The Study of Wear Resistance of the Artificial Knee Joint

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Abstract: In aging society, the artificial knee replacement become increasingly common, however wear of the artificial knee components will happen after long-term use, which thus gives rise to other problems, or even failure. This research mainly aims at analyzing the wear of these artificial components and evaluating the cryogenic treatment for wear resistance. Wear analysis focuses on in-vitro measurements. The in-vitro measurement can be accomplished by AMTI Force5 wear testing machine in accordance with ISO 14243 standard. Then the cryogenic treatment was utilized to compare the wear performance of components with and without this treatment. The in-vitro wear testing results indicate that AMTI Force5 wear tester in accordance with ISO 14243 standard is more practical and widely accepted by customers, which is useful for in-vitro wear measurement. In addition, the results show that the cryogenic treatment can significantly enhance the wear resistance.
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1. Introduction

Knee joints are the largest and most important joints, which are vulnerable to various injuries and diseases. Knee structure is mainly composed of the femur, tibia, patella and meniscus formed and fixed by the external muscles and ligaments. Typical components commonly used in artificial knee joint contain the femoral components, tibial components, patella and tibial bearing component as shown in Figure 1[1].

Joint replacement surgery is a well-proven method of relieving the symptoms of advanced osteoarthritis of the knee. This is a very common procedure performed in the worldwide [2-3]. While this surgery has a high success rate, implants do fail by a number of mechanisms. Wear of the ultra-high molecular weight polyethylene (UHMWPE) bearing component is a major factor in implant failure; some studies showing that up to 16% of knee fail due to wear [4]. Catastrophic wear can lead to mechanical failure. Wear debris has been associated with the most common mode of failure, which is aseptic loosening [5-7].

Measurement of wear is an important part of design assessment. There are two types of wear measurements--in-vivo, and in-vitro simulation methods.

Currently, there are no satisfactory in vivo methods for assessing knee replacement wear [2, 8-9]. From the practical point of view, the current standard method of design assessment in vitro wear simulation method follows the ISO 14243 standard [10-12].

Cryogenic treatment can improve the material properties by decreasing the residual stress, stabilizing dimensional accuracy and even increasing the life of the tools. It has been widely used in tools, cutting and mold industry [13-18].

The purpose of this study is to analyze the wear of these artificial components and to evaluate the feasibility and effect of cryogenic treatment on wear resistance.

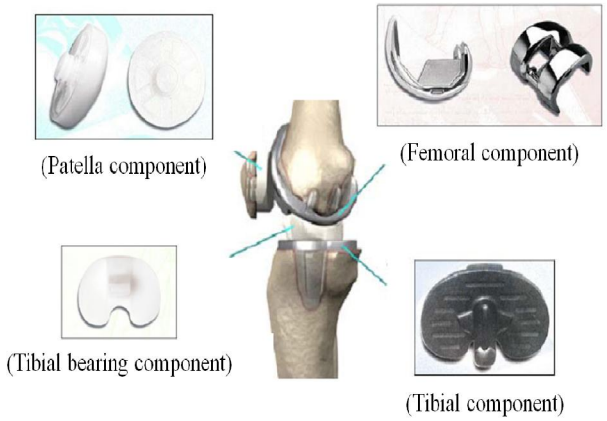

Figure 1 The components of an artificial knee joint.

2. Experimental

2.1 Experimental Procedures

Experimental procedure follows ISO 14243 standard (titled: Implants for surgery — wear of total knee joint prostheses). The total knee-joint prosthesis is mounted in an apparatus which applies a cyclic variation of flexion/extension angle and contact force to the interface between tibial and femoral components, simulating normal human gait [14, 19]. The

principle and test description can be found in the previous published paper [20]. Two sets of these components are prepared for a comparative purpose. One set is not cryo-treated and the other is cryo-treated.

2.2 Cryogenic Treatment

Cryogenics is a branch of physics dealing with subzero or deep-cold treatment. Cryogenic treatment is now being recognized as a valuable and crucial tool for industry. The LS-100 processor, as shown in Figure 2 was used in this study.

Figure 2 LS-100 Cryogenic Processor.

2.3 Specimen and Test Conditions

Specimens (shown in Figure 3):

United Orthopedic Corporation (U2 Total Knee System):

U2 Posterior Stabilized Tibial Insert (UHMWPE, Fixed Bearing)

U2 Femoral Component PS (CoCrMo)

U2 Tibial Base Plate (Ti6Al4V)

Because the major contact face between the tibia insert and femoral component is that we interest, tibia insert and femoral components are cryo-treated.

Figure 3 Specimen tested.

Testing Conditions:

The test specimens were soaked in the fluid test medium at 37℃±2℃. Fluid test medium: calf serum (25% ± 2%) diluted with the de-ionized water.

2.4 Test Equipment:

The AMTI Force5 was used as the testing machine which is a servo-hydraulic machine with four independent actuators. It provides a vertical tension and compression axis with rotation about the same axis, and a horizontal axis with translation and rotation. With these actuators the machine can be used for many different independent or combined motions. The AMTI Force 5 is supplied with an easily adjustable load frame (24 inch clearance between the cross head and the load cell is standard) making it suitable for material, fatigue, orthopedic, product, and other single and multi-axis testing.

Figure 4 Testing machine: AMTI Force 5

3. Results and Discussion

3.1 Acceptance or pass/fail criteria

Acceptance criteria was set as the specimen completes the designated 5 x 10^6 load cycles without broken-up or delaminated of the articulating surfaces. Total number of cycles applied: 5,000,000 cycles. Both the cryo-treated and not cryo-treated sets pass the acceptance criteria.

3.2 Observation of articular surfaces

Descriptions of all the articular surfaces of both component femoral and tibial insert after testing completed are as following: (no matter these specimens are cryo-treated and not cryo-treated)

(1) Scratching was a major wear pattern on the surface of femoral component (Figure 5).

(2) There were four major wear pattern on the articular surface of insert [21], (1) pitting; (2) scratching; (3) burnishing; (4) deformation (Figure 6).

(3) Burnishing was a major wear pattern on

insert backside surface (Figure 7)

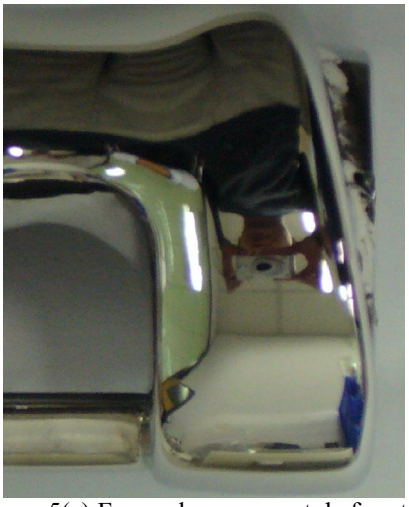

Figure 5(a) Femoral component: before test

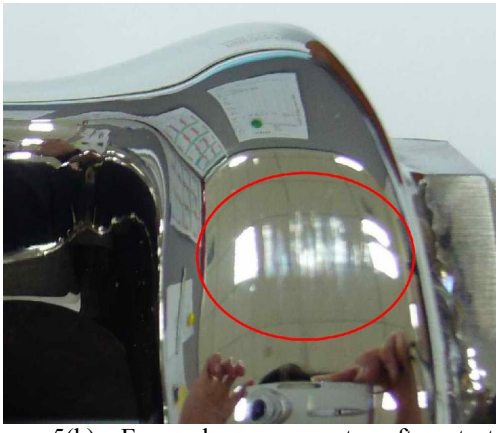

Figure 5(b) Femoral component: after test of 5,000,000 cycles.

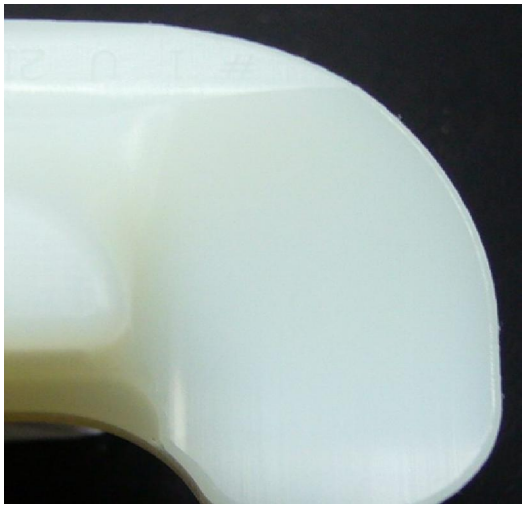

Figure 6(a) Insert: before test

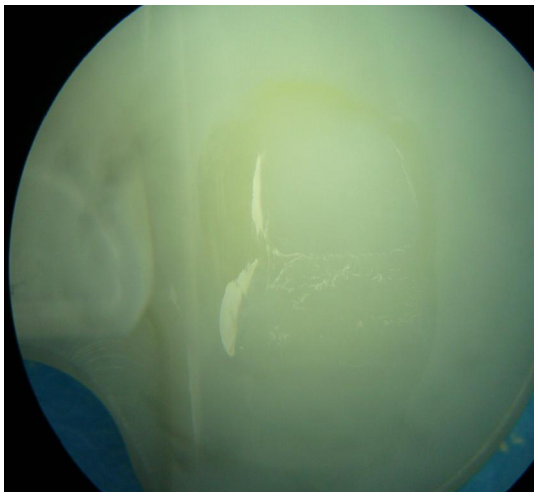

Figure 6(b) Insert: after test of 5,000,000 cycles.

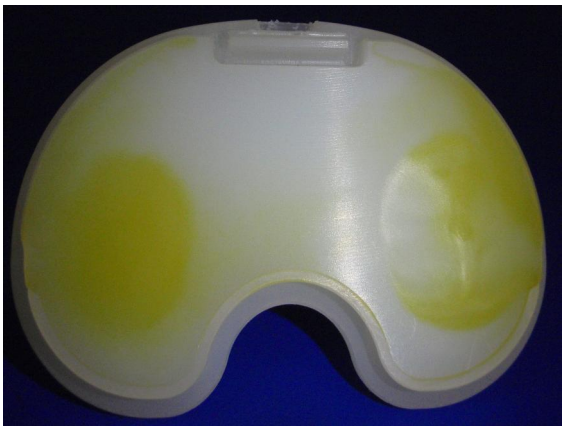

Figure 7 Insert backside surface after test of 5,000,000 cycles.

3.3 Comparisons of articular surfaces of not cryo-treated and cryo-treated specimens.

In comparison with the articular surfaces of femoral components after test of 5,000,000 cycles for not cryo-treated and cryo-treated, you can find more and deep scratching in the not cryo-treated femoral component compared with the one with cryo-treated (as shown in Figure 8). It also has the similar situation for tibial insert (as shown in Figure 9).

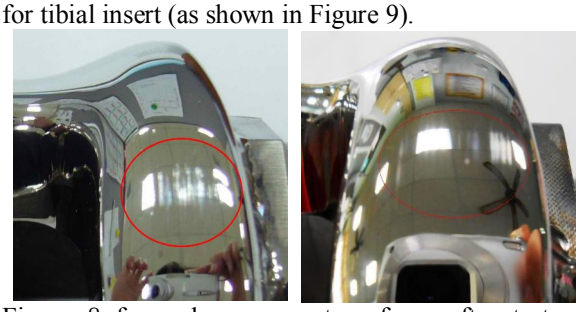

Figure 8 femoral component surfaces after test of 5,000,000 cycles (left: not cryo-treated, right: cryo-treated).

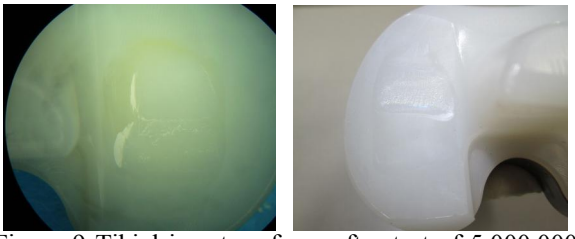

Figure 9 Tibial insert surfaces after test of 5,000,000 cycles (left: not cryo-treated, right: cryo-treated).

3.4 Wear analysis

The insert was only measured first time before testing and after testing completion of 5,000,000 cycles. Tables 1 and 2 outlined the change in mass of tibial insert and insert plus baseplate and cement for not cryo-treated and cryo-treated specimens respectively.

Not cryo-treated:

Wear rate: The loss of insert weight was the difference of insert weight before and after tests, which divided by 10 was the average wear rate each 500,000 cycles.

- The total loss of insert: 15.34814-15.31051=0.03763 (g)
- Wear rate: 0.03763/10=0.003763 (g/500,000 cycles)

Cryo-treated:

- The total loss of insert: 15.03910-15.03312=0.00598 (g)
- Wear rate: 0.00598/10=0.000598 (g/500,000 cycles)

Compared with the wear rates of not cryo-treated and cryo-treated, it is obvious that the cryogenic treatment can significantly enhance the wear resistance.

4. Conclusions

In this study, we have experimentally analyzed the wear of the artificial components following the ISO 14243 standard and evaluate the cryogenic treatment for wear resistance. The results of both cryo-treated and not cryo-treated cases revealed the specimens were able to withstand 5 x 10^6 cycles without break-up or delamination of the articulating surfaces. It was found that the articular surfaces of not cryo-treated had more scratching and wear than those of cryo-treated. It was also found that the total loss of tibial insert and wear rate of not cryo-treated was larger and higher than those of cryo-treated. In summary, the testing results show that the cryogenic treatment can significantly enhance the wear resistance.

Table 1 Wear test results of not cryo-treated specimen. (Unit: g)

cycles	0	500,000	1,000,000	2,000,000
Insert	15.34814	- -	- -	- -
Insert+ baseplate+ cement	144.5312	144.6016	144.6005	144.6005
cycles	3,000,000	4,000,000	5,000,000	
Insert	- -	- -	15.31051	
Insert+ baseplate+ cement	144.6221	144.6356	144.4936	

Table 2 Wear test results of cryo-treated specimen. (Unit: g)

cycles	0	500,000	1,000,000	2,000,000
Insert	15.03910	- -	- -	- -
Insert+ baseplate+ cement	121.0173	121.6164	121.6024	121.5991
cycles	3,000,000	4,000,000	5,000,000	
Insert	- -	- -	15.03312	
Insert+ baseplate+ cement	121.6013	121.5893	121.6430	

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