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Optical methods developed for measurement of total wear in orthopaedics

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Abstract: Primary bearing couples used in total hip arthroplasty (THA) or total knee arthroplasty (TKA) wear during their functioning which leads to generation of huge amounts of submicron wear debris. This induce cascade of events resulting eventually in aseptic loosening and periprosthetic osteolysis. That is the reason why prosthetic wear is central to contemporary orthopaedics. Besides extended material and biological studies, an effort is focused on the development of measuring methods able to determine prosthetic wear on retrieved/tested implants.

Keywords: Biomechanics, Arthroplasty, Wear, Optical profilometry

1. Introduction

Arthroplasties are one of the most successful therapies with regard to achieved quality of life and risk-benefit analysis. However, the long-term outcome of this procedure is gradually deteriorated over time in service predominantly due to the wear-related complications such as aseptic loosening and osteolysis which needs revision arthroplasty. The increased rate of revision hip arthroplasties is associated with great economic burden on various health care systems.

The most common material of THA and TKA liners is polyethylene (PE). Previously it was found that PE wear particles initiate cascades of events at the bone-implant interface that result in development of aseptic loosening and osteolysis. There was observed that total hip prostheses with wear rates up to 0.05 mm per year have had lower risk for failure due to periprosthetic osteolysis and aseptic loosening. Conversely, implants with wear rates of more than 0.2 mm per year pose a significantly higher risk of osteolysis development resulting in premature prosthetic failure. This point was of central significance in developing and improving the material features of bearing surfaces. The other practically used

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material is the ceramics. In contrast to polyethylene inserts, the ceramic ones show very low wear during its usage, just about micrometers per year.

The development of new material surfaces and the following preclinical and/or clinical testing call for methods to quantify the wear and to elucidate the causative associations. Some of them follow.

2. Methods

2.1. Scanning profilometry

The object of study is the THA liner that is sometimes called cup due to its shape (See Fig.1). The surface has the rugged profile which is very flat at the centre of cup and very steep around the edge.

Fig. 1. The cup (upper part) and femoral adapter of the total hip arthroplasty.

With respect to the implant shape the one strip projection is perfect to use instead. Method based on this principle is called the scanning profilometry [1-2]. Its principle is clear from Fig.2.

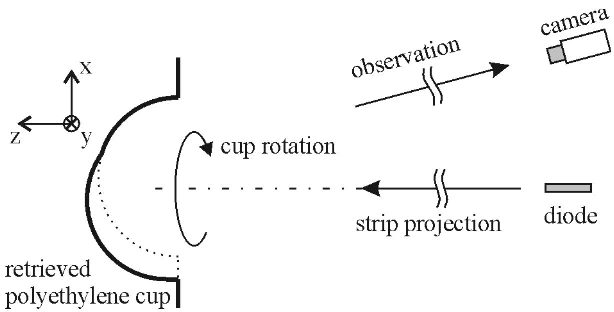

Fig. 2. Principle of the scanning profilometry.

The projected linear strip is deformed by the measured surface in the given direction. Such created linear strip is observed and recorded by a camera. The profile of cup in one direction is computed from this strip deformation. The example of obtained profile is shown on the Fig.3.

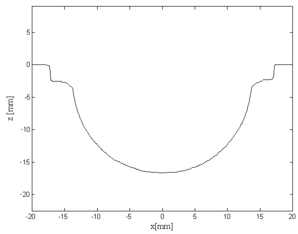

Fig. 3. Computed profile of cup in one direction.

The cup or strip is rotated to cover the whole area of the measured surface. The magnitude of step influences the resolution and sensitivity of the method. The record and the analysis are repeated consequently. The result whole-field profile is obtained connecting the individual linear profiles. The resulting wired model of the cup is shown on Fig.4.

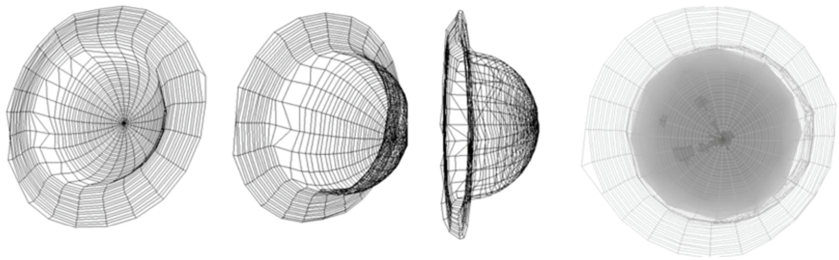

Fig. 4. Resulting WRML map of the cup.

The usual data format of the result profile map can be obtained using the standard conversion of this format (See Fig.5).

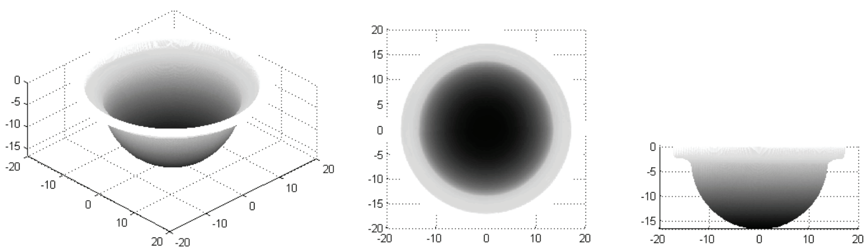

Fig. 5. The whole 3D model of the cup.

The full wear map is obtained by comparing shape of the post-used cup with the shape of original one. Such mathematical processing gives primary the information about the magnitude of total wear but also about the contribution of wear what is useful to determine the various other parameters such as maximum strain areas, the strain direction or the wear anisotropy. The measurement using this optical method is the noncontact and time-sparing. Those are the main advantages of optical methods in comparison with the non-optical ones.

2.2. Phase-shifting profilometry

In the TKA, phase-shifting profilometry (PSP) [3] is used for determination of wear of polyethylene knee insert due to its flattened shape (See Fig.7).

Fig. 6. Knee insert and steel femoral adapter.

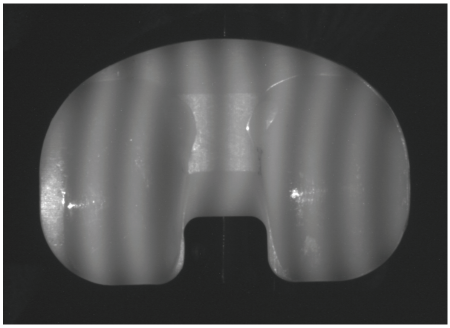

Fig. 7. Polyethylene knee insert of total knee arthroplasty.

The advantage of this method lies in its speed and experimental setup simplicity (See Fig.8).

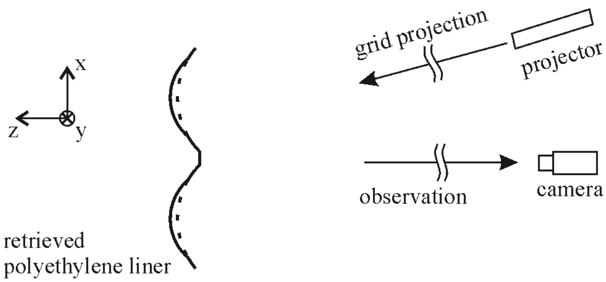

Fig. 8. Experimental setup of PSP.

Sinusoidal pattern realized by data-projector is shown on measured implant, and then, deformed by its shape, detected by camera to the computer. By projecting and detecting several sinusoidal patterns, each moved by constant difference of its phase, it is possible to compute profilometric map of the whole measured surface using appropriate algorithms. After obtaining the 3D model of retrieved knee insert (See Fig.9), the measured surface can be compared with database of unused knee inserts, which contains every type and size of polyethylene implants.

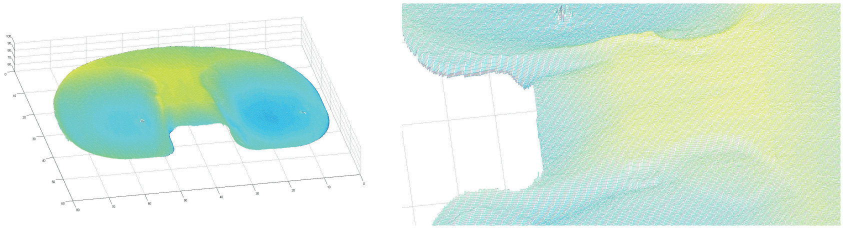

Fig. 9. The whole 3D model of retrieved knee insert.

2.3. Sphereinterferometry

Beside polyethylene inserts in THA, there are used ceramic ones (See Fig.10). They are very resistant to wear, which is realized in micrometers instead of millimetres, like polyethylene ones. In this case, scanning profilometry is not sensitive enough to detect such small deformation. Therefore, the spherointerferometry is used to measuring the wear of ceramic inserts.

Fig. 10. Ceramic insert of THA.

Spherointerferometer is Fizeau-type interferometer, which is adjusted to measure the quality of sphere-shaped objects [4]. The principle of sphereinterferometer lies in interference of the coherent laser beams, one reflected from reference lens and second reflected from measured object (See Fig.11). The result of this measurement is interference pattern (See Fig.12), where every interference fringe comes through areas with same distance between reference lens and measured surface. The height difference between two interference fringes is one half of used light wave length, so this method is very sensitive.

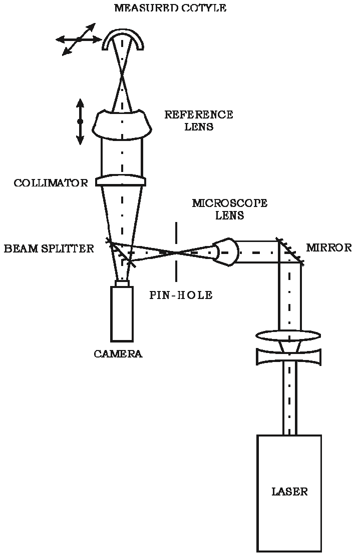

Fig. 11. The scheme of sphereinterferometer.

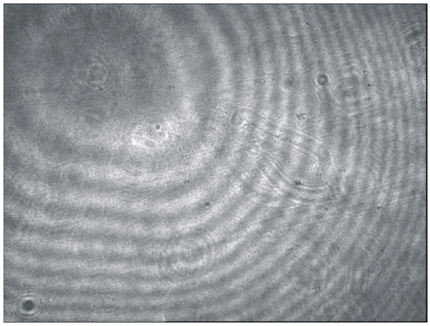

Fig. 12. Interference pattern created by sphereinterferometer.

3. Conclusions

The principle of wear evaluation of THA and TKA liners consists in the determination of measured 3D profile map of retrieved cups. The full wear map is obtained by comparing shape of the post-used cup with the shape of original one. Such mathematical processing gives primary the information about the magnitude of total wear but also about the contribution of wear what is useful to determine the various other parameters such as maximum strain areas, the strain direction or the wear anisotropy. The measurement using the optical methods is the noncontact and time-sparing (moreover, very often in-time or quasi in-time and also full-area). Those are the main advantages of optical methods in comparison with the non-optical ones.

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