International Journal for Research in Engineering Application & Management (IJREAM)
ISSN : 2454-9150 Vol-08, Special Issue, MAY 2022

Reconstruction and Modelling of Hip Joint by Using 3D Slicer and Rapid Prototyping

Mr. Ch. Ramesh*, Mr. K. Prudhvi Sai*, Mr. M.Veera Pradeep*, Mr. T. Krishna Mohan*, Mr. V. Sri Harshith Chowdary*, Mr. A Yeswanth, Dr G Avinash****

***UG students, **Faculty, Department of Mechanical Engineering College, Pragati Engineering College (A)**

ABSTRACT: The use of three-dimensional (3D) printing is becoming more common, including in the field of orthopaedic surgery. There are currently four primary clinical applications for 3D-printing in hip and pelvic surgeries: (i) 3D-printed anatomical models for planning and surgery simulation, (ii) patient-specific instruments (PSI), (iii) generation of prostheses with 3D-additive manufacturing, and (iv) custom 3D-printed prostheses. Simulation surgery using a 3D-printed bone model allows surgeons to develop better surgical approaches, test the feasibility of procedures and determine optimal location and size for prosthesis. PSI will help inform accurate bone cuts and prosthesis placement during surgery. Using 3D-additive manufacturing, especially with a trabecular pattern, is possible to produce a prosthesis mechanically stable and biocompatible prosthesis capable of promoting Osseo integration. Custom implants are useful in patients with massive ace tabular bone loss or periacetabular malignant bone tumours as they may improve the fit between implants and patient-specific anatomy. 3D-printing technology can improve surgical efficiency, shorten operation times and reduce exposure to radiation. This technology also offers new potential for treating complex hip joint diseases. Orthopaedic surgeons should develop guidelines to outline the most effective uses of 3D-printing technology to maximize patient benefits. In this study we are developing the hip joint from the conventional CT/MRI scans to study the hip joint. In this study, the determining factors for hip replacement and the different fabrication techniques such as direct 3D printing, Fused Deposition Modeling (FDM), Selective Laser Sintering (SLS) and stereo lithography(SLA) for hip replacement.

Key words: Modelling, Prototype, 3D Prinint, Tumours, FDM and SLS

I. INTRODUCTION

Three-dimensional (3D) printing technology is additive manufacturing that produces 3D shapes by stacking two-dimensional (2D) cross-sectional shapes with various materials. It is used for laminated manufacturing, such as rapid prototyping (RP). In the early days, there were a number of key limitations in printing materials, moulding time, size, precision and strength of the moulding's, which limited industrial uses. In recent years, however, printing materials have been diversified including metals, and printing equipment has been developed accordingly. The paradigm of industrial use is rapidly changing as the production of complex shapes and customized products become possible. Today, 3D-printing technology can be used to create simulation models or medical implants, thus significantly aiding doctors and medical companies by optimizing the way a surgeon plans and executes a procedure. The application of 3D-printing technology to clinical medicine has already become the fastest growing innovation in the medical field.

The use of 3D-printing in the field of orthopaedic surgery is rapidly increasing. The ease of segmenting bone from computed tomography (CT) scans, and the variety of available 3D printers enables researchers, manufacturers, and surgeons to easily use 3D-printing technology. Over the last decade, there have been significant developments in the orthopaedic surgery field, especially in hip and pelvic surgeries. Many scientific papers have been published regarding research in the field of 3D-printed hip prosthesis.

Currently, the use of 3D-printing technology in hip and pelvic surgeries can be divided into four important categories. First is the development of anatomical models based on patient imaging; these bone models can facilitate an improved understanding of the path-anatomy and surgeons can use it to simulate the surgery to potentially improve execution. Second is the synthesis of patient-specific instruments (PSI) that may increase the accuracy of a surgery; most PSIs are manufactured in the form of guides or jigs. Third is the production of arthroplasty implants; 3D-printed hip implants are advantageous because ingrowth surfaces can be modified to optimize

 DOI : 10.35291/2454-9150.2022.0266

bony ingrowth. Forth is the development of custom implants. Unlike standard sized implants, a custom implant created using patient-specific medical images can be a perfect match for the patient's unique anatomy. Importantly, the use of 3D-printed custom implants has recently been reported in not only pelvic tumour surgery but also in difficult revision hip arthroplasty with severe acetabular bone loss.

Annually, the number of people globally experiencing pains from organ failure or dysfunction from a devastating tissue is on the rise, and this usually affects children and the ageing population. Traumas or illnesses, which include strokes, joint degeneration and heart attacks, can adversely reduce the life quality of the victims and lead to the significant damage of the tissues where new medications are incapable of efficient healing. The hip joint comprises two bones which are the femur (thigh bone) and pelvis as illustrated in Figure 1.1. This joint is the biggest ball and socket synovial joint in the body. This ball is the femur head, which is the rounded edge of the femur while the socket is a curved dip around the lower region of the pelvis (acetabulum). The femur headsets in the pelvis give shape to the hip joint.

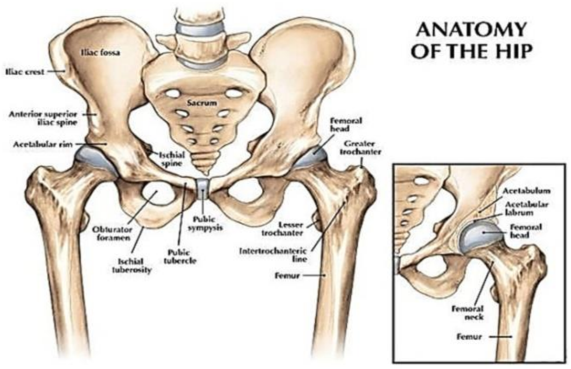

Fig 1 Anatomy of the Hip Joint

Hip pain is common, and it can affect anyone at any age; however, it is most common with the elderly. For instance, in the United States, 76 million people are experiencing some type of pain, and this is a sizeable chunk of the population. It is difficult to pinpoint the specific causes of these pains, but the clues lie in the type of pain and the location of the pain. For most cases of the hip, the pains relate to any problem emanating from the lower back or buttocks region. Meanwhile, the hip problems are relative to the source of the pain in the groin, thigh region and in some cases, the knee because of the hip innervation when the nerve is stimulated. In addition, in the United Kingdom, the National Health Services (NHS) has been supervising the National joint registry for England, Wales, Northern Ireland and Isle of Man (NJR) for all forms of hip surgeries. From the NJR review of 2016, about 101,651 replacements were done that single year which was roughly a 3.5% increase from the previous year.

The several conditions which lead to hip pains can be a result of the following: arthritis, injuries, pinched wounds, cancer and other problems such as lifestyle. Arthritis, in particular, is a broadly known condition which refers to pain and inflammation in a joint according to NHS UK and this is mainly due to more than 10 million people currently have this condition which affects people of all ages not excluding children. The cartilage, although flexible, is a firm connective tissue in the joint. The joints are protected when the cartilage absorbs the shock and pressure created when there is movement and stress is applied to them. Cartilage tissue reduction in standard amounts can lead to various forms of arthritis. Osteoarthritis (OA), which is the known form of arthritis commonly caused by normal wear and tear and an injury/infection, will most times aggravate the breakdown of the cartilage tissue. On surgical treatments are considered the first line of action during the treatment of hip pains. Most of the hip replacement implants (90–95%) are durable for at least 10 years; there is a rising public demand for increasing the life span of these implants based on increasing life expectancy amongst the older population with joint degeneration illness. As a result, revision hip arthroplasty could be considered when the implant fails due to several reasons such as the aseptic loosening (51.9%), instability (16.9%), infection (5.5%), and debilitating pain, per prosthetic fractures or component failure. In addition, there is a limitation on the conventional 2D scans currently, which frequently does not provide well-detailed imagery during implantation. However, this review focuses on the current state of 3D printing technology and the required materials needed to support cell adhesion and growth. Therefore, at this point, a brief review of real-life application of 3D printing needs to be provided.

Hip surgery involves hip replacement and an alternative surgical option for hip arthritis. When the treatments and medications applied do not nip the hip pains to a suitable level, this surgery for reposting or replacement of the hip joint may be the next solution.

About a quarter of the UK population needs a clinical check for musculoskeletal (MSK) conditions to be carried out at least once a year and about 25% or more of all the surgical routines handled by the NHS are mostly based on MSK conditions. There is currently a large variation in the rate of Hip surgeries between the developed countries, and this influences a surgeon’s decision.

In the United Kingdom, the NHS has accepted the value-based healthcare system (VBHC), which has the goal of increasing the obtained values from limited resources that are accessible to the populace. These values in healthcare can be defined as the result that affects the patients and carers that is related to the cost of providing the results. From the study, it was finalized that an approved multidisciplinary team (MDT) consists of experienced service management, orthopaedic nursing staff, physiotherapy and the specialist orthopaedic consultant surgeon. MDT approach permits staff to engage at an enhanced supervisory level, and this facilitates the patients

 DOI : 10.35291/2454-9150.2022.0266

maximizing each result from the treatment. Severe hip deformities present a huge challenge for the MDT that requires the selection of the right form of hip implant, in a bid to attain an error-free replacement with a near-perfect solution to the deformity.

In comparison with the conventional technologies which are solely CT and MRI imaging, a 3D model provides more details for the team and can be also be used by the MDT to simulate the operation. Generally, two main ways 3D printers can be used in hip surgery are either as implants or models. 3D printed implants can be made from suitable materials which are ideal for the reconstruction of huge and unclassifiable acetabular defects. 3D printed models of patients can assist in planning surgery, delivering surgery and teaching surgery.

3D PRINTING FOR HIP REPLACEMENT

There has been a significant improvement in bio implants in the current decade, where a wide variety of fabrication methods are being applied. In 2018, the global orthopaedic implant is estimated to be at USD 4.747 billion and a compounded annual growth rate (CAGR) of 5.1% is expected from 2019 to 2026 as depicted in Figure 2. In the human body, the biological functioning is complicated, with the huge differences in biomechanical properties from bone to bone. Such an instance is the elastic modulus of the critical section of denser bones varying from 16–20 GPA; this is a magnitude greater than the trabecular bone. Therefore, it can be understood that certain biomechanical errors are bound to happen between the recently implanted parts and closer bones with similar properties. Furthermore, from a medical perspective, these biomechanical properties may differ greatly from the body to the body. Hence, a need for fabrication techniques that can meet specific geometry for a precise injury/defect is justifiable. Additive manufacturing (AM), also termed rapid prototyping (RP) technology, is a common name for the fabrication technique depending on the idea of surface development. From its emergence in the 1980s, this technique has been garnering research interest in the sector of manufacturing. In contrast to conventional implants, 3D printed implants can be tailored to several forms of diseases. With the possession of excellent design ability, 3D printed implants can solve certain challenges where it is complicated to insert and repair the different conventional implants together.

The process of 3D printing include the capability of bio mimicking extracellular matrix (ECM) and the ability to fabricate adaptable scaffolds regardless of the shape complexities for the cell distribution to done homogenously. However, the major limitation is the accessibility of suitable biomaterials that possess the stability and intrinsic properties for 3D printing of scaffold. An additional limitation is a time required for scaffold fabrication, and that time increases when the design becomes more complex and accurate. It is worth noting that 3D printers utilize varying powdered mixtures and materials; the size of the structures can easily affect the printability of the scaffold for most materials in 3D printing. For a material to be a viable choice for tissue regeneration, it should be printable with a great degree of reproducibility from 3D printing. These materials should be affordable, effective and malleable to create the morphology required for the designed scaffold. Within the last four decades, various 3D Printing (3DP) techniques have been suggested due to the processing approach. Of importance is the ASTM/ISO 52900:2015 standard designated over 50 different 3D techniques which can be grouped as (i) binder jetting, (ii) direct deposition, (iii) material extrusion (FDM), (iv) material jetting/inkjet, (v) powder bed fusion (SLS), (vi) sheet lamination, (vii) stereo lithography (SLA, DLP). For this review, the emphasis is on direct 3D techniques which usually utilize several forms in atmospheric conditions such as fluids capable of solidifying, Nano fine powdered particles, layered sheets and flexible filaments.

Currently, 3D printing products do not have a formal legal standing that clarifies them both for implantable and non-implantable devices. Using Europe as the base reference, whole 3D-printed products can be classified as customized tools under the regulation (EU) 2017/745 of the European Parliament and of the council of 5 April 2017 It was stated that "any device specifically made in accordance with a written prescription of any person authorized by national law by virtue of that person's professional qualifications which gives, under that person's responsibility, specific design characteristics, and is intended for the sole use of a particular patient exclusively to meet their individual conditions and needs". Varying from mass-produced devices "which need to be adapted to meet the specific requirements of any professional user and devices which are mass produced by means of industrial manufacturing processes in accordance with the written prescriptions of any authorized person shall not be considered to be custom-made devices. In fact, manufacturers of customized tools are only assured through a commitment of conformity assessment methods whereby the tools must comply with the performance and safety requirements.

II. PROCESSING MRI AND CT SCAN DATA

Medical Scanning

Medical Imaging generates a representation of a patient's anatomy in order to facilitate medical diagnosis. Techniques include Computerized Tomography (CT), Magnetic Resonance Imaging (MRI) and Ultrasound. These tools increase diagnostic accuracy hence reducing both risk and the recovery time of the patient. Specific technologies are outlined below.

CT Scanning

A CT scan, also known as CAT (Computer Axial Tomography) is a non-invasive medical scanning

DOI : 10.35291/2454-9150.2022.0266

technique. It uses x-ray technology to obtain geometric data of a body from different positions. A CT scan uses modified x-ray technology, selectively exposing sections of the patient to radiation. The data is then processed to generate a cross-section of the human body's tissues and organs [2]. In order to facilitate the tomography of certain organs, x-ray opaque material may be ingested or injected. Radiologists interpret tomography, identifying trauma, diseases and determining the existence and impact of various pathologies.

ULTIMAKER CURA

Cura is an open source slicing application for 3D printers. It was created by David Bram who was later employed by Ultimaker, a 3D printer manufacturing company, to maintain the software. Cura is available under LGPLv3 license. Cura was initially released under the open source Affero General Public License version 3, but on 28 September 2017 the license was changed to LGPLv3. This change allowed for more integration with third-party CAD applications. Development is hosted on Git Hub. Ultimaker Cura is used by over one million users worldwide and handles 1.4 million print jobs per week. It is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well.

III. RESULTS AND DISCUSSIONS

Segmenting HIP Bones from CT scan Files

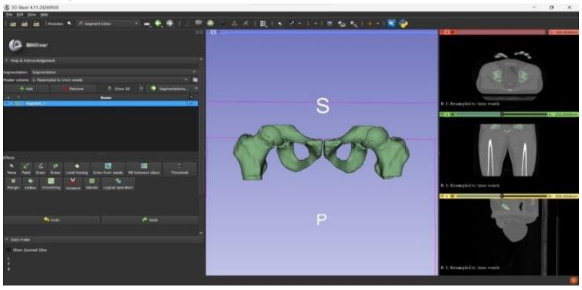

Fig 2 Segmentation of HIP Bones

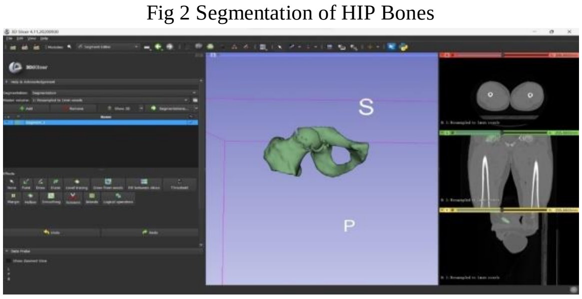

Fig 3 Segmentation of One Side HIP Bone

Rapid Prototyping of Hip Joint

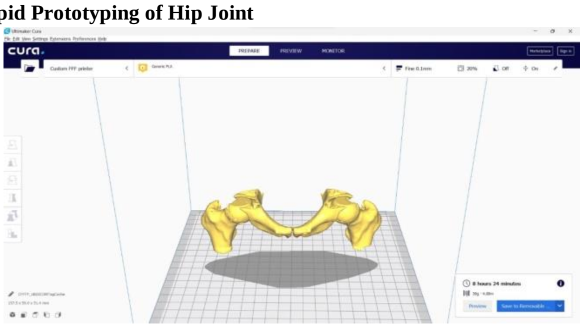

Fig 4 Slicing Of Hip Joint in First Orientation

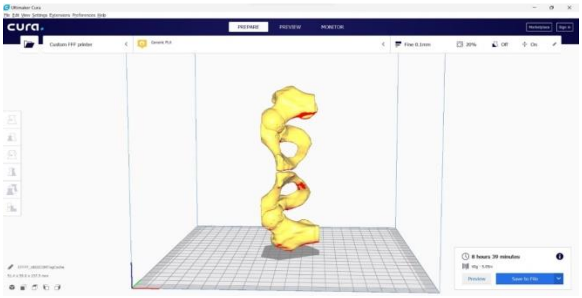

Fig 5 Slicing Of Hip Joint in Second Orientation

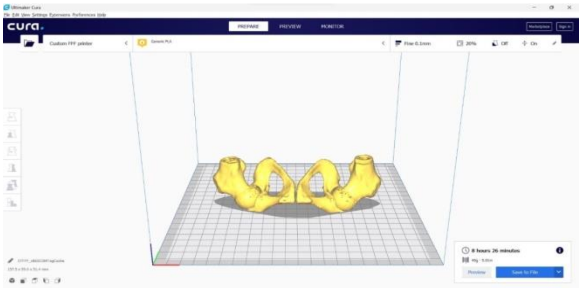

Fig 6 Slicing Of Hip Joint in Third Orientation

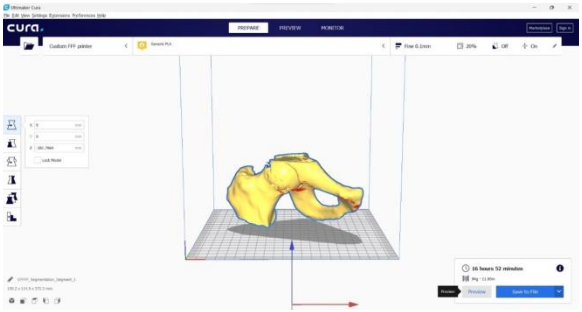

Fig 7 Slicing Of One Side Hip Bone in First Orientation

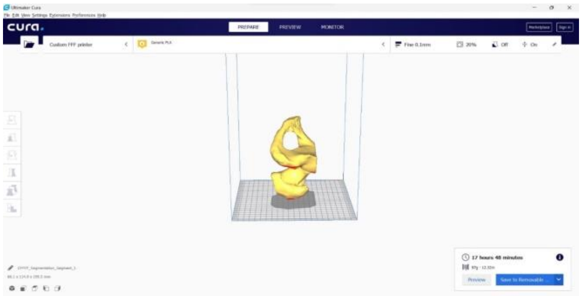

Fig 8 Slicing Of One Side Hip Bone in Second Orientation

Fig 9 Slicing Of One Side Hip Bone in Third Orientation

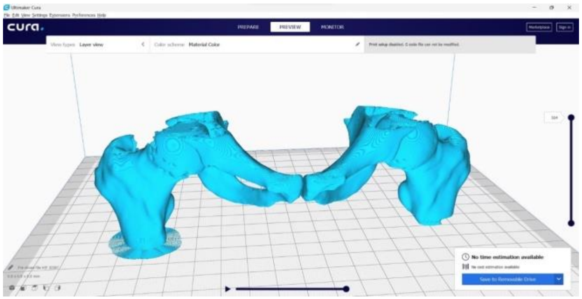

Fig 10 Layered View Of Hip Joint

 DOI : 10.35291/2454-9150.2022.0266

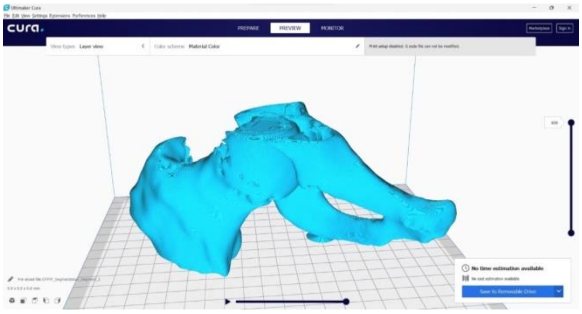

Fig 11 Layered View of One Side Hip Bone

IV. CONCLUSIONS

1. The DICOM format of the scan data was converted to .stl file using 3D Slicer software. Prior to 3D printing, pre-processing of CAD model was done for removing extra mesh islands and to reconstruct the patches/holes in the bone model using Blender and Mesh mixer software.

2. Different 3D printing technologies has been study to in which printing process hip joint can be printed. Depends on the prototype and application of joint different 3D printing technologies has been studied

3. Processed models of hip joint is imported to CURA slicing software and optimized best orientation for two models.

4. The time taken to build the implants/models on the FDM 3D printer was less than the time taken to build the same implants with other methods.

5. Studied the different fractures in hip joint and PSI we can reduce the surgery time and we can prepare the prosthesis before the surgery and we can directly implant in the human body

6. Future work from this research is to broaden this examination to include new materials that are biocompatible, to use other AM technologies, to redefine measurement procedure, to address other related AM research problems and to find new material that meet the current recommendation of the FDA and can be used on existing and emerging 3D printing machines.

7. Further research is to explore materials and 3D printer that can be used for 3D printing delicate organs like the kidney, liver, etc. so that 3D printed organ can be produced for patients who requires organ transplant due to liver and knee failure

V. REFERENCES

[1] Do A.V., Khorsand B., Geary S.M., Salem A.K. 3D printing of scaffolds for tissue regeneration applications Adv. Health. Mater. 2015;4:1742–1762. doi: 10.1002/adhm.201500168

[2] The Editors of Encyclopaedia Britannica Pelvis, Encyclopaedia Britannica. Encyclopaedia Britannica Inc. [(accessed on 11 November 2020)]; Available online.

[3] Rodriguez D. The Basics of Hip Pain, Everyday Health. [(accessed on 11 November 2020)];2009 Available online.

[4] Committee N.S. National Joint Registry for England and Wales: 14th Annual Report. Northern Ireland and the Isle of Man (NJR); Hemel Hempstead, UK: 2018.

[5] Jain A., Clamp K. Adult Hip Pain. InnovAiT 2019:13:21–27. doi: 10.1177/1755738019884353.

[6] Older J. Charnley low-friction arthroplasty: A worldwide retrospective review at 15 to 20 years. J. Arthroplast. 2002;17:675–680. doi: 10.1054/arth.2002.31973. [

[7] Furnes O., Lie S.A., Espehaug B., Vollset S.E., Engesaeter L.B., Havelin L.I. Hip disease and the prognosis of total Hip replacements: A review of 53,698 primary total Hip replacements reported to the Norwegian arthroplasty register 1987–1999. J. Bone Joint Surg. Br. Vol. 2001;83:579. doi: 10.1302/0301-620X.83B4.0830579.

[8] Hughes A.J., DeBuitleir C., Soden P., O'Donnchadha B., Tansey A., Abdulkarim A., McMahon C., Hurson C.J. 3D printing aids acetabular reconstruction in complex revision Hip arthroplasty. Adv. Orthop. 2017:8925050. doi: 10.1155/2017/8925050.

[9] Gabriel L., Casey J., Gee M., Palmer C., Sinha J., Moxham J., Colegate-Stone T.J. Value-based healthcare analysis of joint replacement surgery for patients with primary Hip osteoarthritis. BMJ Open Qual. 2019;8:e000549. doi: 10.1136/bmjoq-2018-000549.

[10] Hart A.J., Hart A., Panagiotopoulou V., Henckel J. Personalised orthopaedics–using 3D printing for tailor-made technical teaching, pre-operative planning and precise placement of implants. Orthop Prod. News. 2017;178:22–26.

[11] Polaris Market Research Polaris Market Research. [(accessed on 11 November 2020)]; Available online.

[12] Kang C.W., Fang F.Z. State of the art of bio implants manufacturing: Part I. Adv. Manuf. 2018;6:20–40. doi: 10.1007/s40436-017-0207-4.

[13] Kang C.W., Fang F.Z. State of the art of bio implants manufacturing: Part II. Adv. Manuf. 2018;6:137–154. doi: 10.1007/s40436-018-0218-9.

[14] Gharde S., Goud R., Nimje S., Kandasubramanian B. Aggrandized flexural properties of assorted natural biological materials. In: Kaushik K., Davim Paulo J., editors. Biodegradable Composites: Materials, Manufacturing and Engineering. De Gruyter; Berlin, Germany: 2020. Chapter 6.

[15] Gharde S., Surendren A., Korde J.M., Saini S., Deoray N., Goud R., Nimje S., Kandasubramanian B. Recent Advances in Additive Manufacturing of Bio-Inspired Materials. In: Prakash C., Singh S., Singh R., Ramakrishna S., Pabla B.S., Puri S., Uddin M.S., editors. Biomanufacturing. Springer International Publishing; Cham, Switzerland: 2019. pp. 35–68.

 DOI : 10.35291/2454-9150.2022.0266