Friction in hip-joint prostheses and its influence on the fixation of the artificial head

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The head of an implanted hip joint endoprosthesis is exposed to torques, which are transferred during gait due to the friction between the head and the cup prosthesis. In prostheses with ceramic ball heads, which are widely used now, and in which the head is fixed onto the stem by conical clamping, these torques could possibly affect the connection. In this study, torques transferred from the cup to the head are compared to the torques which are required to loosen the head from the metallic spigot. The results show that for the investigated head and taper types and sizes, under normal conditions the connection is safe with respect to undesired rotation. However, it is shown that for polluted sliding surfaces the fixation strength could possibly be exceeded. © *1998 Kluwer Academic Publishers*

1. Introduction

Alumina and zirconia have become generally appreciated materials for the ball component of hip joint endoprostheses due to the excellent biocompatibility and the advantageous wear behavior. These heads are fixed on a metal stem of a titanium or cobalt chrome alloy by conical clamping. The head articulates against an implanted cup of polyethylene (UHMWPE) for both head materials, or of alumina in the case of an alumina head. The ceramic head has to withstand forces in the range of a multiple of the body weight, as well as torques, which during gait are transferred from the cup to the head. Whereas the forces, which are compressive ones, only contribute to stresses in the head and do not affect the fixation on the stem, the torques possibly could lead to a loosening of the head–taper fixation ad thus, to harmful metallic wear particles produced by the head–taper sliding. The aim of this study was a comparison of the transferred torques to the fixation strengths of the heads.

2. Methods

2.1. Torques transferred during gait

In the first step, the torque generated by the cup was measured. The size of this torque is determined by the normal forces of all involved surface elements of the articulating head and cup surfaces and of their distances to the instantaneous axis of rotation. Only that component of the torque which is aligned with the head and taper axis can act as a removal torque. During a gait cycle, the direction and the height of the load change permanently [1, 2]. At the same time, the angle between the axes of symmetry of the head and the cup also varies. Additionally, these quantities are influenced by the individual characteristics of the patient. This shows that a complete simulation of the real situation would be too complicated. Therefore, the measurement was performed in a simplified model in which the direction of the cup axis was fixed and aligned with the head and taper axis (Fig. 1), i.e. the complete torque which is transferred from the cup has to be compensated by the head–taper fixation.

In the set-up, a constant axial force was applied, then the cup was rotated under load with an angle velocity assumed according to physiological situations (typically $360^\circ\ min^{-1}$). An elastic fixation of the head and taper with respect to torsion allowed the transferred torque to be increased until the friction was overcome. Then a sliding phase followed. The measurements were carried out with different axial loads between 1 and 10 kN. Different head and cup diameters (22, 28, 32 mm), both head materials (alumina and zirconia) and, in the case of alumina heads, also both cup materials (UHMWPE and alumina), were investigated. Measurements were performed under dry conditions, i.e. in a laboratory atmosphere, as well as using Ringer's solution as a lubricant to simulate synovial liquid. In an additional series, the effect of pollution of the articulating surfaces should be studied. Therefore, in these tests, 2 mg bone cement particles were inserted between the head and the cup, positioned approximately at the level of maximum effectiveness with respect to an increase of the torque. Long-term effects, such as abrasion of the articulating surfaces, were not considered.

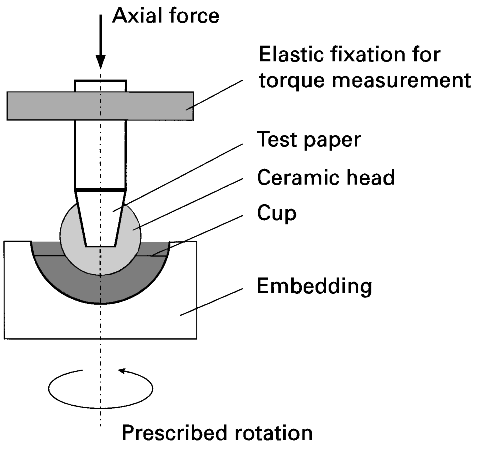

Figure 1 Schematic drawing of the set-up for the measurement of the friction between the head and the cup.

2.2. Resistance against torsion of the head–taper fixation

The resistance to torsion of the head–taper connection can be measured in a slightly modified arrangement. The cup is replaced by a device which allows the ball head to be gripped. The ball, which before was pressed on the spigot by a defined axial load ("preload") and then unloaded, can be rotated with respect to the spigot. The increasing torque leads to a loosening of the connection and the torque at failure can be measured. First measurements showed that a simple gripping device consisting of two concave hemispheres with adapted diameter between which the ball was clamped, cannot be used for the tests. The additional deformation of the head by screwing both parts together increased, i.e. falsified the head–taper connection strength. This effect was also observed when a boron carbide powder was applied to increase the friction between the surfaces and thus, to reduce the clamping force. In the final set-up, two parallel surfaces were ground at opposite sides of the heads and the heads were fixed by form fit. It was sufficient to remove 1 mm at each side to create adequate surfaces for the removal from the spigot. Only heads with 28 mm diameter, which nowadays are of greatest relevance, were used for these investigations. Heads were supplied by three manufacturers. Three different neck lengths were used and both head materials were tested. The heads were combined with 12/14 titanium alloy tapers of two different surface structures (roughnesses $>60\,\mu m$ and $<20\,\mu m$). The angles of the tapers and of the head boreholes were known, the individual differences varying between $1'$ and $12'$. (For reasons of construction, the taper angle is always slightly smaller than the head angle.) The initial axial loads, which were used to fix the heads on the tapers, were 2, 4 and 7 kN. The relatively low load level of 2 kN was used, assuming this to be the minimum load to which a prosthesis might be exposed. It would correspond to a very careful person who never practises activities such as walking fast or running, for instance. Any higher loading would reduce the risk of loosening the connection.

3. Results

3.1. Torques transferred from the cup to the head

Typical results of the torque transferred by the rotation between the head and the cup in the test set-up are shown in Fig. 2. Initially, the curves show an increase of the torque before the adhesive friction is overcome. Then, in some cases, a drop is observed at the start of the subsequent sliding. This is mainly observed when PE cups are used. For the alumina/alumina combinations, the transition is generally more continuous. Fig. 3 shows some results obtained with different head–taper combinations for an axial load of 2 kN. The friction values at the stick–slip transition is denoted as "peak", whereas the average value in the sliding phase is referred to as "plateau". The friction is reduced when the sliding surfaces are moistened with Ringer's solution. For all investigated types and sizes of combinations, the scattering of the friction values is very high; in the tests performed, no clear influence of the materials or of the head sizes (22–32 mm) could be demonstrated.

The tests in which the surfaces were polluted by bone cement particles led to somewhat higher friction values in the cases of polyethylene cups. However, the friction increased considerably for alumina/alumina combinations. This is probably due to the much smaller gap between the alumina head and the alumina cup compared to the ceramics–PE pairs.

3.2. Resistance against torsion of the head–taper fixation

First tests showed that only head and spigots should be tested which have not been used before at the *same* preload level (e.g. 2 kN), because in repetitive tests, different fixation strengths resulted from the modification of the surfaces by preceding experiments. Nevertheless, to obtain additional information, the tests were subsequently repeated with *higher* preloads, assuming that the preceding tests at 2 kN would not influence these results considerably. In the torques necessary to remove the heads from the spigots, a relatively large scattering was also observed. The values obtained were 9 ± 3 Nm for a fixation by 2 kN axial

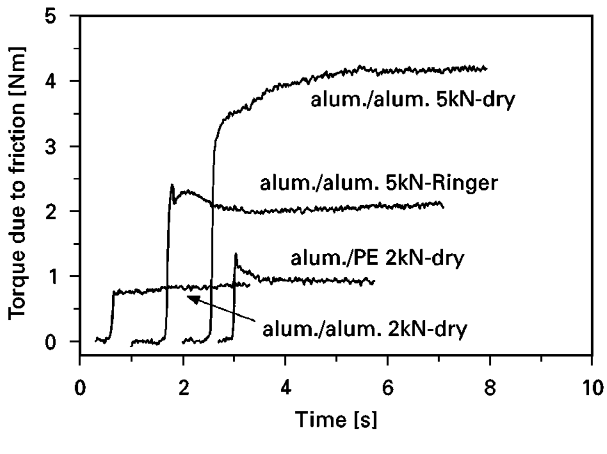

Figure 2 Typical torque curves produced by the friction between the cup and the head.

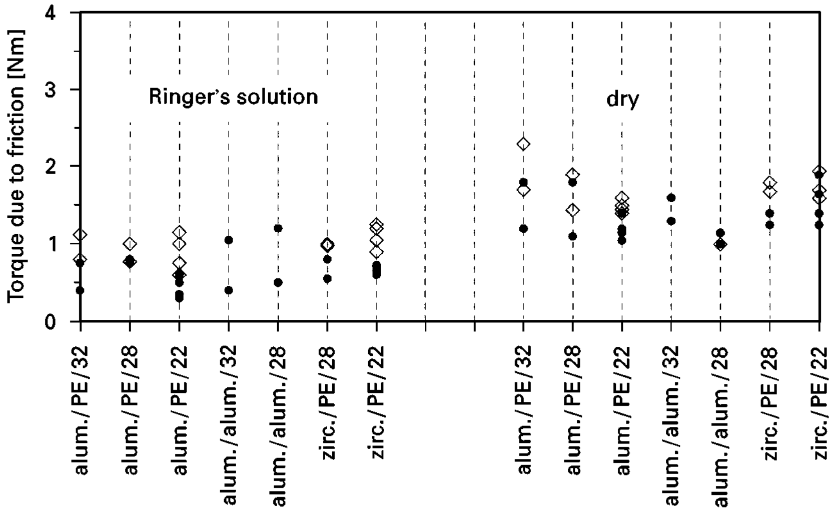

Figure 3 Torques obtained for different head–cup combinations at 2 kN axial load: (●) plateau, (◇) peak.

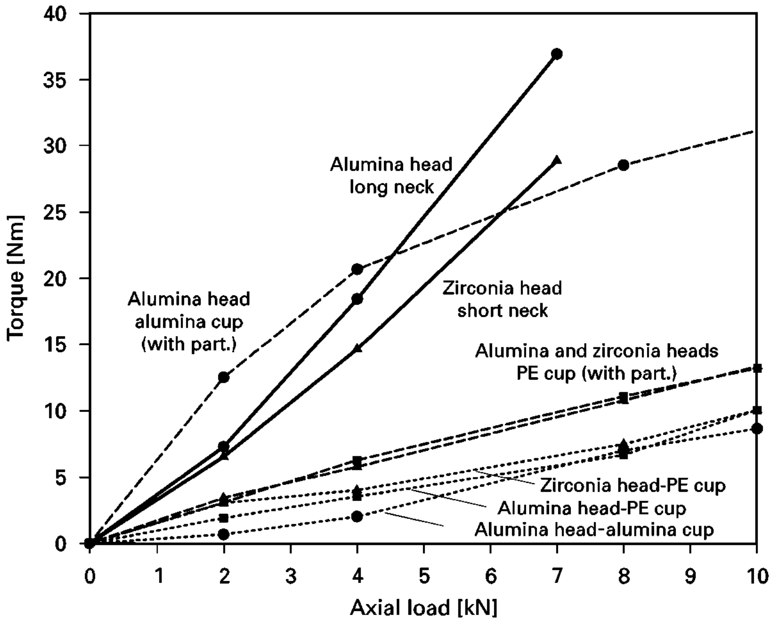

Figure 4 Comparison of torques between heads and cups and torques for removal of the head from the spigot (selected pairs). (....) cup friction with undisturbed surfaces; (– – – –) cup friction with particles; (——) torques for head removal.

loading. No influence of the taper fit could be found between 1′ and 12′ angle difference. Only a slight tendency could possibly be verified with respect to the zirconia heads of one producer, which showed fixation strengths in the upper region, i.e. up to 15 Nm. These values were also higher than the torques obtained with the same head geometry, but the head consisting of alumina instead of zirconia.

In Fig. 4, removal torques for two selected individual head–taper pairs are shown for different preload levels (solid lines). The relation between these torques and the axial fixation forces does not deviate very much from linearity in most cases, but it differs slightly for the types of heads investigated. The values obtained distinctly exceed the torques transferred by a cup in the normal case (dotted lines). The fixation strength can be exceeded, if an alumina/alumina combination is used and the cup–head contact surface is polluted by bone cement particles, for instance (upper dashed line); due to the very good fit between the alumina cup and head, such particles can impede the free sliding of the surfaces.

4. Conclusion

The comparison of torques which were necessary to remove 28 mm hip joint heads from 12/14 titanium alloy spigots, with the torques which are transferred from the cup to the head, demonstrated that this head–taper fixation is suited to guarantee safety in the normal case, even if the experiments also showed that the difference between the removal torque and the cup friction torque was not as large as expected. As other types of fixation (e.g. tapers other than 12/14 or of other materials) are also used, it seems to be reasonable to recommend a standard for the minimum fixation strength.

The high friction results presented, assuming a pollution of sliding alumina/alumina surfaces, are only intended to point out this problem. The quantitative results are determined by the arbitrarily chosen amount of bone cement particles. The additional, and possibly even more dangerous, long-term effect of abrasion of the articulating surfaces, has not been considered.

Acknowledgments

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