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3- Dimensional (3D) Printing Technology in Forensic Medicine- An Overview of Indian Scenario

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Abstract: In this paper, we take a look at the current state of 3D printing technology as it pertains to forensic medicine in India. From developing anatomical models for disease detection and surgical planning to its promise in bio mechanical modelling and tool creation, the book examines the many uses and difficulties of 3D printing in the area. The research highlights the value of precise digital 3D modelling, careful consideration of materials, and repeated testing of prototypes. It also calls into question the viability of 3D printing on a large scale and emphasizes the need for standardized methods and ethical principles in the use of this technology in forensics. While 3D printing is still in its infancy in India, there is hope for its future development and effect in forensic medicine because to continuous research and interdisciplinary cooperation.

Keywords: 3D Printing, Forensic Medicine. Anatomical Models, Bio mechanical Modeling, Digital 3D Modeling, Indian Scenario

Introduction

The field of forensic medicine has witnessed a significant transformation with the advent of 3D printing technology, a revolutionary manufacturing process that allows for the creation of three-dimensional objects from digital models. In the context of India, this technology has begun to make inroads into forensic applications, promising to revolutionize the way investigations are conducted and medical practices are carried out. This paper delves into the current state of 3D printing technology within the realm of forensic medicine in India, shedding light on its diverse applications, associated challenges, and the immense potential it holds.

The use of 3D printing in forensic medicine spans various facets, from the development of anatomical models for disease detection and surgical planning to its utility in bio mechanical modeling and the creation of specialized tools. This technology relies on the precise digital rendering of three-dimensional objects, enabling forensic experts to replicate intricate anatomical structures and evidentiary items with a level of detail and accuracy previously unattainable. However, while the promise of 3D printing is evident, it comes with its own set of technical and practical challenges.

Materials play a crucial role in 3D printing, and the selection of appropriate materials must consider factors such as mechanical properties, durability, and suitability for forensic applications. Moreover, the balance between rapid prototyping and mass production is a critical consideration, especially in a forensic context where both precision and efficiency are paramount. Establishing standardized protocols, ethical guidelines, and best practices is imperative to harness the full potential of 3D printing in forensics.

In the Indian scenario, 3D printing technology in forensic medicine is still in its nascent stages, with initial studies and proof-of-concept research paving the way for future advancements. Collaboration across various disciplines, rigorous validation of measurements, and adherence to ethical standards are key factors that will shape the trajectory of 3D printing's impact on forensic medicine in India and beyond.

This paper aims to provide a comprehensive overview of the applications, challenges, and potential of 3D printing in forensic medicine within the Indian context. It underscores the trans formative capabilities of this technology and the need for a concerted effort to leverage its capabilities effectively, ultimately enhancing the precision and efficacy of forensic investigations and medical practices.

3D-printing

The phrase "3D-printing" refers to a family of processes that use successive layers of material to create three-dimensional forms. One popular and cost-effective 3D printing method is Fused Deposition Modelling (FDM). FDM operates by continuously feeding a thermoplastic material through a heated nozzle, where it melts and is layered onto the print bed. This process builds layers upon layers, ultimately forming the desired three-dimensional object.

Common materials used in 3D printing, particularly in desktop printing, include Poly lactic acid (PLA) and acrylonitrile butadiene styrene (ABS). These materials are favored for their availability and ease of use. While PLA is known for its speed and potential low cost, it's essential to note that 3D printing is not limited to these materials. Various other techniques exist, such as photopolymerization, material jetting, binder jetting, sheet lamination, directed energy deposition, and powder bed fusion. This diversity of techniques falls under the broader term "additive manufacturing."

One of the major strengths of 3D printing is its ability to rapidly produce physical objects from digital 3D models using reasonably affordable technologies like PLA or ABS printing. This capability facilitates various applications, including rapid prototyping, the creation of new products, replacement components, and the manufacturing of basic 3D models for display. These tools allow for on-site production and quick testing of designs.

While "rapid prototyping" is often used interchangeably with 3D printing, it refers to a distinct process. In rapid prototyping, a designer creates a digital 3D model for use in development and improvement cycles. 3D printing enables the efficient creation of a single physical instance of the digital model, providing a cost-effective and precise way to evaluate the design. Multiple iterations of prototyping and improvement are typically performed before considering the digital 3D model as complete.

Importantly, the final shape of a digital 3D model does not have to be decided during the rapid prototyping stage. Each case is evaluated individually to determine whether the prototypes that passed testing can be used for the final product or if a different production approach is necessary. Once the design phase is complete, the same 3D model can be sent for more complex production methods, such as binder-jetting for metal objects or laser sintering for high-definition acrylic items.

Description of the technique and steps

General object creation and manufacturing

In general, the process of manufacturing an item may be addressed via a variety of methods, such as the processing of sheet metal, casting, and moulding, machining, manually sculpting or carving using a variety of materials including clay, and last but not least, 3D printing. Each of these processes can be used to manufacture an object. Some of these approaches, such as 3D printing, need for the creation of a digital 3D model of the product beforehand [8, 36].

Creating a digital 3D model

When the surface of an item has to be digitally specified before the manufacturing process can begin, that surface needs to be capable of enclosing a volume in such a manner that the volume is defined by the surface as a so-called solid [14].

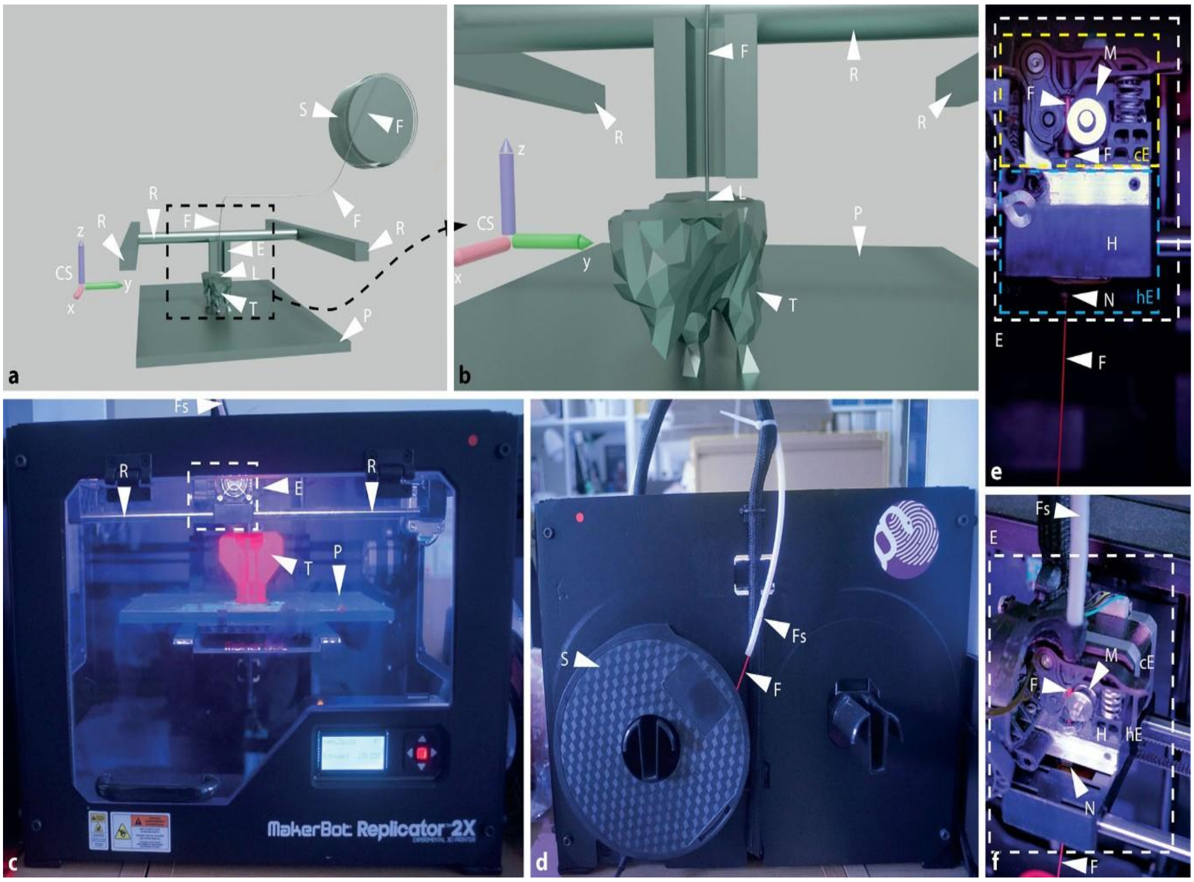

Figure 1 for an explanation of how a 3D printer that uses PLA works; remember to take into account the coordinate system (CS) in pictures (a) and (b). The 3D printer's extruder (E) is connected to the flexible PLA filament of uniform diameter (F), which is supplied on a roll and attached on a spool (S). Cold ends (cE) and hot ends (hE) are common components of the extruder. To feed the cold, solid filament into the hot end, a motor (M) is housed in the cold end. Since the filament loses its rigidity when melted, the motor can only properly move it while it is still solid. The PLA is melted in the hot end and then extruded via a nozzle (N). The hot end incorporates components to create, regulate, and transfer heat (H). Any properly calibrated 3D printer will transfer the liquid PLA to the material just above L, beneath the nozzle. To construct the model (T), PLA is deposited in successive layers onto a buildplate(P) that is subsequently lowered (and therefore shifted in the direction of -Z). As the sculpture progresses, additional PLA layers are added to the top (also see OFig. 3, pictures a-c). After the first layer of PLA has cooled and set, you may deposit a second layer. Printing too quickly might cause warping because the extruder must be moved along rails (R) in the X and Y directions to access opposite sides of the build plate. The technological operation of our PLA-based 3D printer is represented by the symbolic representations in a and b. The 3D printer we used to manufacture the model in O Fig. 3 is illustrated in images c and d. The device's setup originally had a pair of ABS extruders, but it was later upgraded to include a PLA extruder (designated as Extruder E in the following text). After we removed the fan used to regulate temperature, the inner workings of our experimental extruder (E) were visible in images e and f.

Capturing the surface of an existing actual item (perhaps by 3D scanning or photogrammetry) or manually building the 3D model using software are the two primary methods of making a 3D model [43]. One may do both by first capturing the surface of a real-world item in three dimensions, and then using that three-dimensional model in digital post-production.

Digital 3D models created using 3D surface capture may be overly big, jagged, or noisy. In most cases, editing is necessary to fix non-manifolds and get solid geometry [2, 11]. Computed tomography (CT) scan- ning has been utilised to initiate 3D model construction, despite the fact that not all surface angles are conducive to 3D surface capture [11, 24]. To generate a more convincing visual realism, such as by smoothing [11], certain digital 3D models were altered, although not necessarily for technological reasons.

Parametric (as opposed to free-form) modelling is the prefered method for making 3D models in computer programmes. One option is to employ 3D software, which might enable the user to return to the digital 3D model and make modifications to the object's form, design, size, location, or orientation with more ease [9].

Finite element modelling can be used to in- vestigate mechanical properties of a given 3D model, or to compare some physical properties of the real object with vir- tual object properties, which is yet another benefit of using digital 3D models for object creation rather than directly building physical models. If it takes a long time and a lot of materials to make a single 3D print, finite element modelling may be a quicker option than conventional physical testing for iterating on the design [5].

The material and testing factors

Additive manufactured or 3D printed PLA or ABS models have a very low mechanical strength, are vulnerable to environmental factors like moisture, and have anisotropic mechanical characteristics [12, 22, 23]. Mechanical anisotropy is particularly pronounced in FDM processes and manifests as a tendency for the object to break easier along its build layers than perpendicular to them (up to roughly 50% difference in directional stability [12]). 3D printing may have trouble creating hollow spaces and overhangs without the usage of support structures [12].

These features should not be considered static, but rather as work in progress. The infill may have any pattern and density, while the shells on the outside define the object's shape and thickness throughout the 3D printing process. This means that certain infills may be used to increase the mechanical stability of a 3D print [26]. The mechanical stability of PLA is also being progressively improved, for instance by adding carbon fibre [16]. The use of chemicals allows for the smoothing of surfaces [4]. Each case has to be evaluated on its own merits to see whether the inherent mechanical anisotropy poses an issue and if it can be overcome by adjusting the digital 3D model's orientation with respect to the print bed and the stacking coordinates [1].

It does not seem to be simple, and may need conversation with the subjects, to test the pedagogical or explanatory value of any 3D printed rendition over presentations in a flat form (as on paper).

Both numerical modelling and experimental testing may be necessary for validating 3D models and 3D printed objects [5, 16, 23]. Material behaviour with regard to fluids, microorganisms, or repetitive strain may be significant in forensic medicine.

Forensic medical application areas

Diagnostics, medical demonstration, and instruction

The technological foundation for 3D printing anatomical models seems to be medical imaging, especially post-mortem computed tomography (PMCT) imag- ing [27]. Pathology, foreign substances like missiles, and traumas are all things that may be modelled in this way. Numerous medical uses for 3D models have been identified [35], including their use in medical education, surgical planning, and implant definition. In one instance of a complex skull fracture, the 3D printed documentation was found to be quite lifelike, especially when contrasted to the autopsy result [21].

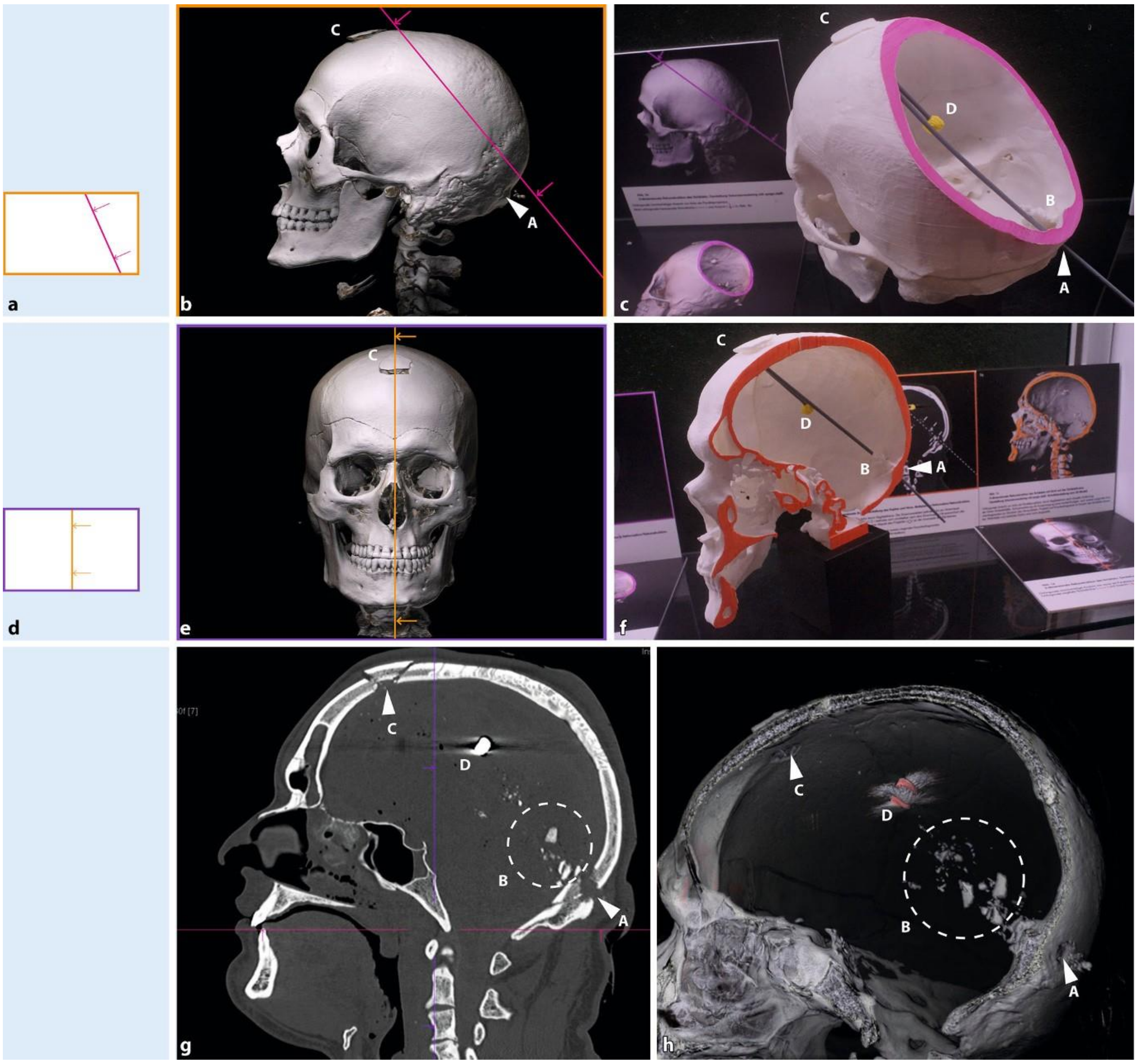

Fig. 2 Two identical 3D printed representations of an injury are shown in for illustrative reasons. An occipital skull defect (entrance, A) and what seemed to be neighbouring bone fragments within the skull (B) were consistent with a gunshot wound to the back of the head (pistol, calibre 9 mm). Imagesgandh depicts a frontal bone fracture in the form of a funnel at the coronary suture, which is taken to represent an internal ricochet (C) and the final position of the projectile (D). Both an oblique occipitoparietal (a-c) and a sagittal (d-f) slice were used to create the data for the skull's two 3D prints (c, f). The projectile's 3D-printed analogue (D in c and f) was placed on a grey rod to demonstrate its potential trajectory. The spatial arrangement of both reality and CT images may be investigated with the aid of symbolic colours (schematic depiction of relative image orientations: a and d; orthogonal views: b and e; 3D models: c and f).

One research looked at the morphology of 3D-printed MRI findings of the supratentorial brain to differentiate MS lesions from non-specific white-matter alterations for diagnostic purposes [31]. In another use, severely broken facial and skull bones were replaced with 3D printed replicas to improve the diagnostic value of facial photos for identification and to make the corpse more acceptable to the bereaved [42].

While it is simple to establish the viability of producing such exhibits [11, 13], it seems that reports on such models having actually been utilised in court are uncommon.

No more technical specifics of the 3D models were revealed [38], however one case had a 6-year-old girl's head injuries being submitted in court as a 3D printed model.

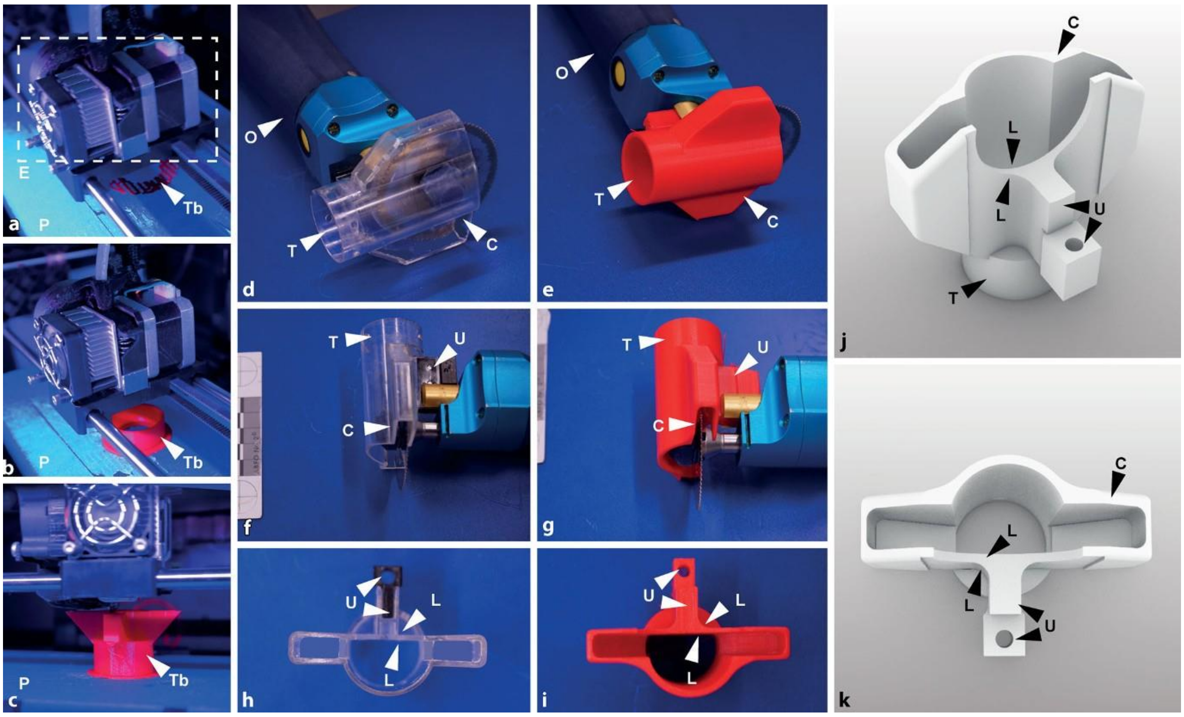

Fig. 3 Making use of 3D printing technology to create, test, and refine spare components for an autopsy instrument. When cutting bone, especially when opening skulls for autopsy (O), we utilise an oscillating saw. A suction hose may be connected to the saw's circular aperture (T) thanks to the plastic cover (see transparent component in d, f, and h), and the saw's cover's form also partially encloses the blade (C), flattening the air stream. A mount point (U) is put into a section of the saw and secured with a screw, allowing the plastic cover to be attached to the saw. A common failure mode for this plastic guard was dislodging itself from its mounting point (U) and the saw blade cover (L). We 3D-printed a replacement part prototype (red part in e, g, and i) to test the viability of the approach. Compared to the original, our design has filleted improvements at the junction of the mount point (U) and other components (see L in figures h and i). As a first estimate, this design change was made to lessen the occurrence of fractures in this component. Until additional improvements in both technology and application can be made, the prototype will be put on hold. From left to right, you can see the various stages of this component's 3D printing process (extruder E, buildplate P, and the model in progress at Tb). Image a depicts the first PLA layers of the model (Tb) being adhered to the build plate (P). Images b and c, taken 15 and 30 minutes after picture a, respectively, show the component's gradual development. The ability to 3D print an item with little or no support structures depends in large part on how the digital 3D model is oriented with respect to the build plate.

In another highly fascinating situation, Baier et al. (2018) [3] published their findings. In that case, investigators had to visually compare a complicated skull fracture pattern to possible weapons. With the use of micro-CT scans, a high-resolution 3D print was made using stereolithography and white resin (to mimic the colour of real bone). One of the practical benefits was that the jurors and the judge could examine the exhibit without having to worry about anybody being hurt.

We investigated 3D printing in the context of teaching using 3D injury visualisation. In our application, we used a number of graphic representations, including 2D and 3D printouts, to present the case of a deadly head shot.

Mechanical replicas and lethal force

3D printing is also being utilised in biomechanical applications.

To study the effects of head blows, researchers used a biomechanical simulation that included a 3D printed skull model with approximating biofidelity using two different materials using polyjet technology [20].

The many anatomical substructures found in the temporal bone, such as the vascular, necessitated the use of different ratios of several thermoset polymers in the construction of the temporal bone models utilised for surgical bone simulation. The second model, which used micro-CT data, outperformed the first, which used standard clinical CT data [34]. For this purpose, functionality is more important than aesthetics.

Research on the impact resistance of 3D-printed nylon and continuously reinforced Kevlar found that the material architecture, rather than the specifics of the printing process, was the determining factor in the composites' resistance to force [39].

Although the potential effect of 3D-printed weapons is low, it is nonetheless an unusual use to keep an eye on. Partially 3D printed, the Liberator's discharge seems to scatter polymer shards far and wide [18, 19].

Finally, 3D-printed projectiles were developed. One problem that was addressed in this manner was the delivery of long-acting birth control pills to animals in the form of biodegradable projectiles that had been 3D printed specifically for that purpose. There, pellets of PLA were combined with powdered progesterone, a contraceptive medication [25].

Tools and tools parts

Another field where prototyping is useful is forensic medicine, namely the construction of tools and application components.

We realised that some of the necessary pieces may not be commercially accessible when new applications emerge, such as post-mortem computed tomography angiography (PMCTA), while others may be produced with convenience, thus we designed and built them in-house [37]. These components went through as many as 10 design iterations before arriving at their final forms.

On rare occasions, forensic medicine may employ off-label use of commercially accessible materials, such as vibration saws [41] designed for cast removal, that look to benefit from additional adaption. A plastic attachment to our oscillating autopsy bone saw has been breaking off in the same spot rather often. This led us to develop a prototype for a component replacement, with the weak region strengthened (O Fig. 3), over the course of around four design iterations.

In this field, physical testing and recording of component performance and failure may first pose the most pressing concerns, later to be used for certification and control of quality. In addition, there may be legal considerations, such as copyright, patent, or liability difficulties.

Discussion

It's not always clear if learning how to use new software and devices is worthwhile or whether it's preferable to outsource such responsibilities. Due to the technical requirements for both the software and hardware components, cooperation for 3D printing may need to be carefully assessed against the establishment of one's own device or the use of a 3D printing service [44]. As 3D printing is a method that seems fraught with procedural and con- ceptual issues, and where typical rapid prototyping cycles may easily exceed 20 or 50 cycle counts—far from preceding methods such as clay modeling—one's own corporate or institutional setting that impacts prototype culture may play a considerable role in this [36]. However, a safer but more difficult to implement recommendation is to not operate any 3D-printers on an institutional or cor- porate network, at least not permanently [30].

Whether or whether 3D-printed plastic representations of anatomical or medicolegal specimens may be used as evidence in a court of law is still up for dispute. After all, the effort to disseminate information for the sake of comprehending a certain spatial configuration may be seen as only one component of a larger whole, a first stage on the way to something else entirely. It may be that staying on that road and providing enough viewpoints is the key to effectively conveying the spatial linkages at play. Even outside of forensics, the utility of a 3D presentation has been called into question by filmmakers who, in an effort to make their work more immersive, have turned to stereoscopy [17]. The 3D-printed skull, on the other hand, was favoured above pictures and printed images in a research conducted with participants from both legal and non-legal backgrounds [7].

There may be new methods to conduct tests or enhance current goods that can be made possible by using 3D printing to make new parts, components, or other structures to support practical work (often known as "things"). We have found that a high enough number of prototyping cycles is an essential factor in this case.

Ultimately, it is up to the individual's goals while creating 3D models. Once a final design has been established, it may not be as practical to use 3D printing for mass production as switching to other techniques of manufacturing. Among the options, a break-even analysis may be computed. Injection moulding scales well for bigger quantities [15], whereas 3D printing (depending on details) may only be good up to around 200 units. However, 3D printing does not appear to be a large-scale activity within the specific application domain of forensic medicine so far [33]. This may change if designs are changed and improved at regular intervals (every 50 units), if manufacturing is dispersed geographically, or if 3D printing is crowd-sourced.

3D printing in forensics- Indian scenario

In India, 3D printing for forensic purposes is relatively new.Documentation in India that makes use of 3D scanning is quite rare. [45] The studies are still in the proof-of-concept phase [46], during which the potential benefits and drawbacks of the technology are being evaluated. In a research employing 3D scanning and printing, Johnson et al. [29] reconstructed missing teeth based on intra-alveolar anatomy. This project was an early test of using 3D scanning and printing to replace lost teeth after death. The authors used 3D scanning and printing to recreate broken dental and osseous remnants in a series of studies [30-32]. The total morpho-logical error in the reconstructed dental remains was 0.0526 0.05 mm [32], while the osseous remains were rebuilt with an error of +/- 2.00 mm [30,31]. The authors of the same research [31] used 3D technology to recreate the zygomatic process in patients who were missing both of theirs. In their review, Chaudhary et al. [37] also stressed the significance of 3D printing in forensics.Important considerations and advice for advancing 3D printing in Indian forensics:

- More studies are needed to verify measurements and evaluate the surface quality of 3D prints made using various forensic 3D printing technologies.
- Best practises in forensics employing 3D technology may be developed by first identifying the many forensic disciplines where this technology can be used successfully, and then adopting a multi-disciplinary approach to doing so.
- The establishment of standard operating procedures for collecting 3D scans and establishing modelling and printing parameters.
- Making precise copies of evidence requires developing standards for determining printing settings (layerheight, temperature, printing speed), as well as post-processing procedures.
- Guidelines for the use of 3D technology and the presenting of recreated evidence are being developed from a legal and ethical perspective.

Conclusion

3D printing, as it turns out, refers to a subfield of manufacturing that encompasses everything from the design and creation of digital 3D models to the testing of prototypes and, finally, the production of finished goods. Possible uses in forensic medicine include creating anatomical models to display disease or injuries, making replacement components for tools, and creating biomechanical simulations. All of them, however, are rather recent developments. Considering the technical requirements for software and hardware elements, it may be preferable to use a 3D printing service or to seek col- laboration for 3D printing with a local facility. It's fascinating to keep an eye on the state of the art in 3D printing as it continues to evolve, both in terms of the software it uses and the hardware it employs.

Forensic medicine has benefited greatly from the advent of 3D printing technology. This article has offered a high-level review of its uses, difficulties, and possibilities in the Indian setting. It is clear that 3D printing has many applications, from biomechanical modelling and tool development to the creation of anatomical models that help in pathology detection and surgery planning. Although there is much potential in 3D printing, there are also technical and practical obstacles to overcome. Prototyping vs mass production is a delicate balancing act that must take into account material constraints, mechanical qualities, and the potential for error. The entire potential of this technology in forensic applications cannot be tapped into unless standardised methods, ethical norms, and best practises are established. In the Indian context, 3D printing in forensics is just getting started, with preliminary research and proof-of-concept studies opening the way for more advanced applications down the road. The future of 3D printing's effect on forensic medicine in India and abroad will be heavily influenced by inter-disciplinary collaboration, the validation of measurements, and the observance of ethical norms. As this technology develops further, it may one day improve the accuracy, efficiency, and efficacy of forensic investigations and medical procedures.

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