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NEW APPROCH FOR ELBOW PROSTHESIS TECHNOLOGY

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ABSTRACT

Elbow is a bone joint having a single axis and performing two movements: flexion and extension. Because this axis, passing through trochlea and humerus, is not perfectly transversal, but oriented from outside to inside, forward to backward and from up to low, during the two movements the forearm and the arm form an opened angle. Consequently, the complex movement guided around this axis supposes particular shapes for the articulated bones in elbow and to design and realize prosthesis in case of important damage becomes a long and difficult procedure. More, the dimensions of prosthesis depend on anthropomorphic sizes of every patient.

For these reasons, in the present paper, we propose an approach much more rapid and more cheap – rapid prototyping (RP). The proposed technology is thermal injection, which is a part of RP technology. It allows executing rapidly solid 3D models by CAD and, after that the prototype is done in short time, in accord with needed dimensions and with a very good quality. The specific device is technically simple, needs less material and more rapid.

1. ELEMENTS OF ARM'S BIOMECHANICS

The human arm contains bones, joints, muscles, nerves, and blood vessels. Many of these muscles are used for everyday tasks. The humerus is the (upper) arm bone. It joins with the scapula above at the shoulder joint (or glenohumeral joint) and with the ulna and radius below at the elbow joint. The upper arm bone is not easily broken. It is built to handle pressure of up to 13361 N (300 lbs).

The elbow joint (figure 1) is actually three separate joints; the ulnohumeral joint, the radiohumeral joint and the superior radioulnar joint. A single joint capsule encloses all three joints.

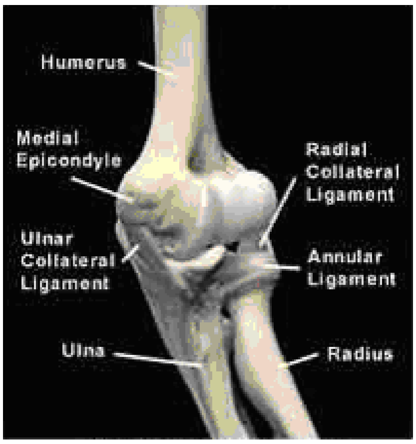

Figure 1. Elbow joint.

Figure 2. Carrying angle of elbow.

Movement between the ulna and the humerus occurs at the ulnohumeral joint. Movement between the radius and the humerus occurs at the radiohumeral joint and movement between the radius and the ulna occurs at the superior radioulnar joint. The ulnohumeral and radiohumeral joints are modified hinge joints. The biceps, brachialis, and brachioradialis muscles bend (flex) these two joints. The triceps muscles on the back of the arm straighten (extend) these two joints. Normal elbow flexion varies between 135 degrees to 155 degrees. The superior radioulnar joint is a pivot joint. This joint allows supination and pronation of the forearm and wrist to occur. Supination is rotation of the forearm so that the palm is turned up. Pronation is rotation of the forearm so that the palm is turned down. The biceps and supinator muscles supinate the elbow. The pronator quadratus, pronator teres and flexor carpi radialis muscles pronate the elbow.

When the elbow is fully extended and supinated, the forearm is angled slightly away from the long axis of the humerus. This angle is called the "carrying angle" (visible in the right half of the figure 2, right). In men this angle ranges between 10 to 15 degrees and in women this angle ranges between 15 to 20 degrees. Muscle weakness or ligament injury can lead to abnormal biomechanics of the elbow that can result in abnormal forces in the elbow. Over time these abnormal forces can cause the articular cartilage of the elbow to wear out prematurely. Finally, injury to the bones, ligaments and other support structures of the elbow can occur when excessive extension, flexion, rotational or side-to-side forces are applied to the elbow.

2. ELBOW PROSTHESIS – NECESSITY AND CONDITIONS

Total rejection of elbow is due to radial head fracture, to fracture/sprain when after the cubitus growth the radial head comes no more in its place. A lot of causes can produce health problems for the elbow joint and between them the most important are accidents and sport practice. Injuries to the elbow joint are becoming more and more prominent in today's sporting society. This is largely because of the biomechanical demands during popular sports such as baseball, softball, and tennis; wherein the majority of elbow injuries occur. Implications for injuries in these sports range from overuse to incorrect mechanics, which cause increased loads at the elbow joint. This can be seen in the overhead throwing motion where a large varus torque leads to tensile injuries in the medial elbow and compressive injuries in the lateral elbow. The tennis serve produces large varus torque like in baseball pitching, but significantly less elbow extension velocity and elbow flexion torque. Most of sports are followed by degenerative illness driving to elbow immobility, serous arthritis and, finally, to implanted prosthetic devices. Technically, the total elbow replacement is relatively simple in comparison with hip or knee replacement.

Design and make an elbow prosthesis supposes to accomplish some essential exigencies as: (a) maximum simplicity and practicality in design; (b) minimum total weight; (c) adequate shape and dimensions; (d) minimum energy consumption from a light external energy resource; (e) adequate dynamic capability compatible with other prosthetic arms. To obtain optimal design parameters for such a system, it is necessary as a first step to simulate the behavior of the arm so that design variables could be tested. These parameters strongly influence the choice of mechanisms and components used in the authors' design. The second step consists in choosing the adequate materials and technologies to realize it.

3. STRUCTURE AND CONSTRUCTION OF AN ELBOW PROSTHESIS

3.1. Basic structure of elbow prosthesis

First elbow prosthesis was designed considering that the natural articulation is a hinge type one without taking into account the surrounding soft tissues. This solution failed because of great stresses acting in it. Even the prosthesis fixation is done in normal limits; instability or stiffness of joint, nerve lesion and internal structure of the bone could produce prosthesis failure.

Elbow prosthesis is done from a metallic alloy named vitallium and can be implanted only if its dimensions are less than the femoral head size. In any condition a bigger prosthesis cannot be implanted. Modern prosthesis are also built as a hinge joint but they are provided with fixation spigots with aim to reduce internal stresses (figure 3).

Due to size restrictions in the case of elbow prosthesis, implants are built in three dimensional ranges: “large size” for patients presenting a high erosion level of affected bones, “medium size” for patients with average height and average level of bones erosion and "little size" for patients with little height of for children. Every range involves series of prosthesis parts' dimensional components.

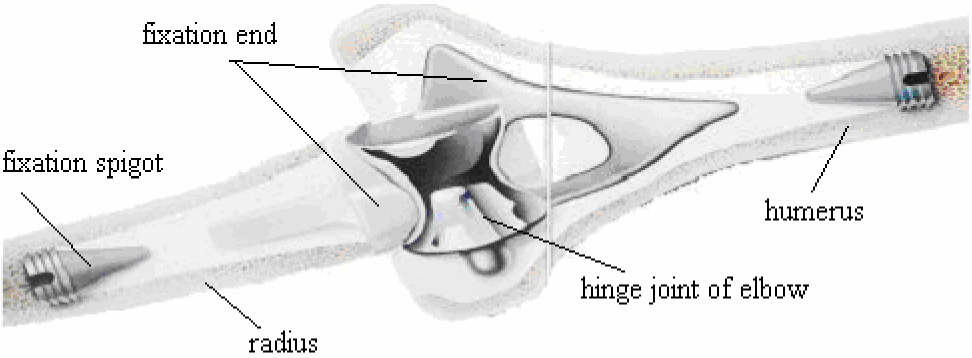

Figure 3. Implanted elbow prosthesis.

3.2. Introduction in Rapid Prototyping (RP) concept

Classical technologies that suppose removing excessive material to realize a prototype are for some time (end of '80) exceeded by RP technology, which realizes them more rapid and more economic without using excessive material. The RP process is based on a technology that creates rapidly 3D solid models with data coming from CAM without any human intervention. Besides the short fabrication time, RP allowed discovering new designs and improving products quality with much higher profit.

3.3 Working principle

For RP process, the geometric shape of an object is obtained by an assisted design system (CAD) as showed in figure 4. In most cases, the model is divided in a triangles network and saved as standard format STL. This file is than transferred to a RP system, which divides the triangular network along the vertical axis in a great number of horizontal sections having specified dimensions. These sections are used to do thin layers of the real prototype. Less the sections are, more precise the layers will be.

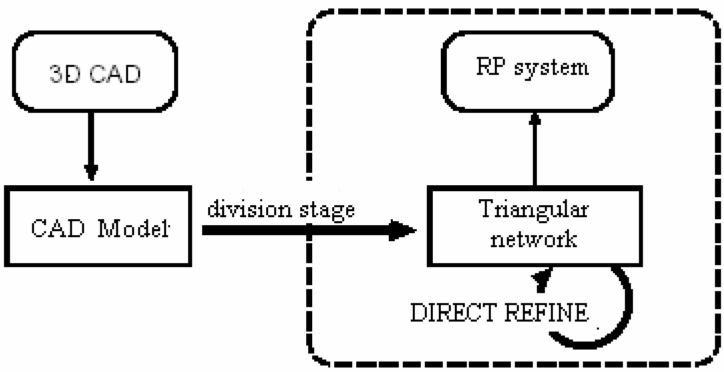

Figure 4. Direct refine of RP process.

One o the most important task of the method is to give a smooth surface to the prototype, which depends on a large variety of parameters. One of them is the accuracy and finesse of triangular original shape's division. CAD role ends when the STL file will be exported and, than, the RP software begins to act.

The basic idea is to define a smooth surface by infinite reiteration and subdivision of the polygon according to the adopted rule.

Generally, a subdivision is obtained in two stages: division and positioning. During the division stage, new lines are added to the graphic structure of polygonal network. Than, the new lines together with the old ones are localized during the positioning stage. These two stages are repeated till the whole structure is defined. In a lot of planes based on triangular network the division pattern 4:1 is used – a vertex is introduced for every edge and this one is divided in two. Than the triangular side is divided in other four less than it and so, four multiplies the edges number.

3.4. Critters to choose the RP procedure

Once the RP technology chosen, the next step is to choose the procedure corresponding to the specific necessity of the case. Choosing is more difficult than the procedure itself because there are a great number of procedures in the RP concept, each of them having good and weak parts. There are a lot of parameters characterizing the adapted procedure and they can be separated in three groups: (a) physical considerations; (b) operational considerations and (c) applicability. The principal aim is to obtain fastest, with highest accuracy and at lowest possible cost the prototype. Also, is very important to be considered the type of material. Any program, as can do the preparation of the file for RP: AutoCAD, Pro-E, Ideas, Intergraph, or others, but for all of them is necessary to have a geometric model to be transmitted to RP system.
The principal RP procedures are the next:

- the first RP prototype machine used as basic procedure the stereo-lithography (SL) and it is still successfully used. In this procedure, the prototypes are made by solidification of a photosensitive material under UV laser light. It allows obtaining shapes with complicated complex geometric shapes.
- laser syntheses (SLS) that uses powders of polymers, metallic or ceramic in an additive conception process layer by layer. For metallic parts a polymeric adhesive is used and the laser light melts it to conglomerate the metallic powder.
- lamination process (LOM) in which a layer is put on the previous and the shape of the profile is cut in it. After all layers are laminated and cut, the excessive material is taken off.
- a similar laminating process can be applied on papers sheets (PLT) put on a warm support one after the other.
- melting and sedimentation (FDM) process consists in melting a filament and forming a very thin layer from the melted metal.
- 3D printing technology builds the model from thermoplastic successive layers (with 0,007 mm accuracy) by multijet modeling techniques. The data are transmitted from the CAD design system.
- ❖ Choosing a specific process to realize elbow prosthesis components depends on each utilized material, on their shapes and on their dimensions.

4. CONCLUSIONS

Rapid Prototyping concept is based on a technology realizing 3D solid models in short time using data from a design system CAD without human intervention and these models can be immediately utilized as prototypes. Besides the fact that RP technology is cheaper, it is also surer from the point of view of personnel protection because the human is not interfering in the process.
If a dimensions change or even a new design is necessary only few things are modified in comparison with other technologies, and these in CAM conception, all these driving to low costs and a higher accessibility for the beneficiary. Many biomaterials can be used for prosthesis construction and their choice depends on characteristic to reproduce a dynamic answer quite alike with the dynamic behavior of the natural human part, in occurrence, the bone components of the elbow hinge joint.

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