Study and computer-aided analysis of artificial human wrist

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Abstract: The wrist joint is frequently affected by rheumatoid arthritis, resulting in wrist pain, deformity and ultimately loss of function. Artificial wrist implants have been introduced to treat the rheumatoid wrist, to attempt to alleviate pain and restore some function to the joint. This paper describes the anatomy of wrist and the design of an artificial wrist design. The artificial joint part consists of two parts, which are distal part and radius part. Computer aided engineering design is being used and help engineers quickly build up three-dimension model. Besides, Computer aided analysis and simulation have been set up to analyze the stress and total deformation.

Keywords: Biomedical engineering, artificial joint, engineering analysis,

Introduction: The wrist joint is one of the most complex joints within the human body comprising eight carpal bones, the radius and the ulna [1]. Rheumatoid arthritis is a common crippling inflammatory joint disease that can involve any of the synovial joints and frequently involves the wrist [2,3]. Joint arthroplasty is an attractive solution for improving function while reliving the pain, especially for some patients whose arthritis symptoms become disabling [4]. The advantage of a wrist displacement is patients who have a joint replaced will have movement of the wrist [5]. This paper describes the anatomy of the wrist, followed by a design of artificial wrist.

Project description

1 Anatomy

Fig.1 Anatomy of wrist joint

The wrist is a more complicated joint that the shoulder and the elbow. On the other hand of the wrist, there are two rows of bones at the base of the hand. There are four bones in the first rows. The bones in these rows are called carpals. The long thin bones of the hand radiate out from one row of carpals and form the basis of the fingers and thumb.

The radius and the ulna are the two long bones of the forearm that form a joint with the first row of carpals.

The ends of the bones are covered with an elastic tissue cartilage. Cartilage creates a slick surface that enables the bones to move smoothly when they move against each other. The friction is very low, and synovial fluid lubricates the joints as usual.

2 The design of the artificial wrist

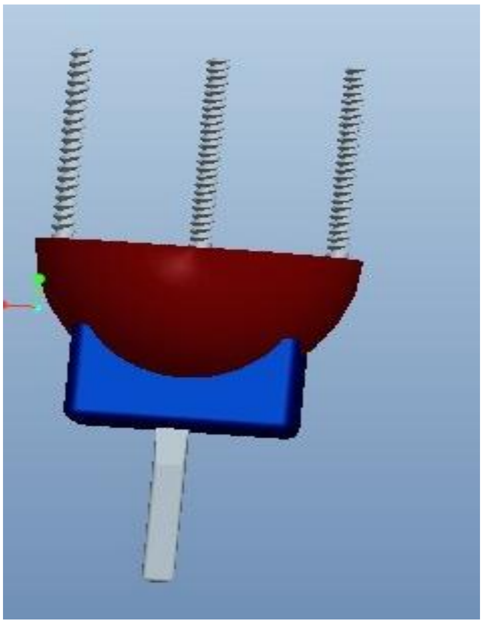

Fig.2 3D model of artificial wrist

From the Fig. 2, we can see that there are two parts for the artificial wrist joint. The distal part (upper part) consists of three screw bars and a semi sphere. In the Wrist Replacement Surgery, the damaged ends of the lower arm bones are removed, and the first row of carpals bone may also be removed. This distal part will be screwed into the center hand bone. Another part is called the radial part. The radial part (lower part) is a socket which is inserted into radius.

This artificial wrist joint shown in the Fig.2 is in the form of a restricted ball-and-socket joint. There a ball-and-socket joint is connected to several metacarpal bones via a yoke and bone nails. The movement of the ball and socket joint is restricted in comparison with an intermediate shell, and the movement of the intermediate shell is restricted in comparison with the bearing shell attached in the radius by grooves disposed so that they intersect one another, in which guide bones slide but cannot twist. The joint permits swiveling about two rigid axes which intersect in the ball-and-socket joint. For a wrist joint the use of such an implant represents great intervention, which is not justified in all disorders of the wrist joint.

Especially in arthritic disorders of the wrist joint, when a reduction of the pain takes priority over a restricted function of the wrist joint, reduced intervention can be an advantage.

Fig3 is what it looks like finally after the joint replacement surgery

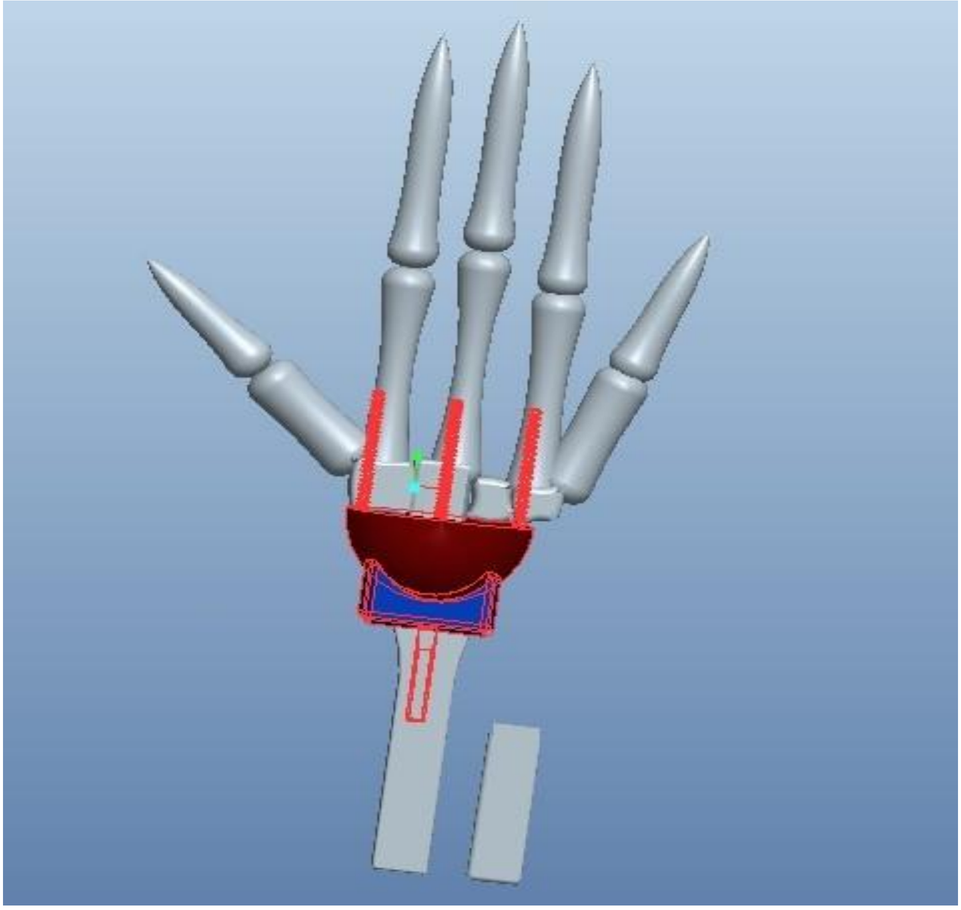

Fig.3 Wrist arthroplasty

3 Mathematic analysis and FEA simulation

The material of the screw part is carbon fabric, the prosperities of the ceramic is

Density	ρ	1192 g/cm2
Young's Module	E	180-200Gpa
Yield	σy	4137 Mpa
Diameter	d	0.5cm

We know a beam of uniform section, loaded in simple tension by a force, F, carries a stress

$$\sigma = F/A \quad (1)$$

$$\rightarrow F = \sigma A = \sigma(\frac{d}{2})^\wedge 2$$

In order to keep the screw bar in a elastic state while being pulled, the pulled force

$$\text{Fpull}<=\sigma y * \pi(\frac{d}{2})\text{^}2 \qquad (2)$$

Suppose $\sigma y = 2000Mpa, then$

$$\text{Fpull}<=2000*10\text{^}6*\pi(5 * 10^{-3})\text{^}2=3927\text{N}$$

That is to say, the resistance force of all untwisted mechanism should be smaller than 3927N.The mathematic model is being setup as elastic bending of beam.

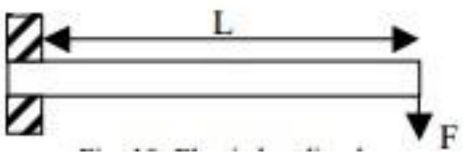

Fig.4

The displacement of the beam

$$\delta\text{=FL^3/C1EL} \qquad (3)$$

$$\text{I=}\ \ \pi r\text{^}4\ /4 \qquad (4)$$

Here, C1=3. Combine two equations above:

$$\delta_{theory}\text{ =3927*0.18^3/3*210*10^9*(3.14*0.003^4/4) =30mm}$$

I will set up force loading in analysis first. Here, on each bar there is F=66.7lbs=296.56N.

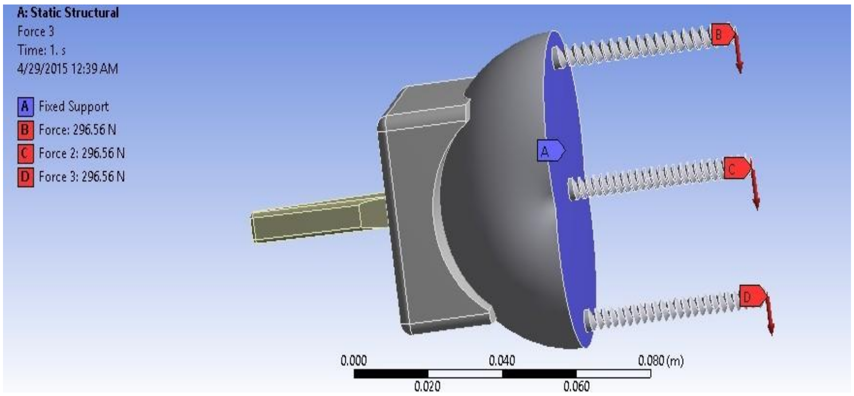

Fig 5 Fix support and force loading

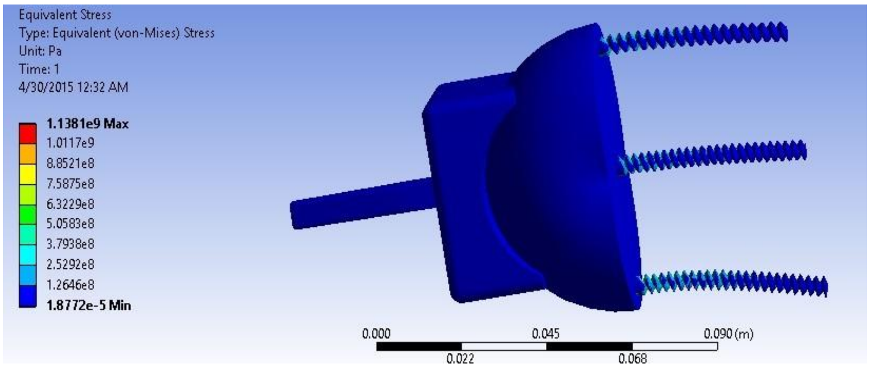

Fig. 6 Equivalent stress simulation

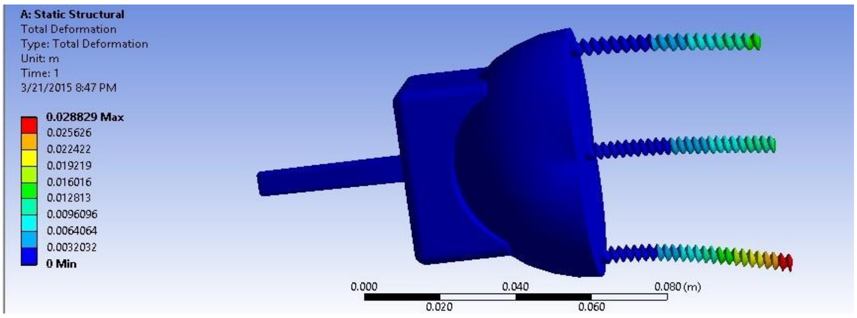

Fig. 7: Deflection simulation

The three figures above show that the maximum stress

$$\sigma\text{max}=1.138*10\text{^}9<\sigma\text{y}$$

It will not have the plastic bending, which is safe.

Moreover, the FEA analysis shows the maximum displacement of the screw bar

$$\delta_{FEA}=0.028\text{m}=28\text{mm}\approx \delta_{theory}=30\text{mm}$$

$$\text{Err}= (\delta_{theory} - \delta_{FEA})/\delta_{theory}=6.7\%$$

The FEA analysis shows that the component is safe and well-working.

Conclusion

The joint arthroplasty is an attractive solution for improving the function while reliving the pain, especially for some patients whose arthritis symptoms become disabling. The advantage of a wrist replacement is patients who have a joint replaced will have the movement of the wrist. The study of this paper describes a new design of the artificial wrist. All model are drawn in computer aided designed software Pro/Engineering. Computer aided analysis (FEA) simulations has been set up in Pro/Mechanical and the results match academic calculation.

References

[1] Stanley JK. The rheumatoid wrist. Current Orthopaedics 1991;5:13-21.

[2] Lachiewicz PF. Rheumatoid arthritis of the hip. J Am Acad Orthop Surg 1997;5:332-8.

[3] Chmell MJ, Scott RD. Total knee arthroplasty in patients with rheumatoid arthritis. An overview. Clin Orthop 1999;366;54-60.

[4] Carlson JR, Simmons BP. Wrist arthrodesis after failed wrist implant arthroplasty. J Hand Surg Am 1998;23;898-8.

[5] Menon J. Universal total wrist Implant: experience with a carpal component fixed with three screws. J Arthroplasty 1998;13:515-23