 3D printing is transforming manufacturing, medicine, architecture, and countless other fields.

II. CAD MODELLING OF SPINE BONE

III. CAD TOOL-SOLID WORK 2020

Solid Works 2016 is a 3D mechanical design system built with adaptive technology and solid modeling capabilities. The Solid Works 2016 software includes features for 3D modeling, information management, collaboration, and technical support with DSS you can:

1. Create 3D models and 2D manufacturing drawings.
2. Create adaptive features, parts, and subassemblies.
3. Manage thousands of parts and large assemblies.
4. Use third-party applications, with an Application Program Interface (API).
5. Use VBA to access the Autodesk Inventor API. Create programs to automate repetitive tasks. On the Help menu, choose Programmer Help.
6. Import SAT, STEP, and AutoCAD and Autodesk Mechanical Desktop (DWG) files for use in Autodesk Inventor. Export Autodesk Inventor file to AutoCAD, Autodesk Mechanical Desktop, and IGES formats.
7. Collaborate with multiple designers in the modeling process.
8. Link to web tools to access industry resources, share data, and communicate with colleagues.
9. Use the integrated Design Support System (DSS) for help as you work.

IV. WORKING WITH ASSEMBLIES

- Turn off the visibility of nonessential components. Access the parts we need and update graphics faster.
- Use design representations. Create design representations that highlight specific design problems or assembly subsystems, and apply them when opening the assembly model.
- Turn off part adaptivity. After we size components, turn off adaptivity to speed up solutions and prevent accidental changes.
- Assign different colors to components. Select colors from the Color list on the Standard toolbar.
- Use the browser to find components. Point to a component in the browser to highlight in the graphics window.
- Use color to identify components groups. Using attributes, find components in specific subsystems or from specific vendors and color-code them in named representations.

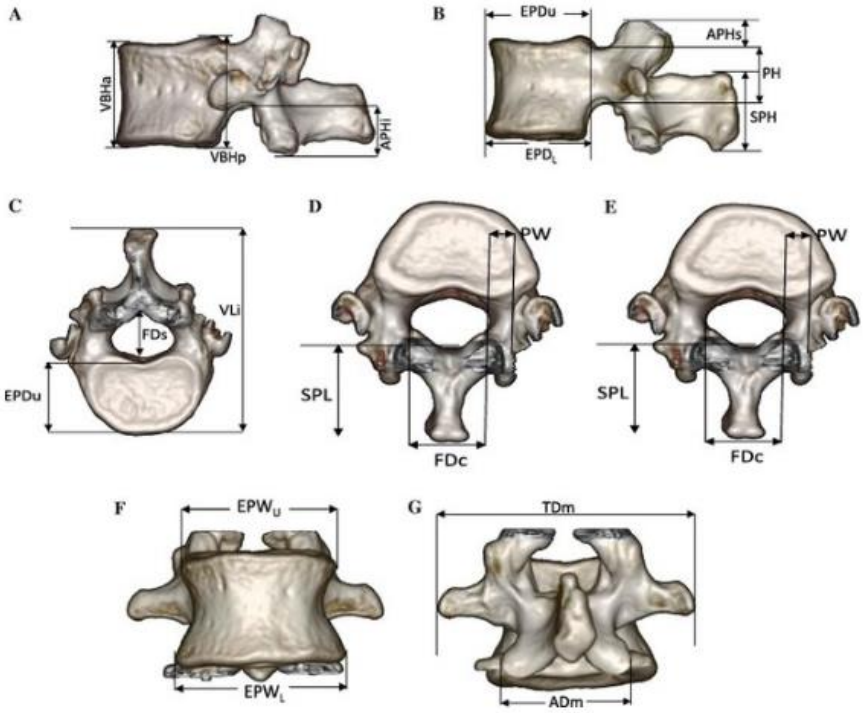

Fig. 1 The shape and dimensions of the different spine bones

Fig. 1 is reflected in detail drawing of different spine bones which are useful for orthopedic operation for the replacement of different parts of spine bones. Using part features creates all components of the structure. All assemblies are created using various components (part) by constrained their relative motion. Using part modeling environment to create structure. First to make the geometry of standard section pipe with respect their practical data to measure the thickness of plate and amount of extruded part by using extrude command in feature operation. Further using the new sketch on-base extruded component and sketch an existing extruded feature to identifying model width. As shown in Figure 2 to 3, there are different orientations of 3 D Printer such as isometric view, front view, top view, and side view.

Fig. 2 Isometric view of Left Side Spine

Fig. 3 Isometric view of Right-Side Spine

V. PRACTICAL MODEL AND TESTING

Both spine bones have been 3D printed in two orientations: longitudinal and transverse, as can be seen in Figures 4 and 5.

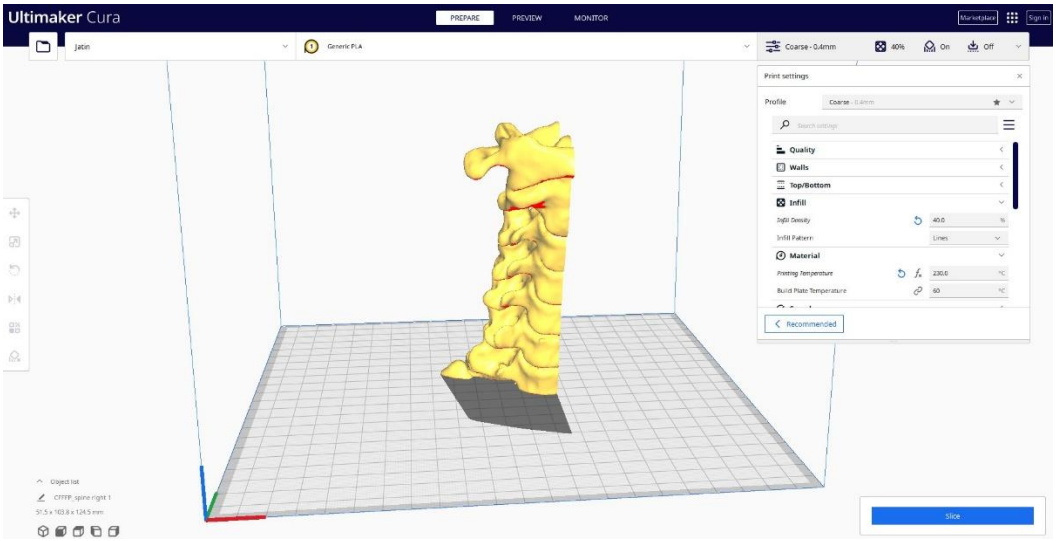

Fig. 4 Right side Spin 3D printed in longitudinal directions

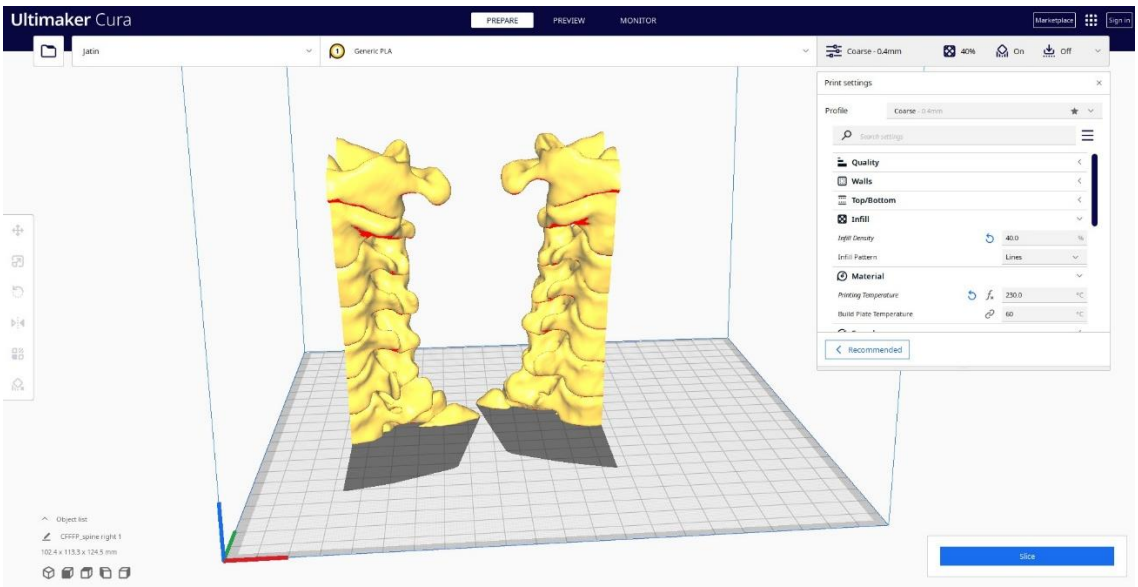

Fig. 5 Both Left and Right Side Spine Bones, 3D printed in transversal directions

Cura is one of the most popular and widely used slicing software for 3D printing. Developed by Ultimaker, Cura is an open-source program that prepares digital 3D models for printing by converting them into G-code, which guides the movements

and actions of a 3D printer. The software takes a 3D model file (commonly in STL, OBJ, or 3MF format) and slices it into thin horizontal layers, determining how the printer will build the object layer by layer. It also allows users to configure critical print settings such as layer height, print speed, infill density, support structures, and nozzle temperature, among many others.

Cura offers a user-friendly interface suitable for both beginners and advanced users. It features a “Recommended” mode with simplified settings for novices, while the “Custom” mode provides access to hundreds of parameters for experienced users who want fine control over the printing process. Cura also includes print time estimates, material usage calculations, and preview options to visualize the sliced model before printing.

Ultimaker printers, Cura supports a wide range of third-party 3D printers, making it highly versatile. Users can download pre-configured printer profiles or add custom ones. Cura also supports plugins and integration with design software like SolidWorks and Autodesk Fusion 360, expanding its functionality. Overall, Cura plays a vital role in the 3D printing workflow, bridging the gap between digital design and physical fabrication with precision and flexibility.

Working with Cura software involves a systematic process that transforms a 3D model into a printable file. After downloading and installing Cura from the official Ultimaker website, the first step is to open the software and select your 3D printer model from the available list or add a custom one. Once the printer is set up, you can import a 3D model into Cura by either clicking "Open File" or simply dragging and dropping the file into the workspace. Cura supports common 3D model formats such as .STL, .OBJ, and .3MF.

Once the model is loaded, you can manipulate it using tools for moving, scaling, rotating, and mirroring to ensure it's properly positioned on the virtual print bed. After adjusting the model, the next step is to configure the print settings. Cura offers a “Recommended” mode for beginners with simplified options, and a “Custom” mode that provides access to advanced parameters such as layer height, print speed, infill density, support structures, and temperature settings for both the nozzle and heated bed. It's important to also select the appropriate material profile, such as PLA or ABS, to match what you'll be using in the printer.

Once all settings are adjusted, you click the "Slice" button. Cura will process the model and generate a G-code file, which contains all the instructions needed for the printer. You can then preview the sliced model, layer by layer, to check for issues with supports, infill, or other aspects of the print. After verifying the preview, the G-code can be saved to an SD card, USB stick, or sent directly to a connected printer.

The final step is to load the G-code into your 3D printer and start the printing process. It's recommended to monitor the first few layers of the print to ensure proper bed adhesion and printer operation. Once the print is complete, the object can be removed from the build plate and any necessary post-processing, such as support removal or surface finishing, can be carried out. This workflow makes Cura an essential and efficient tool in the 3D printing process.

Fig. 6 Spines Physical Prototype

Fig. 7 Spines use in Surgery

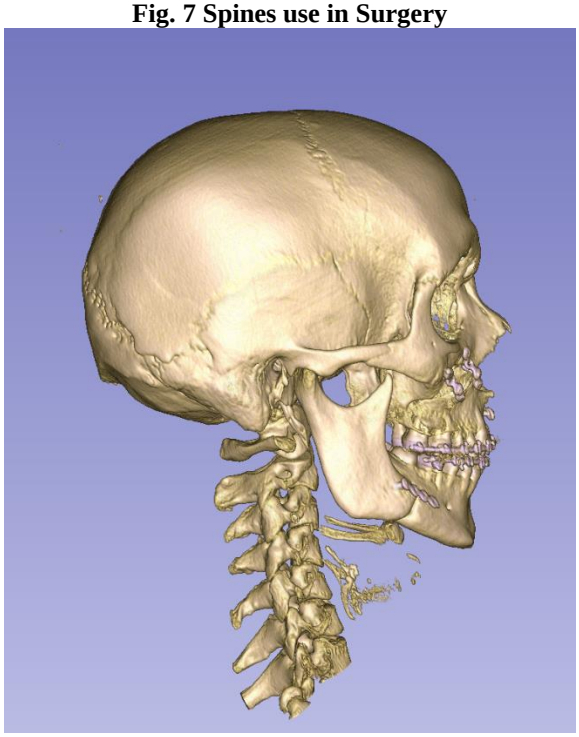

Fig. 8 Practical Match with Real Boen Part for Surgery

As shown in Figure 6 to 8 which containing 3D printed part of both left and right spine which tested different environment as medical standards and also check possible geometrical constrain and strenth also. Also tested each part part practically assembled with respect to real bones assembly from beck area to bottom area spines assembly. There are different appraoch used for testing as per body internal part with mechanical material characteristic then it was survives that long life inside human body.

To ensure the safety, effectiveness, and reliability of a 3D printed bone part used in medical applications, especially for procedures such as spinal bone replacement, a comprehensive evaluation process must be followed. This process includes multiple stages of inspection and testing to confirm that the part meets medical, mechanical, and regulatory standards. The first step typically involves a visual and dimensional inspection, where tools such as calipers, 3D scanners, or coordinate measuring machines (CMM) are used to compare the physical part to the original digital design. CT scanning can also help assess internal accuracy and identify any voids or printing defects that may not be visible on the surface. Surface finish is carefully examined to ensure that it is appropriate for surgical use and for integration with biological tissues.

Mechanical testing is another critical aspect of the evaluation. The 3D printed part must undergo tests such as tensile, compression, bending, and fatigue tests to ensure that it can withstand physiological loads over time. These tests verify that the printed material has the strength and durability required for long-term use inside the human body. In addition to macro-level strength, the hardness and microstructure of the material are assessed through advanced techniques like Scanning Electron Microscopy (SEM) or X-ray Diffraction (XRD), especially if metallic or composite materials are used.

Material characterization and verification are essential to confirm that the 3D printed part is made from certified medical-grade materials. The density and porosity of the structure are measured to ensure compatibility with bone growth and biological function. For parts designed to mimic the structure of real bone, these characteristics are crucial to facilitate osseointegration. Biocompatibility and sterilization testing are mandatory to ensure the part does not cause adverse reactions in the human body. ISO 10993 standards are typically followed for testing cytotoxicity, sensitization, and irritation, and the ability of the part to withstand sterilization processes (such as autoclaving or gamma radiation) is also verified.

Fit and function testing is performed to ensure that the part matches the patient's anatomy precisely and functions properly within a surgical context. This may include trial fittings using anatomical models or simulations with cadaver specimens. If the implant is designed to work with screws or plates, assembly and fixation tests are conducted to check alignment and fit. The imaging compatibility of the 3D printed part must also be verified to ensure it does not interfere with diagnostic imaging such as X-rays, CT scans, or MRIs, depending on the clinical need.

Lastly, compliance with medical regulatory standards is required. The entire design, manufacturing, and validation process must meet the criteria set by regulatory bodies such as the FDA (in the USA), CE (in Europe), or BIS (in India), as well as follow international standards such as ISO 13485 for medical device quality management and ASTM F42 for additive Smanufacturing. Thorough documentation of all evaluations, tests, and approvals ensures that the 3D printed bone part is safe, reliable, and ready for surgical application in real patients.

VI.CONCLUSION

The capability of 3D printed parts in medical surgery, particularly for spine bone replacement, represents a significant advancement in personalized healthcare. 3D printing allows for the creation of patient-specific implants that match the anatomical structure of an individual's spine with high precision. These implants can be made from biocompatible materials such as titanium or medical-grade polymers, offering excellent mechanical strength, osseointegration, and long-term stability. The technology also enables the fabrication of complex geometries, such as porous structures, which promote bone in-growth and reduce implant weight. Moreover, the rapid prototyping feature of 3D printing shortens surgical preparation time and improves surgical outcomes by enhancing implant fit and alignment. As a result, 3D printed spinal implants not only improve patient recovery and comfort but also open new possibilities for customized, minimally invasive, and more effective spinal surgeries. With ongoing research and regulatory advancements, the role of 3D printing in spinal surgery is expected to expand, making it a cornerstone of future orthopaedic and neurosurgical practices.

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