© IJEDR 2018 | Volume 6, Issue 3 | ISSN: 2321-9939

Fabrication and Impact Analysis of Femur Bone

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Abstract— Biomaterials are the materials suited to the capacity that they perform, frequently and biologically supported by a complex progressive structure. Biomaterials are completely self-gathering and shape at close surrounding temperatures. The main aim of this project plans to demonstrate Femur bone, particularly a human femur, is adjusted to the body's needs and its basic capacities. It portrays the science of bone and furthermore thinks about it as a building material. Bones such as the femur is subjected to a bending moment, and the stresses generated by the different impact. In this work we analyze and fabricated the bone with suitable materials like PLA (poly lactic acid) and ABS (acrylonitrile butadiene-styrene) .This is project is mainly focused on fabrication and impact analysis of femur bone and replacing it in place of the damaged bone. Replacement of bone is done firstly by designing the bone, secondly by analysing its properties and its characteristics. Then it is to be printed three dimensionally by a 3D Printer for the demonstration purpose. if it reaches the expected calculations then it is prepared accordingly with suitable materials and finally the finished bone will be replaced in the place of the infected femur bone. In this the two Artificial bones are suited i.e. PLA and ABS. Modelling of Bone is done by using Fusion 360. Impact analysis has been done using explicit Dynamics in ansys to select the suitable material.

Index Terms—Explicit Dynamics, Analysis, 3D printing

I.INTRODUCTION

1.1Human Bone

The properties of biomaterials are very impressive, and in many cases can be compared directly to those of man-made materials, such as in the use of wood for engineering applications, and the use of silk for making light, strong rope. This is all the more remarkable if we consider that biomaterials are entirely self-assembling and form at near ambient temperatures.

Biomaterials are ideally suited to the function that they perform, often aided by a complex hierarchical structure. In many cases this leads to high degrees of anisotropy in the structure and the resultant properties. A good example of this is seen in the structure of bone.

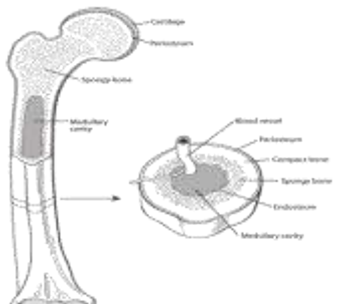


Figure: 1.1: Parts of a Bone

Our project aims to show you how bone, specifically a human femur, is adapted to the body's needs and its structural functions. It describes the biology of bone and also considers it as an engineering material.

1.1.1Structure and composition of bone

Long bones such as the femur contain two distinct morphological types of bone:

Cortical (compact) bone

Trabecular (spongy) bone

Cortical bone forms a dense cylinder down the shaft of the bone surrounding the central marrow cavity. While cortical bone accounts for 80% of the mass of bone in the human body, it has a much lower surface area than cancellous bone due to its lower porosity.

1.1.2 Biomechanics

Biomechanics is the study of how the systems and structures of biological organisms, from the smallest plants to the largest animals, react to various forces and external stimuli. In humans, biomechanics often refers to the study of how the skeletal and musculature systems work under different conditions. In biomechanics more generally, scientists often try to apply physics and other mathematically based forms of analysis to discover the limits and capabilities of biological systems

1.1.3Composition

Bone itself consists mainly of collagen fibres and an inorganic bone mineral in the form of small crystals. In vivo bone (living bone in the body) contains between 10% and 20% water. Of its dry mass, approximately 60-70% is bone mineral. Most of the rest is collagen, but bone also contains a small amount of other substances such as proteins and inorganic salts. Collagen is the main fibrous protein in the body. It has a triple helical structure, and specific points along the collagen fibres serve as nucleation sites for the bone mineral crystals. The composition of the mineral component can be approximated as hydroxyapatite (HA), with the chemical formula $Ca_{10}(PO_4)_6(OH)_2$.

1.1.3. Stresses

Bones such as the femur are subjected to a bending moment, and the stresses (both tensile and compressive) generated by this bending moment account for the structure and distribution of cancellous and cortical bone. In the upper section of the femur, the cancellous bone is composed of two distinct systems of trabeculae.

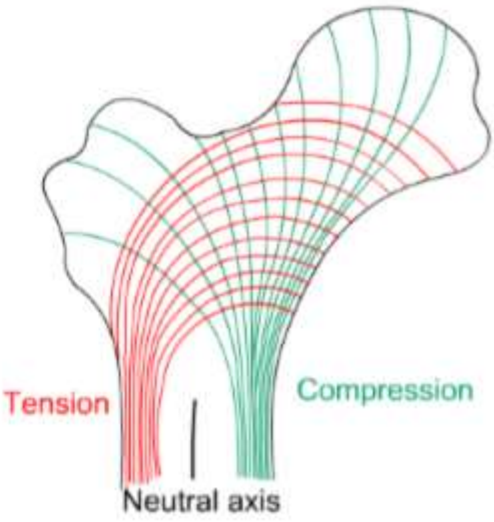


Fig1.2: Computed lines of constant stress from the analysis of various transverse section.

These trabeculae follow the lines of maximum tensile stress, and in general are lighter in structure than those of the compressive system. The greatest strength is therefore achieved with the minimum of material. The distribution of the compact bone in the shaft is also due to the requirement to resist the bending moment stresses.

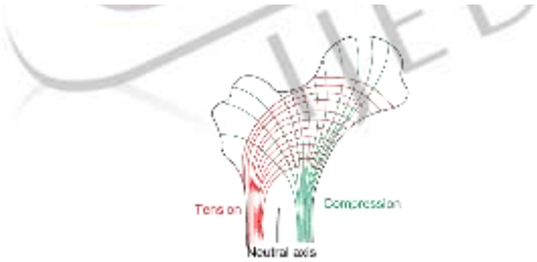
1.2. Benign bone tumours

Benign tumours do not spread to other tissues and organs and so are not usually life threatening. They are generally cured by surgery. Types of benign bone tumours include:

Osteoid osteoma, Osteoblastoma, Osteochondroma.

These benign tumors are not discussed further here. This information is only about bone

1.2.1. Malignant bone tumours



Osteosarcoma: Osteosarcoma (also called osteogenic sarcoma) is the most common primary bone cancer. This cancer starts in the bone cells. It most often occurs in young people between the ages of 10 and 30, but about 10% of osteosarcoma cases develop in people in their 60s and 70s. It is rare in middle-aged people, and is more common in males than females. These tumours develop most often in bones of the arms, legs, or pelvis.

Fibro sarcoma: This is another type of cancer that develops more often in soft tissues than it does in bones. Fibro sarcoma usually occurs in elderly and middle-aged adults. Bones in the legs, arms, and jaw are most often affected.

1.3. Bone replacement

Bone replacement materials can be needed for a variety of reasons. They are sometimes required when a section of bone is missing and the gap needs to be filled in, for example following an accident or after the removal of a tumour.

There are several options for this type of bone replacement:

- Allografts involve using material from another patient. However, there are risks of infection and the implant being rejected, and the strength of the replacement bone may be reduced due to sterilisation.
- Autografts involve using material from the same patient, but from a different site (such as the pelvis). Although this reduces the chances of rejection, there is a limited amount of material available, and two surgical procedures are needed, leading to more pain and a higher risk of infection.

- Synthetic materials are gradually becoming more popular. Hydroxyapatite can be prepared easily in a laboratory, but since it is a ceramic, it is too brittle to be used on its own for large-scale applications. Composites of hydroxyapatite with degradable polymers can also be used, which resorb over time and allow bone to regrow and fill the space.

1.3.1. Titanium-Foam Implant Mimics Bone Structure

The structure of load-bearing titanium-based implants looks set to change following research led by scientists working at the Fraunhofer Institute for Manufacturing Technology and Advanced Materials Research (IFAM) in Dresden, Germany. The researchers have created a titanium foam for use in implants into which bone cells and blood vessels could grow, enabling better integration of implants into the skeleton. Another advantage of titanium foam is that it has mechanical properties that are more similar to those of bone than to those of solid metal alloys. This load imbalance may lead, in some cases, to the deterioration of the surrounding bone and the implant's working itself loose. Titanium foam, in contrast, has minimal rigidity, but it maintains the strength and durability of solid metal alloys.

1.3.2 .Laser shaping Technique Creates Custom-Fit, Degradable Implants

In a separate Fraunhofer Institutes development, scientists from the Institute for Laser Technology (ILT; Aachen, Germany) have announced that they are now able to manufacture custom-fit, degradable implants suitable for facial, maxillary, and cranial bone replacement. Because the implants contain β-tricalciumphosphate (β-TCP), they are also osteoinductive and encourage the growth of new bone to repair the break before the implant itself degrades. The scientists created the implants using a laser-shaping technique that enables them to build tiny interconnecting pores into the structure. Importantly, these pores encourage the growth of blood vessels and connective tissue into the implant, essential for the successful breakdown of the implant later.

1.3.3. Biological Joint Replacement

Scientists have used for the first time endogenous stem cells to regenerate a missing joint in animals, suggesting that biological joint replacement in humans may be a realistic goal. Publishing their findings in The Lancet, scientists from Columbia University (New York, New York), the University of Missouri College of Veterinary Medicine and School of Medicine (Columbia, Missouri), and Clemson University (South Carolina) reported that rabbits—from which they had removed a hip joint and replaced it with a growth-factor-infused scaffold—were able to regenerate a functional joint within four weeks.

The research team developed its joint-replacement technique using a collagen hydrogel infused with transforming growth factor β 3 (TGFβ3), which attracted the rabbit's own stem cells to an anatomically accurate scaffold comprising a composite of poly-ε-caprolactone and hydroxyapatite. Upon reaching the scaffold, the stem cells differentiated into cartilage and bone, forming separate layers. Within four weeks of surgery, rabbits that had received the TGFβ3-infused scaffold were able to place weight on their new joint and use it to move around. Such advances in stem-cell therapy clearly threaten the long-term dominance of metal implants. One significant advantage of a biological joint replacement is that future surgical intervention would be less likely than with today's artificial joints, which need replacement if they wear out..

2. BIOMECHANICS

Biomechanics is the study of how the systems and structures of biological organisms, from the smallest plants to the largest animals, react to various forces and external stimuli. In humans, biomechanics often refers to the study of how the skeletal and musculature systems work under different conditions. In biomechanics more generally, scientists often try to apply physics and other mathematically based forms of analysis to discover the limits and capabilities of biological systems.

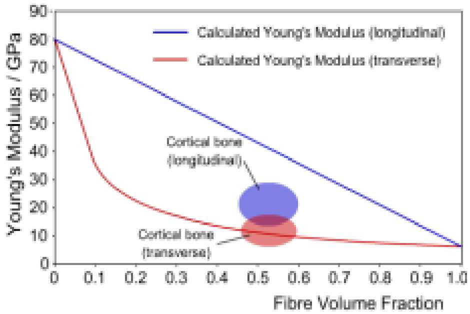
3. MECHANICAL PROPERTIES OF BONE

3.1. Introduction

Although an organic material, bone can often be considered in the same way as man-made engineering materials. However, due to the nature of its synthesis it is likely to show more variation in measured properties than typical engineering materials. Factors include:

3.2. Modulus

Bone can be considered to consist primarily of collagen fibres and an inorganic matrix, and so on a simple level it can be analysed as a fibre composite. Composites are materials that are composed of two or more different components. They are commonly used in engineering and industry where the combination of the two materials creates a composite with properties that are superior to those of the individual components. The Young's Modulus of aligned fibre composites can be calculated using



the Rule of Mixtures and the Inverse Rule of Mixtures for loading parallel and perpendicular to the fibres respectively.

3.6. Fracture Toughness

In contrast to the findings for tensile and compressive strength and modulus, the values of toughness in the transverse direction are generally higher than those in the longitudinal direction. This is due to the presence of the cement lines in the microstructure. These are narrow regions around the outermost lamellae in the osteons, and they form the weakest constituent of bone. Crack propagation parallel to the osteons can occur much more easily through these regions and this significantly decreases the fracture toughness of cortical bone in the longitudinal direction. If a crack is propagating perpendicular to an osteon it will change direction when it reaches a cement line, thus blunting the crack

4 Explicit Dynamic analysis of Bone

4.1Analysis Overview and Assumptions

To evaluate the mechanical properties of the cancellous bone biopsies, they were put through a simulated 1% strain compression test. This value is consistent with other compression tests found in the literature, although there is some variation. Karim and Vashishth used 0.6% and 1.1% apparent-level strain for pre-yield and post-yield tests, respectively. The values were chosen based on a yield point of 0.8% for cancellous bone. Since a linear elastic model was used in this research, the exact level of applied strain is not crucial. The results can be scaled to any reasonable level of strain.Now that the background assumptions are clear, the minutiae of the procedure itself will be specified. Any finite element analysis can be divided into three fundamental steps: pre-processing, processing, and post-processing. Pre-processing encompasses

4.3. Pre-processing

In an engineering analysis, the classic pre-processing steps are:

1) Geometry definition,
2) Mesh generation,
3) Application of material properties, and
4) Setting loads and boundary conditions.

The first two steps are complete by the time ANSYS APDL is put into use. The geometry is taken from the STL file obtained using micro-CT. The meshing is done in ANSYS ICEM, and can be imported directly into APDL using the command ‘File>Read Input from’. The default tetrahedral element type in ICEM is SOLID185, and that was not modified for this analysis. SOLID 185 is an 8-node element with 3 DOFS at each node. The tetrahedral version is a degenerate element with 4 shared nodes at one vertex, and two shared nodes at a second vertex. Generally, it is not recommended to have more than 10% tetrahedral elements in a model, but this rule was violated because tetrahedral elements excel at capturing the geometry of irregular surfaces. Any shortfall of the element was remedied by using a finer mesh.

4.4. Processing

Selecting a solver is an often-overlooked part of the FEA process. The majority of the time, the ANSYS default sparse solver works well. When that is the case, solving requires no more effort than clicking a button. However, as the total degrees of freedom increase, some consideration of the solver is justified. Above 500,000 DOF, the Preconditioned Conjugate Gradient (PCG) solver becomes the more attractive option. The PCG solver is iterative, and less robust than the sparse solver. Nevertheless, it worked well in this application.

4.5. Post-processing

The direct output of any finite element model is simply a value for each degree of freedom at each node. For SOLID185, the only degrees of freedom are displacements in the coordinate directions. Using equations of linear elasticity on the function, stress and strain can be determined at any point. Specifically, the information extracted from each model included the reaction force, the energy equivalent strain, and the maximum von Mises stress. The left image is an exaggerated display of the displacement, with the original shape outlined in white. The image to the right is a counter plot based on the vector sum of displacement. Unsurprisingly, the displacement is greatest at the top, and least at the bottom. More interestingly, the displacement shows a clear relationship with the plates in the biopsy. The von Misses stress is plotted, and it shows that the majority of the biopsy is lightly stressed. A close-up on the right revels that small portions of the trabeculae are responsible for the high stresses. So, much of the structure is under-utilized, at least for this one loading condition. The finite element method can produce some exquisite-looking figures, but caution should be used in interpreting them. Just because the results look good does not mean that they are accurate or pertinent. The color contour plot, in particular, is subject to manipulation by altering the scale. All of the plots presented here use the ANSYS default scale, but readers should still be hesitant to make any conclusions based solely on the figures.

ANSYS Results for the PLA Material

4.6. Procedure followed in ANSYS (Diagramtic Description)

Fig 4.1: Importing the bone model to ANSYS

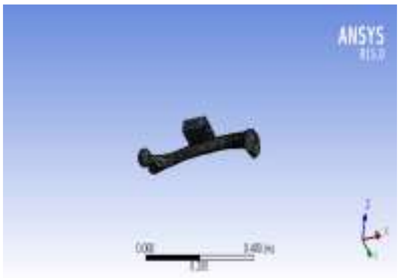


Fig 4.2: Mesh formation of the bone model

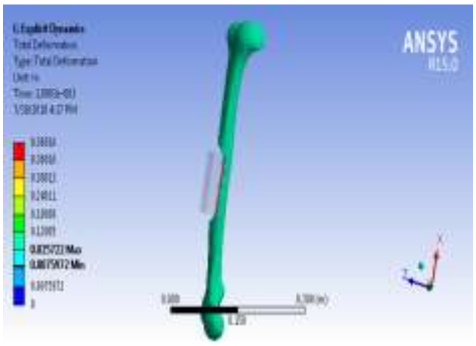


Fig 4.3: Total Deformation of the bone

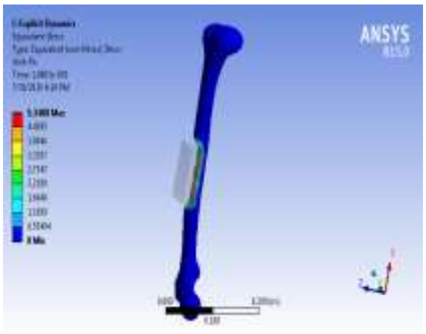


Fig 4.4: Varying Maximum and Minimum Principal stresses PLA

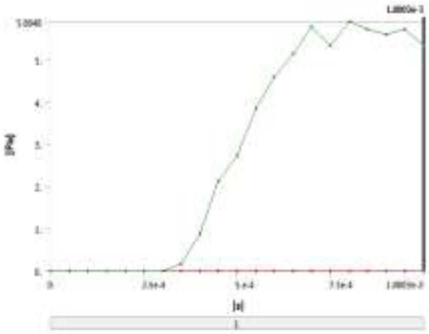


Fig 4.5: Max Principal stress vs Time

Tab:4.1: Varying Maximum and Minimum Principal Stresses of PLA

Time [s]	Minimum [Pa]	Maximum [Pa]
1.1755e-038		
5.0347e-005		
1.0055e-004		
1.501e-004		0.
2.0031e-004		
2.5051e-004		
3.0006e-004		
3.5027e-004		0.15293
4.0047e-004		0.87943
4.5003e-004		2.1202
5.0023e-004	0.	2.7182
5.5043e-004		3.8533
6.0064e-004		4.5838
6.5019e-004		5.1382
7.004e-004		5.7679
7.506e-004		5.3284
8.0015e-004		5.8948
8.5036e-004		5.7054
9.0056e-004		5.5861
9.5011e-004		5.7205
1.0003e-003		

ANSYS Results for the ABS Material

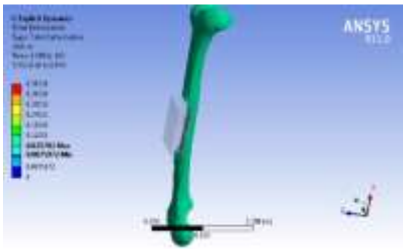


Fig 4.6: Total Deformation of the bone

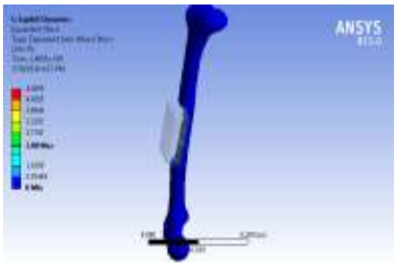


Fig4.4: Varying Maximum and Minimum Principal stresses ABS

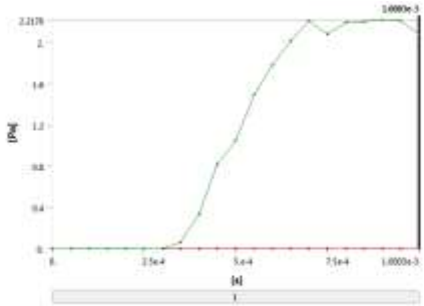


Fig 4.8: Max Principal stress vs Time ABS

Fig 4.7: Varying Maximum and Minimum Principal stresses ABS

Time [s]	Minimum [Pa]	Maximum [Pa]	
1.1755e-038			
5.0347e-005			
1.0055e-004			
1.501e-004		0.	
2.0031e-004			
2.5051e-004			
3.0006e-004			
3.5027e-004		5.8845e-002	
4.0047e-004		0.33848	
4.5003e-004		0.81668	
5.0023e-004	0.	1.0487	
5.5043e-004		1.491	
6.0064e-004		1.7829	
6.5019e-004		2.0115	
7.004e-004		2.2113	
7.506e-004			2.08
8.0015e-004			2.1945
8.5036e-004			2.2025
9.0056e-004			2.2176
9.5011e-004			2.2122
1.0003e-003			2.08

Tab 4.2: Varying Maximum and Minimum Principal Stresses of PLA

5. 3D PRINTING

3D Printing, also known as Additive Manufacturing (AM), refers to processes used to create a three-dimensional object in which layers of material are formed under computer control to create an object. Objects can be of almost any shape or geometry and typically are produced using digital model data from a 3D model or another electronic data source such as an Additive Manufacturing File (AMF) file. Stereo Lithography (STL) is one of the most common file types that 3D printers can read. Thus, unlike material removed from a stock in the conventional machining process, 3D printing or AM builds a three-dimensional object from computer-aided design (CAD) model or AMF file by successively adding material layer by layer.

5.1. Modelling:

3D printable models may be created with a computer-aided design (CAD) package, via a 3D scanner, or by a plain digital camera and photo grammetry software. 3D printed models created with CAD result in reduced errors and can be corrected before printing, allowing verification in the design of the object before it is printed. CAD model used for 3D printing The manual modelling process of preparing geometric data for 3D computer graphics is similar to plastic arts such as sculpting. 3D scanning is a process of collecting digital data on the shape and appearance of a real object, creating a digital model based on it.

5.2. Printing: Before printing a 3D model from an STL file, it must first be examined for errors.

5.5. Material Extrusion: The most commonly used technology in this process is Fused Deposition Modeling (FDM).

Fused deposition modelling (FDM), a method of rapid prototyping:

- Nozzle ejecting molten material (plastic),
- Deposited material (modelled part),
- Controlled movable table.

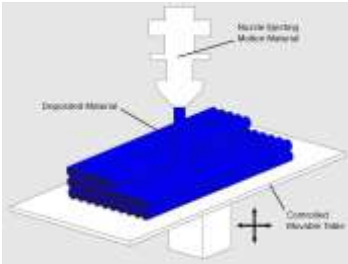


Fig 5.1: **Fused Deposition Modelling (FDM)**

The FDM technology works using a plastic filament or metal wire which is unwound from a coil and supplying material to an extrusion nozzle which can turn the flow on and off. The nozzle is heated to melt the material and can be moved in both horizontal and vertical directions by a numerically controlled mechanism, directly controlled by a computer-aided manufacturing (CAM) software package. The object is produced by extruding melted material to form layers as the material hardens immediately after extrusion from the nozzle. This technology is most widely used with two plastic filament material types: ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic acid).

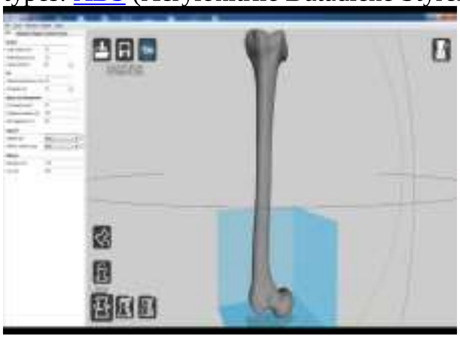


Fig 5.2: Importing of Bone .Stl file into Cura Software

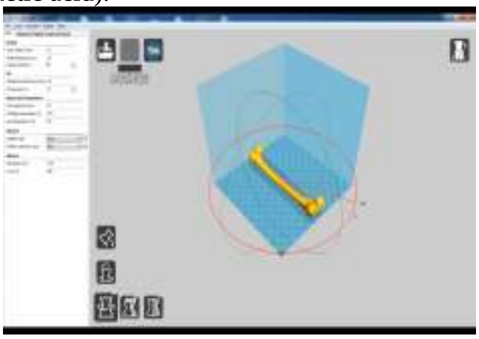


Fig5.3: Final Bone Model ready for printing.

Fig 5.4: Our final 3D Printed Femur Bone

Conclusions

Our project deals with design of femur bone and then analysing it with various factors that cause failure of the femur bone and finally 3D Print it.

- ✓ Our main reason for choosing this project is to find a better remedy for patients suffering from bone fracture rather than suffering with it.

- ✓ We have analysed problems related to bone design.
- ✓ Modelling the patients unaffected bone by scanning it through CT Scan as a source and then designing it three dimensionally by using ANSYS software.
- ✓ Analysis of a particular bone is done by checking various factors that result in failure of bone like various stresses and forces and then final results are produced.
- ✓ Finally after analysis it is converted into .stl file and then imported to 3D Printing software and then checked with the printer specifications and then Gcode file is given to the printer for final printing with the material that has properties of a bone.
- ✓ Explicit dynamics of femur bone exhibits the best material for impacts. It is PLA analyzed in our project.

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