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## Introduction

Orthopedic surgery is moving ahead in leaps and bounds. Precision in performing procedures is of paramount importance. The scope of this has grown many folds with the introduction of 3D printing technology in the field of medicine. This technology has already proven its mantle in the fields of aerospace, jewelry making, dentistry, etc. However its inclusion to treat patients brings exciting possibilities and advantages. Chuck Hall is considered as the father of 3D printing and is the first one to develop stereolithography (STL) in 1984, which is a critical element of this technology.

The 3D printing technology may provide a chance for the orthopedic surgeons and technicians to independently develop innovative medical devices [1].

Based on imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), raw data in DICOM format is processed into a 3D model (Fig. 26.1), which can be manipulated and used as a template for virtual planning [2]. The prototypes of the bones can be obtained using the layered manufacturing technique (LMT) for teaching, presentation, and surgical design.

Metal 3D printing is of particular relevance to orthopedic practice, as it allows customized implants or devices to be made. These printers are still costly and are not readily available; however, these would also become an affordable reality in the future. 3D printed implants and devices will also open a new avenue of the research model. It needs to be established that the biomechanical proportions are acceptable before implanting the devices. We will also discuss the bioprinting which could be the ultimate game-changer in healthcare delivery [3].

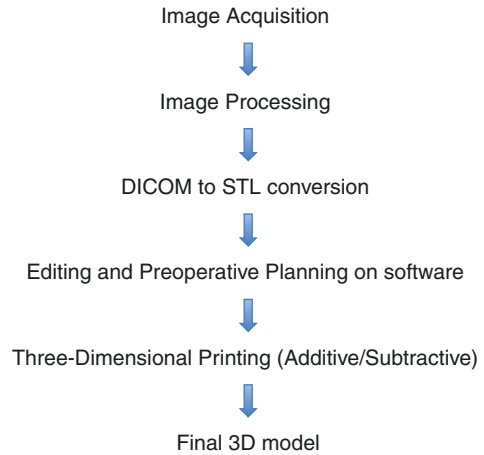
This technology will not take away presurgical planning from the surgeon [4]. On the other hand, it will get surgeons even closer to the details of the problem to

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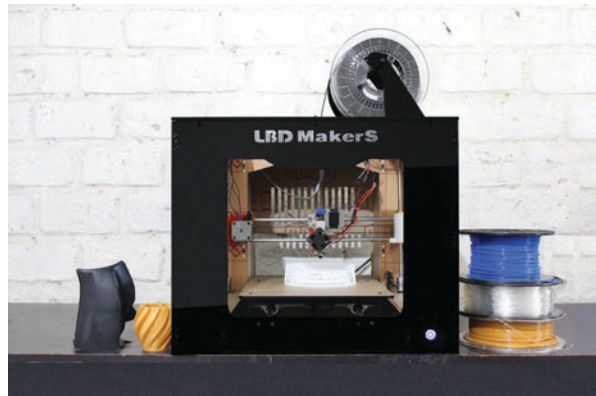
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**Fig. 26.1** The process of 3D printing



**Fig. 26.2** A 3D printing machine



be addressed. This technological progress has merely provided us with more efficient means for going forward, and a “real-world” clinical translation would reveal the value and future of 3D printing in orthopedics.

### Three-Dimensional Printing

Three-dimensional printers use a variety of technologies to “additively manufacture” or construct objects layer by layer [5, 6]. Whereas the old manufacturing methods included the subtraction of layers from raw material, 3D printing works on the model of “additive manufacturing.” In additive manufacturing, layer by layer of the raw material is “added” in a predetermined manner (Fig. 26.2), hence achieving accurate and excellent three-dimensional framework.

Industrial-grade printers use lasers to precisely sinter granular substrates (e.g., metal or plastic powders). After each layer of the structure is completed,

the printer adds a new layer of unfused powder on top of the old one, and the subsequent round of sintering builds the next cross section fused to the previous one. The advantages of these printers are high print speeds, ability to recycle unfused powder easily, and capacity to use stronger materials with higher melting points (e.g., titanium, which had been challenging to sculpt by standard subtractive methods).

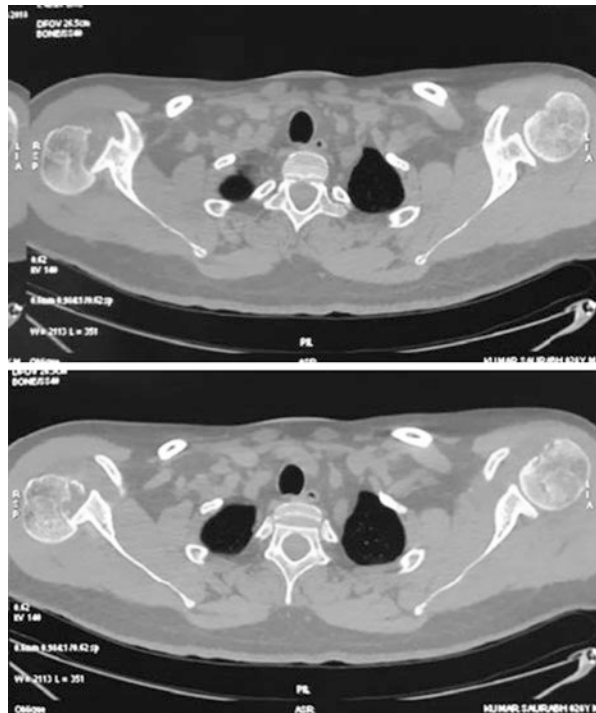
## Uses in Orthopedics

### Preoperative Planning

3D printing technology can help manufacture bone models which can be used in complex orthopedic cases. The scenarios like compound fractures with bone loss, especially occurring after high-speed road traffic accidents and bomb blasts, can be easily managed by developing a prototype of the contralateral side and can be used as a guide during surgery (Fig. 26.3). In cases where there is no normal side to the template on, normal anatomy can be used to make models which in turn can help in fitting the missing pieces.

Another scenario is complex joint replacements, wherein the surgeon can develop a 3D model, know of the possible intraoperative hurdles, and plan accordingly.

**Fig. 26.3** CT images of the shoulder showing fracture and posterior dislocation of the right shoulder joint



Overall, the innovation of using 3D printed replicas of bone fractures can help doctors, surgeons, and researchers thoroughly test methods before the surgery even begins.

1. *Complex trauma*: 3D printing is especially useful in complex trauma cases [7]. The 3D printed models provide a visual and tactile aid in conceptualizing complex fracture patterns (Fig. 26.4). The model can be sterilized and reviewed intraoperatively as required. Preoperative reviews of the 3D model can allow the surgeon to anticipate intraoperative difficulties, selection of optimal surgical approach, and need for specific equipment. Challenging pelvic fractures provide an example of these concepts.

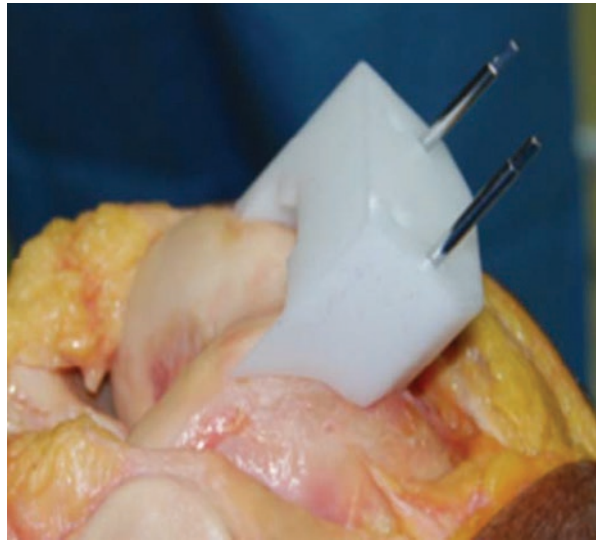
There are published examples where 3D technology has been utilized in complex cases of the upper limb and lower limb osteotomies. These articles support the notion that this technology simplifies complex surgery, providing confidence that goals of surgery are being achieved and reduce operative time. Trials comparing routine preoperative planning with the use of 3D printing are required.

2. *Arthroplasty*: Most implant companies have 3D printed guides available to assist in standard knee joint arthroplasty. A guide to assist with hip resurfacing has also been described. This process is commonly called patient-specific instrumentation [8]. Patients have either a CT scan or a MRI scan to produce DICOM images. 3D images are then created, and a preoperative surgical plan is constructed to achieve perfect implant placement. Disposable cutting blocks are then fabricated

**Fig. 26.4** A 3D printed model of the shoulder, showing posterior dislocation



**Fig. 26.5** A 3D printed customized knee block for total knee replacement



to match and conform to the patient's anatomy using 3D printing technology (Fig. 26.5). The proposed benefits include improved reproducibility of component alignment, reduced surgical time, and optimized efficiency and cost-effectiveness. Despite these proposed benefits, it is yet to be proven to be better than the standard techniques.

3D printing has allowed the emergence of custom implants. Customized implants for joint arthroplasty are useful when the patient does not fit the standard range of implant size or their disease.

3. *Spinal surgery*: Preoperative computer-assisted planning and custom 3D printed guides have also been described in pedicle screw placement.
4. *Pediatric orthopedics*: Pediatric orthopedic surgeons have utilized 3D printed models to assist in the management of complex spine scoliosis, coalition in the foot, and Perthes' and Blount's disease. The models were used to assist in preoperative planning, communication with the patient, reference during surgery with reported improvements in the safety of the procedure, and reducing operative time. Simple and complex osteotomies can be planned using models preoperatively. The surgeon can study the deformity and plan the surgery with a computer model. This includes the exact placement of implants and the ideal osteotomy site. 3D printing can produce jigs to allow for pre-drilling of holes for customized plates with built-in osteotomy guides.

### **Intraoperative Guides**

3D printing can also help in manufacturing guides which can be used intraoperatively for taking precise bone cuts. These can dramatically decrease the surgical time and have widespread implications for the patient, surgeon, and hospital setup. The anesthesia time for the patient as well as the OR efficiency can be improved while ensuring superior outcomes.

Cases like complex deformities and severe kyphoscoliosis can be dealt with in a more efficient and scientific manner by using specific 3D printed jigs.

### **Training**

3D printing can also help develop models which can be used for training as well as presentation purposes. Moreover, using the 3D printed models can redefine patient education wherein the patients can themselves understand their problem and measures are being taken to rectify the problem.

### **Research**

Improvements in implant design is an important area which can be effectively dealt with using 3D printing. Earlier, during the times of normal manufacturing, even a small change in the design used much time, but with the advent of rapid prototyping technology, the designer can improvise and develop a new implant. It can be easily available and much cheaper than the old implant designing protocols. The developer can check the prototype for accuracy and any fallacies and can rapidly order changes and reassess the resultant product. Certain metals like titanium have been approved to be used in these 3D printers and can help manufacture implants.

The 3D printing technology holds much promise in all fields of medicine, but the field which has been revolutionized the most is the field of orthopedics. It has widespread implications for research, development, and improving surgical outcomes.

Studies in the future can be performed to assess the following:

- Study the usefulness and applicability of 3D printing for complex orthopedic problems
- Evaluate the clinic-radiological outcomes of these cases, with the use of 3D printing
- Determine the cost-effectiveness of 3D printing in these challenging cases
- Assess the best indications for 3D printing in difficult orthopedic cases
- Analyze the complexities associated with 3D printing and how to overcome these problems

### **Indications:**

- Cases with complex orthopedic problems (severe deformities of the bones and joints), which usually are considered challenging and difficult surgically
- Patients who are willing to give consent for the use of 3D printing and to undergo preoperative CT scan

### **Contraindications:**

- Routine orthopedic surgical cases, which can be managed by conventional surgery
- Those cases who are not willing to give consent for the use of 3D printing
- Acute orthopedic condition and traumatic injuries, which require immediate treatment and cannot wait for the 3D printed model

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## Advantages of 3D Printing

There are various advantages of using this technology:

1. *Reduction in the duration of surgery:* With the planning and alterations of implants based on the pathology pre-hand the surgical time spent on table reduces, and the surgeon, as well as the team, exactly knows the accurate surgical steps.
2. *Reduction in intraoperative bleeding:* With pre-hand knowledge about surgical steps and reduction in overall surgical time there is a reduction in the overall per-operative bleeding. This fastens the return to normal faster than conventional.
3. *Increased precision:* With the availability of the exact model in hand the surgeons can plan the surgery better. The implants can be molded beforehand according to the bone shape and size. It increases the precision and reduces the intraoperative duration.
4. *Patient education:* In the recent times with increased patient awareness and knowledge, with the availability of a 3D print model in hand it is easier for the doctor to explain about the pathology and the surgical procedure to be done to the patients. It helps the patient to be well informed, and they exactly know what to expect from the surgical procedure.
5. *Medicolegal litigations:* With the help of models patients are better informed about what to expect. These improve the communication between the doctor and patients and thus reduce the chances of medical litigations.
6. *Patient-specific instruments and jigs:* Every human being is different, and so are the sizes of bones. Hence with this technology, it is possible to customize implants according to the exact patient dimensions and also prepare jigs.

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## Clinical Uses of 3D Printing in Various Medical Specialties

1. Orthopedic surgery
2. Craniofacial surgery
3. Dental surgery
4. Plastic surgery
5. Urology
6. Ophthalmology surgery
7. General surgery

Medical models, surgical implants, surgical guides, external aids, and bio-manufacturing have been done in these fields. Some examples of the usage of 3D printing in medicine are as follows:

1. Bioprinting or tissue and organ fabrication:
  - (a) Bones
  - (b) Cartilage

- (c) Cornea
  - (d) Organs like skin, kidney, liver, and heart
2. Creating anatomical models, implants, and prostheses:
    - (a) Complex fractures and dislocations
    - (b) Deformity correction
    - (c) Patient-specific implants for joint replacement
    - (d) Patient-specific orthosis (braces, foot wear, etc.) and prosthesis (artificial limb)
  3. Pharmaceutical research (drug discoveries, delivery, and dosage forms):
    - (a) Preoperative imaging:
 

In order to procure a 3D printed model, an MRI or CT scan of the involved area is necessary. In cases where there is a defect in the bone (for instance complex acetabular fractures) then the scans of the opposite side are essential in order to replicate the same on the deficient side.
    - (b) Complications:
 

No complications have been reported in the literature yet with the usage of this technology. However, no technology can replace human judgment as no two patients are similar, and conditions intraoperatively seldom may change which may demand alteration of some steps in order to achieve optimal results.
    - (c) Pearls and pitfalls:
 

This is a relatively newer technology in the field of medicine. The learning curve is high. The software is better used by engineers at present; however the surgical planning is to be done by the operating surgeon himself/herself. Hence, in the future, it would be better if the doctor could learn to master the software in order to benefit the patients maximally.

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