Regeneration of Natural Bone and its Dynamic Analysis

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Abstract: Human skeleton could have a number of kinds of fractures but, one of the noticeable number of fracture occurs in the human body takes place within the femur bone. Among all one of the important reason for this sort of fracture is due to it being the longest bone in entire body. Femur bone liable to sustain whole weight of human body. The critical geometry and anisotropy traits of this bone has recounted huge importance within the field of biomedical area. Treating these larger fractures usually by Bone graft. The material used for a bone graft is frequently required different types of exclusive analyses and check for biocompatibility. Bone grafting uses as remedy of the anatomical damage. In spite of that, because of biological constrained and dangers associated with autografts as well as with allografts, it needs substitute treatment and that may be the Bone scaffold. The bone scaffold is a porous material of customized shape and size, that facilitates to develop cells in damaged area. this article gives an in depth assessment of Dynamic analysis of 3D printed bone scaffold.

Keywords: Bone scaffold, Dynamic analysis, cell growth, Bone formation

1. Instruction

The reasons of most bone disorders and degeneration of tissues are categorized into accidental bone loss, or fractures, different types of infections, cancer, age group, and hereditary diseases, which can all results into damage. In spite of this, once the damage reaches to critical point or when it exceeds the limit of the bone's regrowth capacity, treatment is needed to initiate the natural cell growth and to heel the damaged section. Grafting is the current treatment in which tissues can be harvested from patients own body (autograft) or it can be taken from another (donors) body (allograft). Grafting is the painful treatment also there are chances of infections and disease to carry along with the tissue. Another treatment to overcome these issues related to grafting is Bone scaffold. Bone scaffold is

3D printing have its own advantages over conventional manufacturing in fabrication of bone scaffold. customised porous structure which help to initiate the natural cell growth.

The 3D printed bone scaffold has its important application in treating the bone defects. The additively manufactured bone scaffold can be evaluated based on the load carrying capacity, its strength and dynamic behavior as well. The different mechanical characteristic plays an important role in predicting its behavior in human body. There are some of the important and variety of taken into consideration while choosing the literature or material for the study. The performance of bone scaffold is evaluated by static structural analysis and fluid dynamic analysis. Static structural behavior helps to identify mechanical properties and fluid dynamic analysis help to find out proliferation, tissue generation and cell adhesion.

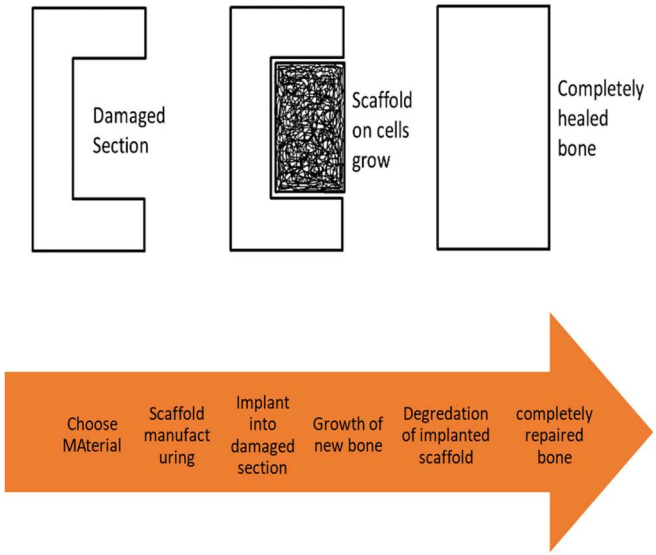

Fig1. Regeneration of natural bone

2. Review Methodology

Analysis of bone scaffold include broadly two types of analysis; one is static and another is dynamics. In static analysis the model is tested for the stationary conditions and in dynamic analysis the movement is considered. In this article review is specifically presented on Fluid dynamic analysis. Number of papers studied which are published from year 2006 to 2021.

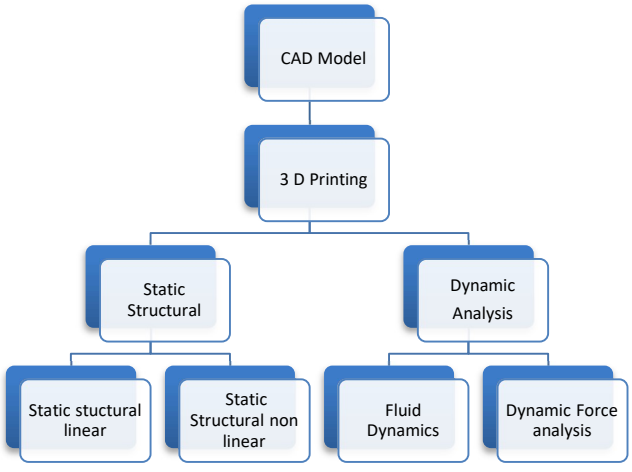

Fig2.Classification of analysis of Bone scaffold

In the present literature, the review is conducted in a systematic way to involve the opted literature articles on the involvement of bone scaffold in the medical treatment. Firstly, the research articles searched out using the combination of key words terms 'Bone scaffold 'AND 'Dynamic analyses AND '3D Printing' AND 'Mechanical Properties'. The online searches were carried out to collect the research articles. Only good quality journal such as peer-reviewed journals are included in this study. Also, only English language articles were included.

3. Literature review

A comprehensive review on Bone scaffold, as an alternate treatment to damaged or fractured bone. In this section of the research article, different essential factors of the bone scaffold are taken into study and review which again are found out from the research articles published in the area of bone scaffold and biomedical. And the brief literature review of bone scaffold has been taken through, to understand about material and different manufacturing processes used for creation of bone scaffold by different informative articles. Study of bone scaffold has been carried out to facilitate the treatment of bone which is one or the other way got damaged. To carry out this important review, research articles from more than two decades are studied from year 2006 to 2021 are studied and listed below:

Raimondi et al [2006]: Performed computational fluid dynamics (CFD) simulations of the flow of culture medium through chondrocyte-seeded 3D porous scaffolds. They also cultured in a direct perfusion bioreactor, for predicting the shear stress acting on cells adhering on the scaffold walls [1].

They also studied shear stresses acting on the cells and conclude about the relationship between perfusion at a known micro fluid dynamic condition and the tissue growth in VITRO.

Milan JL et al [2009]: Fabricated composite scaffold made up of PLA and calcium phosphate and carried out static as well as fluid dynamic analysis on it they carried out perfusion test and found different loading conditions promoting bone formation [2]

Milan JL [2010]: they developed computational model to predict the bone tissue formation and simulated mechanically for forced controlled dynamic compression. They used 1 to 70N ramp force. They have seen under experimentations that during high level of stress strain the scaffold shows heterogeneous mechanical behaviour which again leads to heterogeneous tissue. They concluded as the tissue formation of the scaffold is closely depending on the loading history [3].

Rashia Begum, S [2013]: According to researcher the bone scaffold and tissue engineering involved in mechanical engineering as well as fluid dynamics. They used CT scan data of patient and by reverse engineering they created 3D cad model of the scaffold for different porosity. The

3Dimentional bone scaffold model tested in CFD software for different fluid velocities. [4].

Jolanda Rita Vetsch [2013]: Presented the review article in which they pointed some of the drawbacks of current bone generation technique. And give recommendations about scaffold geometries, its mechanical properties, types of loading and the nutrient concentrations.[5]

Begum, s [2015]: Researcher evaluated the bone scaffold for its mechanical strength and fluid dynamic behaviour. They used CT scan data and method of reverse engineering for creating 3D CAD model and they used MIMIC software for the same. The 15 customised bone scaffold they fabricated using additive manufacturing technique. Carried out the experimentation and conclude as the wall shear stress is important parameter which helps to decide the extent of cell proliferation. [6]

Campos Marin [2016]: according to researcher computational fluid dynamics model can resolve 3D flows and nutrient concentrations in bioreactors. They carried the research to develop to develop a μPIV approach. They have taken the μ-computed tomography geometry for scaffold and then included in CFD model. After experimentation they concluded as there is correlation between velocity profiles computational results.[7]

Nguyen Khoi Tram [2016]: carried out CFD analysis in COMSOL software. They used perfusing fluid as water and unidirectional flow was perfused through the bioreactor chamber in the longitudinal direction. And they found out fluid dynamic viscosity using $Re = \rho \cdot u \cdot dp \mu$.[8]

Marin, Ana Campos et al [2017]: Researcher claim that cell seeding of 3D scaffold is one of the critical steps in bone tissue engineering. According to researcher the properties of tissue are related to cell distribution and density. They developed computational fluid dynamics model along with partial tracking velocimetry which were applied to check sell seeding inside the scaffold. And predicted the effect of gravity and fluid drag. [9]

Davar Ali [2018]: according to researcher permeability and fluid flow as well as wall shear stress important in tissue generation. Researcher claim that fluid properties of blood in measuring permeability results into realistic results. They carried out CFD analysis of lattice-based scaffold. After experimentation they found that the non-Newtonian flow of blood caused almost twice the magnitude of WSS originating from Newtonian blood flow.[10]

Saeid Esmaeili [2019]: another presented case study the fractured bone taken and with 3D printing technique and using biocompatible material as PLA-HA femur designed and tested for different loading such as centralized load, partial load and full load. FEA analysis carried out in Abacus software.[11]

T. J. Sego [2019]: perform experimentation in VITRO and claimed that computational fluid dynamics should be used to drive future construct design and flow application before further tissue bio fabrication and perfusion. They build CFD model and analysed flow characteristics.[12]

Aby K Abraham [2019]: - fabricated cobalt chrome customised bone scaffold by additive manufacturing and evaluated based on the mechanical strength and fluid dynamics behaviour. They experimented and studied fabricated bone scaffold for the static conditions as well as for dynamic conditions. In the experimentation Bone scaffold evaluated for different important mechanical properties in static structural analysis and fluid behaviour in fluid dynamics. After experimentation they conclude as the implant can be in human body for long term. [13]

Zhen Wang [2019]: author used reverse engineering specifically to construct bone scaffold. Fluid of the scaffold simulated through numerical method based on finite volume method. They also carrier out VITRO experiment and evaluated for cell proliferation and the mass flow in computational fluid dynamics.[14]

Ali Reza Saatchi [2019]: Fabricated cubic bone scaffold by additive manufacturing technique and tested it for different angular orientation and for different perfusion bioreactors inlet flowrate. After experimentation they found out as by decreasing the angular orientation between strands in each layer and by increasing the inlet flow rate of a perfusion bioreactor, the magnitude of different parameters and distribution of fluid velocity, fluid shear stress, and wall shear stress inside the scaffold increased. The average fluid velocity, average fluid shear stress, and average wall shear stress inside the scaffold within the bioreactor increased linearly with the inlet flow rate. [15]

Babar Pasha Mahammod [2020]: carried out experimentation on fluid dynamic analysis on the 3D printed bone scaffold. For investigating permeability of HA-PMMA 65% porous scaffold. They have considered Newtonian and non-Newtonian model and found that, the permeability in the case of Newtonian scaffold model is more than the non-Newtonian scaffold model.[16]

Linlin Liu [2020]: mentioned that the architecture of bone scaffold is an essential parameter to be considered in the bone growth. They carried out computational fluid

dynamics on two types of structures, strut structure and curved structure and found that, osteogenic property of a curved structure is better than that of a strut structure, but the mechanical property is not as good as that of the strut structure.[17]

Fuyuan Deng [2020]: explained about the characteristic of bone scaffold as Porosity, porous size, structure of it which are together pays important role in bone regeneration. They fabricated 65% porous bone scaffold using titanium alloy by selective laser melting. And implanted in rabbit for 12 weeks to evaluate the cell growth in VIVO. After operation and taking out scaffold found that Diamond lattice structure unit had best bone growth. Also carried out computational fluid dynamics to study permeability, velocity and flow trajectory. [18]

Sandra Camarero-Espinosa [2021]: fabricated additively manufactured the customised bone scaffold with the biocompatible materials PCL and PLA blend. And carried out experimentation and tested scaffold for cell proliferation, matrix deposition and osteogenic differentiation [19].

4. Research Gap

After studying the research articles mentioned above, and the summary of table. It has been observed that most of the authors have done their research and tested the bone scaffold for static compression. As in case dynamic analysis they attempted Fluid dynamic analysis for evaluating the cell growth and related terminologies like fluid velocity, fluid shear stress, wall shear stress, proliferation etc. Table 1 shows the research gap.

Table1: Research gap

Sr. No	Author	Year of Publication	Bone scaffold	Fluid dynamic Analysis	Dynamic force analysis
1	Raimondi et al	2006	Developed 3D model	Done	Not Done
2	Milan JL et al	2009	Fabricated	Done	Not Done
3	Milan JL et al	2010	Developed 3D model	Done	Not Done
4	Rashia Begum et al	2013	Developed 3D model	Done	Not Done
5	Jolanda Rita Vetsch et al	2013	Review article	Done	Not Done
6	Begum, s et al	2015	Fabricated	Done	Not Done
7	Campos Marin et al	2016	Developed 3D mode	Done	Not Done
8	Nguyen Khoi Tram et al	2016	Developed 3D mode	Done	Not Done
9	Marin, Ana Campos et al	2017	Developed 3D mode	Done	Not Done
10	Davar Ali et al	2018	Developed 3D mode	Done	Not Done
11	Saeid Es maeili et al	2019	Fabricated LA-HA)	Done	Not Done
12	T. J. Sego et al	2019	Developed 3D mode	Done	Not Done
13	Aby K Abraham et al	2019	Fabricated (Cobalt chrome)	Done	Not Done
14	Zhen Wang et al	2019	Developed 3D mode	Done	Not Done
15	Ali Reza Saatchi et al	2019	Developed 3D mode ()	Done	Not Done
16	Babar Pasha Mahammod	2020	Developed 3D mode	Done	Not Done

17	Linlin Liu et al	2020	Fabricated and implanted in rabbit	one	Not Done
18	Fuyuan Deng et al	2020	Fabricated (titanium alloy) and implanted in rabbit	Done	Not Done
19	Sandra Camarero -Espinosa et al	2021	Fabricated (PLA-PCL)	Done	Not Done

5. Discussion and conclusion

From above literature review, we found that there are various researchers working in the field of bone formation and tissue engineering especially in the area of bone scaffold and its analysis to proving that bone scaffold is more advantageous option as compared to allograft or auto graft. The research articles covered in this study are relating, manufactured bone scaffold or reviewed bone scaffold using various bio compatible plastic, ceramics, hydrogel material and as manufacturing technique, Additive manufacturing/ 3D printing / RP used over the conventional manufacturing methods.. In order to evaluate and figure out the properties and behaviour fluid in bone scaffold. And how it is important in cell proliferation and cell growth. Almost every researcher mentioned in this article carried out Fluid dynamic analysis. Few of them implanted the 3D printed bone scaffold into animals like rat or rabbit, to analyse the natural cell growth in damaged section of bone. Still the research was limited to static analysis of the 3D printed bone scaffolds. After implantation of Bone scaffold in damaged section of bone, it would be an integral part of human body. In order to make the bone scaffold as successful and advantageous treatment for treating bone defect, it is required to be tested for dynamic situations as well. How the material will behave in dynamic situation needs to be figured out along with the natural cell growth. Before going for the dynamic force analysis researcher should know about the work which has been conducted in this vibrant area of biomedical. This research paper presents systematic literature review of almost 19 papers in the same area which gives us an idea about the number of different manufacturing methods other than conventional methods used by various researchers, the biocompatible material and the testing of mechanical properties carried out by them. This review clearly shows till the time study were limited to fluid dynamic analysis, so for further study to be carried out in this area this paper will be expedient.

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