

## Expected role of four-dimensional (4D) CT and four-dimensional (4D) MRI for the manufacturing of smart orthopaedics implants using 4D printing



### Keywords:

4D CT  
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Dear Editor,

Four-dimensional computed tomography (4D-CT) and Four-dimensional Magnetic Resonance Imaging (4D-MRI) are upcoming technologies of CT and MRI scans. Here the image recording is done with respect to time, taken as an additional fourth dimension, both to 3D CT and MRI. These techniques provide better information about the body parts such as bones, tissue, and other body organs, by calculating the motion of the respective body part (before & after) concerning time.<sup>1</sup> This fourth-dimensional aspect is quite helpful for the manufacturing of smart implants, tools and devices. 4D printing uses the same technique as 3D printing; only the difference is the input of smart material (such as shape memory alloy) which can change the shape of the part to time.

4D-CT & 4D-MRI techniques are used to improve the quality of patient imaging that has compromised motion of different organs of the body.<sup>2,3</sup> 4D printing handle difficult situation of printing for a medical requirement such as complex surgery, skin grafting, manufacturing of smart implants and organ printing with better accuracy.

4D CT and 4D MRI technologies are referred to as multi dimensional scanning techniques which help to detect even a small nonconformity. Nowadays, with technological developments, a playback of the scan images is produced by these scanning technologies which are in the form of a video. Therefore, these help to observe, track and analyse the internal movements of the body. These scanning techniques are the next step of imaging which is quite accurate & faster. 4D printing manufactures 3D physical products/implants by using smart material, layer by layer, taking input through computer-aided design (CAD) data. The use of smart material with this technology, provide shape changes, when there is a variation in heat/humidity/pressure, with time.<sup>4</sup>

In orthopaedics, while looking at the physical motion of the patient, his joint problem can be very well analysed. The main focuses of these upgraded scanning techniques are to obtain additional information when movement is taking place. Therefore one obtains

precise anatomic information with higher accuracy. Fig. 1 shows a proposed process for creating orthopaedics implants using 4D printing with inputs from 4D CT and 4D MRI.

4D images are captured by using 4D MRI/CT and these images are to be converted into the required format to develop a CAD model, which is printable through 4D printing. The selection of smart material is as per the final requirements of orthopaedic applications. A 4D CT/MRI helps to predict the precise requirements of the amount of shape change of a physical model, i.e. how much it should get expanded. Therefore, one gets an idea of requirements of smart material and associated dimensional requirements towards the actual printing of the model. Orthopaedic models created with the help of these technologies are to provide a better understanding of patient during complicated cases and helpful in teaching and research. 4D printing can print a bone like part using a smart material, and this part can grow in the human body with time. These innovative technologies fulfil various criteria's due to their designing and manufacturing flexibilities. Therefore, by using inputs from a 4D CT/MRI, a surgeon can 4D print a customised

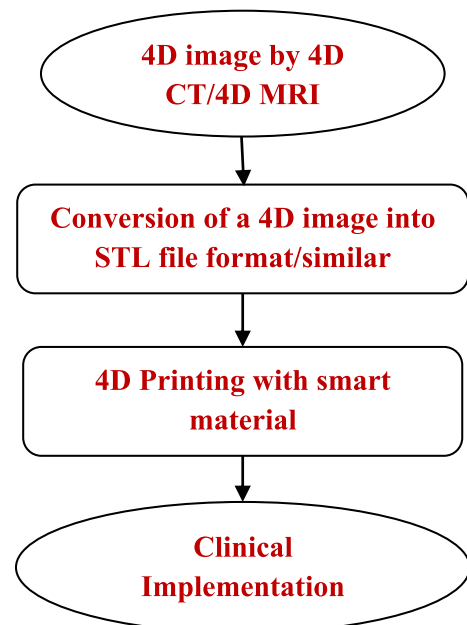


Fig. 1. A proposed process of creating orthopaedics implants with the help of 4D CT/4D MRI using 4D printing.

smart orthopaedics model and perform a mock surgery which helps improve the success rate of operation.

There is a functional requirement for a smart stent that can also grow with the human body. Similarly, implants which can also grow with the growth of the human bodies, creating a self-deforming component and there are endless possibilities in medicine. In this process, 4D CT and 4D MRI have an extensive contribution in data capturing, and then, no doubt the application of smart, programmable and intelligent materials are to be the backbone of solving the future human-related problems. This latest solution will be applicable for complicated orthopaedic surgery to save the life of the patient. It can also print customised multi-material smart orthopaedic implants as per the loading.<sup>5</sup> An orthopaedic surgeon can use this technology to provide better service to the patient, and 3D printing is already used to create 3D orthopaedics implants in lesser time.<sup>6</sup>

The 4D scanning seems to have applications in radiotherapy planning, and help to develop new methods. These are helpful for motion verification and pre-treatment anatomic positions to improve treatment accuracy and help to create significant innovation in the medical field. 4D scanning techniques are to help as an essential tool for the evaluation of cardiovascular diseases that are concerned with the calculations of the blood flow in the heart, thereby helping to reduce the risk and side effects of surgery.<sup>4,7</sup>

This advanced technique of 4D printing provides multi-functionality medical and orthopaedic implants. Change in shape of implants can imagine through these scanning devices before printing through 4D printing. These shapes can be adjusted as per requirement as problem detects through these 4D scanning devices. Surgeons could produce a smart model which was not previously possible by other traditional CT and MRI scan. 4D printing to give a disruptive effect in orthopaedic by creating high quality and performance implants, sourcing the individual patient data being captured by these innovative scanning technologies. Due to its flexibility in manufacturing, it is to create endless possibilities in orthopaedics. We see the potential to develop self-bending stents and other orthopaedics models that help in treatment planning.

The technologies and smart material are in the development stage and sometimes they may not show accurate or reliable results by 4D printing and can be a source of discomfort for the patient. Another limitation of 4D CT and 4D MRI is the higher cost and associated human competencies.<sup>2,8</sup> In future 5D printing can augment 4D printing which can print curved shape orthopaedics implants with better strength.<sup>9</sup> In upcoming years, 4D CT and 4D MRI will play a useful role. Here 4D printing applications will be made in medical as well as in orthopaedics.

## Conflicts of interest

None.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jcot.2019.01.020>.

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