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Anatomical scaffold application for the digital rebuilding of human lower jaw defects

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ABSTRACT

Researchers are making huge efforts in the field of rebuilding the large missing parts of the human lower jaw, and this represents a major challenge in the field of bone engineering based on reconstruction on the basis of human bone implants. This challenge is to create customized designs that fit the physiological, genetic, and anatomical characteristics of each individual patient. Designing these implants specifically for each case will definitely improve and reduce the recovery period. In order to achieve an improvement in the lower jaw surgery process and clinical practice, the required design of a precise three-dimensional engineering scaffold whose external shape resembles the shape of the missing part of a lower jawbone will reduce the appearance of complications during recovery in addition to preserving the teeth to be implanted and meet mechanical as well as aesthetic requirements. The scaffolds that are designed and will be implanted to replace the missing parts of a lower jaw will be subject to great mechanical loads, for this reason, a scaffold that meets the anatomical conditions is designed on the basis of the 3D geometry of patterns be addressed in research. The process of changing the 3D patterns leads to the modification of the mechanical properties of the scaffold. Because of its complex structure, will be applying additive manufacturing techniques to manufacture this scaffold.

1. Introduction

A result of exposure the bone (a lower jaw) to major trauma or one of the bone diseases like cancer, fragility, necrosis, etc. maybe leads to the loss of a large part of the bone tissue, which requires the implantation of a scaffold [1,2,3]. The application of accurate engineering models of scaffolds and their implants to rebuild the missing part of the bone is of great importance in current medical uses in the field of reconstruction of a lost large part of bone tissue [4,5]. Researchers are making unremitting efforts to improve the available and applicable solutions to reconstruct the missing parts of the lower jawbone and to adapt these solutions each specific pathological condition (individual patient). A number of elements have contributed to accelerating the pace of this research, including the development that has been achieved in the field of information technology, electronics, genetics, regenerative medicine, genetic engineering, and applications of additive manufacturing that contributed and helped in the production of engineering structures with complex shapes [6]. Implantation of anatomically shaped scaffolds to reconstruct a missing part of the bone can be considered a standard implant due to its improved ossifying properties, although there are many bone restoration methods that can be used [7].

To complete a successful design process of a scaffold, the application of CAD [8,9] software techniques is employed to re-create a similar geometric model to the missing part of the lower jawbone tissue, where 3D precise geometric models of the cell unit are designed that simulate the complex internal structure of the bone tissue and are completely compatible with the most complex external shape of the missing part. The good

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permeability of the scaffold is supposed to allow the passage of nutrients, cell proliferation, and migration with an approach that has been presented to design a 3D model scaffold that can be implanted instead of the missing part [10-11]. The necessary mechanical tests will be performed for the purpose of avoiding any failure or defect of fracture that may occur during or after the implantation process. The main purpose of scaffold implantation is to reconstruct the lower jaw, aesthetic, and functional rehabilitation, treatment of associated psychological damage, and acceleration of the complete recovery, and make life better after performing the scaffold implant operation [12-14].

2. Method and material

Referential geometrical entities(RGEs) can be curves, points, axes, planes, lines, and other geometrical elements which are considered an important part of the method of anatomically features(MAF). Performing accurate reverse-engineering modeling of the human lower jaw requires correctly identifying the referential geometrical entities that are generated each defect individually. In each polygonal model of a lower jaw, the anatomical features of the acquired samples are determined and defined in relation to the geometry that is built on the support geometry associated with the ribs, such as curves, spline ...etc. Geometric constraints and marks are required when creating the correct lower jaw geometry using the minimum possible basic set of lower jaw elements. Planes and lines are elements of the geometric models of a lower jaw, and they represent the ability to form anatomical features on the surface of the model, and they are considered engineering elements that have a great contribution to rebuilding the 3D missing part of a lower jaw.

Also, anatomical and engineering landmarks can be used to create a three-dimensional model of the surface of the missing part of a lower jaw. Using the basic modeling approach, the construction of3D model of a scaffold can be designed. Fig. 1. Shows a set of referential geometrical entities:

- A sagittal plane, that passes through a lower jaw body and split it into two equal parts left and right
- A vertical plane is a plane that split the lower jaw body into two parts posterior and anterior, bypasses through the body, in the direction of left-right.
- A transversal plane (horizontal) is a plane that passes through the lower jaw body parallel to the ground.
- A medial line is a line that commonly split the face into two equal and similar parts and passes vertically amidst central incisors.

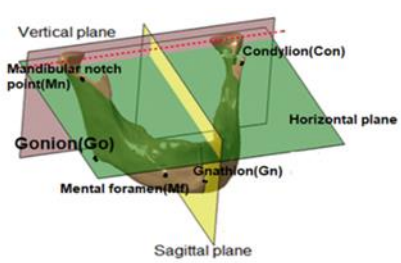

Figure 1. The Referential Geometrical Entities illustrated on a lower jaw

3. Creating a surface of a lower jaw model

To create a model of the surface of the lower jaw, the method of anatomical features is used (MAF) [15, 16]. Through the application of a cloud points that enables to the determination of the desired polygon pattern by selecting the determined points that achieve the desired purpose together with the curves that have been created for the outer surface. It is assumed that the following sequential steps be followed which enable to obtaining of a precise lower jaw surface model [17,18,19].

- Obtaining a computer tomography (CTs) scan or a magnetic resonance images (MRIs) images of the entire a lower jaw in (STL) file format.
- Use appropriate software (CATIA in this research).
- Cleaning photos of impurities and excesses undesirable.
- Determination referential geometrical entities of the full lower jaw.
- The creation of cloud points to the full lower jaw.
- Exclude unwanted points from the points cloud.
- Creation of a polygonal model of the lower jaw.
- Creation of a Curve Splines.
- Creation of a sufficient number of surface models for the anatomical sections and assembling all these individual surface models of anatomical sections are into one complete model

4. Digital scaffold model for large missing part of a lower jaw

To reconstruct the large missing part of the a lower jaw due to its exposure to a major trauma as a result of falling on a hard area, traffic accidents, or due to orthopedic diseases, an action plan must be developed that includes the adoption of various patterns and structures, the application of appropriate procedures and accurate design to create (compose) an engineering model that matches the geometry of the missing part of the a lower jaw and implanting without physical or anatomical obstacles[20-22]. Creating the scaffold and implanting it in the place of the missing part of the lower jaw provides the required mechanical support for the new cells generated, which leads to the restoration of the lost bone tissue structure.

In this paper, the main component of the scaffold design is the multi-cell unit in a three-dimensional space for the purpose of obtaining a volume pattern that represents the missing part of the lower jaw. There are several models for the design of the cell unit such as a box or circular. In this research, the circular model of the elements of the cell unit was applied, which is called the anatomical scaffold model as shown in Fig. 3.

To obtain the required scaffold, the scaffold will be modeled by through the circular pattern of the unit cell, which can be manufactured by applying the available additive manufacturing methods techniques that enable the fabrication of complex structures. Fig. 4.

Changing the diameter of the circular cell unit leads to controlling the scaffold density and this is easily done because the design is still software. For example, with decreasing the value of the unit cell diameter, the scaffold density increases (D = 0.25 mm in this research). The dimensions of the elements will be determined by the place value appropriate which corresponds to the l manufacturing dimension of the molten titanium alloy (SLM, EBM) or sintered titanium alloys (SLS and DMLS). Fig. 6 shows the spline curves that were created based on the anatomical feature of a lower jaw and its relationship to other anatomical features. The missing part is creat by the application of interpolated spline curves were created using the basic RGEs(planes) of the human lower jaw, as well as the polygonal model of the missing part of the lower jaw, which was designed based on additive geometry and MAF, which applied to model the missing part of the lower jawbone, [13]. In this paper, for the purpose of the creation of the volume of the missing part of the lower jawbone, four curves were selected in addition to the curves of the sections of the ends of two parts of the human lower jawbone.

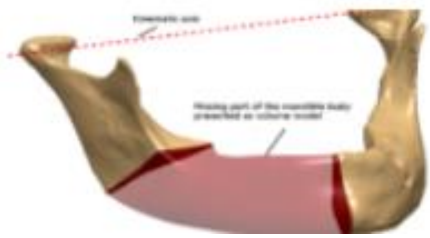

Figure 2. Shown large missing part a lower jaw on the polygonal model

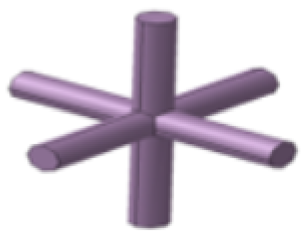

Figure 3. 3D Circular unit cell element

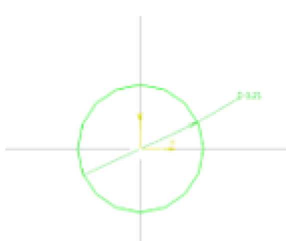

Figure 4. Cylindrical a lattice unit cell diameter

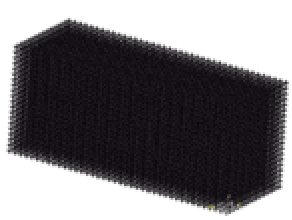

Figure5. Scaffolds patterns of cylindrical unit cell elements

A scaffold created to replace the missing portion of the lower jawbone and new bone tissue cells generated will be in desperate need of the support it provides by one spline curve which is going through the gravity center of the profile curves was chosen. If the difference between the implanted scaffold and the external shape of the missing part of a lower jawbone is large, through the growing process, it is recommended to monitor and follow the shape of the bone to protect the surrounding tissue from damage and facilitate and expedite the patient's recovery process.

After the implantation process, the lower jawbone will grow by generating new bone cells to fill the volume of the missing part with new bone tissue. it is recommended to monitor the growing process and follow the shape of the bone to protect the surrounding tissue from damage and facilitate and expedite the patient's recovery process, especially If the difference between the implanted scaffold and the external shape of the missing part of the lower jawbone is large. The volume model of the missing part of the lower jawbone was created by the application of the volume multi-section technical features, and it is presented in Fig. 7.

The application of the missing lower jaw volume model, which is established based on the application of the feature of the multiple volumetric sections of the missing lower jawbone for the purpose of creation of the modified pattern model for the final scaffold shape. The creation of the volumetric model depends on the application of the boolean removal process.

The main element in the removal process is the removal coefficient and volume model for the missing part of a lower jawbone, a scaffold pattern. The creation of the volumetric model depends on the application of the boolean removal process. The main element in the removal process is the removal coefficient and volume model for the missing part of a lower jawbone, a scaffold pattern. The 3D pattern of the scaffold to the similarity of the missing part (cells unit elements) can be formed by the implementation of the cutting process on the 3D pattern to match the shape of the missing part of the jawbone of a customized patient, after carrying out all design procedures which mention above Fig.8.

The scaled spline curves are applied to the creation of the support of the scaffold and its inner structure by creating a supporting shell element. A shell model will be created by the applying of remove Boolean operation between inner and outer volumes. This approach of scaled curves is applied to enable variation in shell thickness throughout the missing volume, which can be controlled by a scale factor. In order to sure better blood flow, the shell must have included adequate holes throughout the volume. To guarantee less foreign material will remain in the patient body after the recovery process can use the clean medical net to replace the shell model in medicine as a supporting structure. This assembly will still maintain poor stability, and for the purpose of improving its stability, it will be applied geometry of a customized reconstructive plate model. The customized plate model will be connected to the shell contour and also to the right and left sides of a lower jawbone with sufficient screws. This customized plate can be removed later. The plate shape will be adapted to the shape of the outer surface of the shell and a lower jawbone body

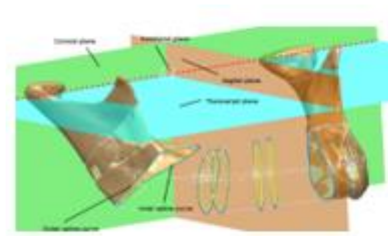

Figure 6. Creation of spline curves of the jawbone missing part

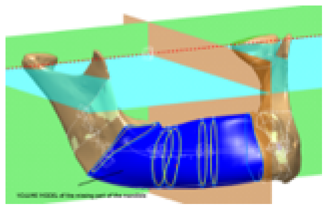

Figure 7. The volume model of the missing part of the lower jawbone

Figure 8. The creation of a cylindrical scaffold model from the unit cell

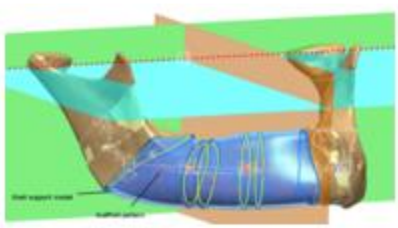

Figure 9. A shell volume model (supporting structure) together with a polygonal model of a lower jaw and the scaffold model

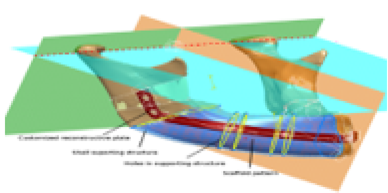

Figure 10. Assembly of the reconstructive plate, shell support structure, and scaffold models

5. New design approach

In order to reduce the use of foreign material in the patient body, a new design strategy based on a lattice "rudder" structure is introduced. They can be positioned where is appropriate to support the scaffold is established.

5.1 Rudder design

This approach presumes use of tubular form, which goes throughout the gravity centers of cross section spline curves and gives support for the surrounding lattice structure. This scaffold design, named rudder (in axial sections, the scaffold design reassembles the ship's rudder), is presented in Fig.11. As can be seen from the image, the structure consists of radial and axial lattices. Also, only one part of the whole structure is presented, but the design intent is clear. Radial lattices are reared near the center axis of tubular form, but, there are more of them if the distance from the center is increased. Axial lattices are going from one side of the missing part to the other side. Increasing the number of lattices in both radial and axial directions, lead to an improved possibility withstand the external forces and stresses that can affect the scaffold in both radial and axial directions without fracture.

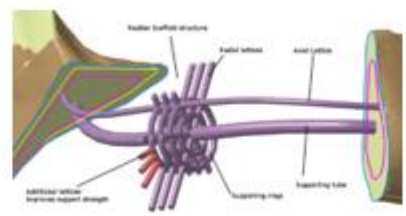

Figure 11. Rudder Scaffold structure

5. Conclusion

It is expected that the design of an anatomical shaped lattice structure of the supporting scaffold will be the ideal solution in the applications of reconstructing the missing part of the bone. The application of (ASLS) gives multiple choices for surgeons in choosing the appropriate method for stabilizing bone fractures when compared to traditional methods of stabilization. The application of (ASLS) is expected to provide a suitable environment that increases and accelerates the process of generating new bone tissue cells. This claim requires the implementation of the anatomical scaffold application procedure and proper fixation to the frame in the designated place. The manufacture of (ASLS) requires the use of additive manufacturing(AM)techniques. Studies in this field also indicate the need to search for materials that can be used in the manufacture of these complex structures(ASLS) that are biocompatible with the patient's tissues and have the ability to biodegrade inside patient tissue after implantation without causing any complications or damage. In this section the authors can refer any specific grant from any agencies

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