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Short Communication

The effect of polyethylene creep on tibial insert locking screw loosening and back-out in prosthetic knee joints

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ABSTRACT

A prosthetic knee joint typically comprises a cobalt–chromium femoral component that articulates with a polyethylene tibial insert. A locking screw may be used to prevent micromotion and dislodgement of the tibial insert from the tibial tray. Screw loosening and back-out have been reported, but the mechanism that causes screw loosening is currently not well understood. In this paper, we experimentally evaluate the effect of polyethylene creep on the preload of the locking screw. We find that the preload decreases significantly as a result of polyethylene creep, which reduces the torque required to loosen the locking screw. The torque applied to the tibial insert due to internal/external rotation within the knee joint during gait could thus drive locking screw loosening and back-out. The results are very similar for different types of polyethylene.

1. Introduction

A prosthetic knee joint consists of a distal femoral component that articulates with a polyethylene tibial insert, secured in a tibial tray that is anchored in the tibia. Dislodgement of the tibial insert from the tibial tray may be caused by trauma, or non-traumatic events such as locking mechanism defect, improper surgical placement, or physiological forces applied to the joint, e.g., during deep flexion (Poulter and Ashworth, 2005; Hedlundh et al., 2000; Park et al., 2007). Several reports in the literature describe specific cases of patients experiencing non-traumatic dislodgement of the tibial insert resulting from locking mechanism disengagement (Wright et al., 2011; Rutten and Janssen, 2009; Anderson et al., 2007; Davis et al., 1991; Ries, 2004; Chen et al., 2011; In et al., 2011; Lachiewicz and Geyer, 2011), attributed to unusual knee loading conditions and kinematics (Davis et al., 1991; Ries, 2004; Chen et al., 2011; In et al., 2011), or even the use of highly crosslinked polyethylene (Lachiewicz and Geyer, 2011).

Three types of locking mechanisms are regularly used to secure the polyethylene tibial insert in the metal tibial tray in total knee arthroplasty (TKA). They can be categorized as linear, peripheral, or central capture mechanisms (Thienpont, 2013). Linear locking mechanisms are based on a tongue and

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groove structure that runs anterior to posterior and/or medial to lateral. Peripheral capture mechanisms use a snap-fit with beveled edges along a portion or the entire perimeter of the tibial insert. Either mechanism may be augmented with a locking pin to reduce micromotion between the tibial insert and tibial tray. Central locking mechanisms use a pin with a peripheral flange for rotational stability or a central locking screw.

In this paper, we focus on failure of the central locking screw mechanism by loosening and back-out. While this is a rare complication (Wright et al., 2011), it has major consequences that lead to surgical re-intervention (Thienpont, 2013). Thus, it is a significant problem, and an understanding of the physical mechanism that drives locking screw loosening is needed to enable designing the next generation locking screws that do not exhibit this failure mode. Several cases of locking screw failure have been discussed in the literature. Shah et al. (2002) reported two cases of locking screw disengagement and subsequent migration. Cho and Youm (2009) investigated 13 cases of locking screw migration resulting from approximately 250–300 surgeries performed at their institution. These prosthetic knee joints used a combined snap-fit and locking screw mechanism. Screw migration was detected on average 27 months after implantation, and in all cases the screw had completely loosened and migrated into the joint. Rapuri et al. (2011) studied five cases of TKA failure due to disengagement of the locking screw. Loosening of the screw is believed to occur because of a counterclockwise torque created by the axial rotation of the femur on the tibia that occurs as the knee extends during gait. This torque is transmitted via the highly rotationally constrained femoral component and tibial post to the locking screw. Over many cycles, this may lead to screw loosening. In the left knee, this mechanism generates a clockwise torque that may actually prevent loosening. However, analysis has shown that one third of all knees exhibit reverse axial rotation with gait. Therefore, failures of this locking mechanism may still occur in the left knee Dennis et al., 2004.

Although clinical observations of locking screw loosening and back-out in TKA have been documented in the literature, the physical mechanism that drives this phenomenon is not yet fully-understood. Torque created during gait (Rapuri et al., 2011) and micromotion between the tibial insert and tibial tray are believed to contribute to locking screw loosening (Anderson et al., 2007). In addition, we hypothesize that the viscoelastic character of the tibial insert, which leads to creep under sustained load (Lee and Pienkowski, 1998), reduces the preload of the locking screw and, thus, the corresponding torque required to loosen the locking screw. Hence, the objective of this paper is to quantify the reduction of the preload of the locking screw as a function of polyethylene creep, for different types of polyethylene used in contemporary prosthetic knee joints.

2. Materials and methods

We experimentally evaluate the effect of creep of four different polyethylene types on locking screw loosening. The polyethylene types are: (a) ultra-high molecular weight polyethylene (UHMWPE) GUR 1020 blended with vitamin E, (b) UHMWPE GUR 1020, (c) GUR 1020 blended with vitamin E, cross-linked with 75 kGy gamma radiation, and (d) GUR 1020 cross-linked with 75 kGy gamma radiation and remelted. Fig. 1(a)–(d) shows $40 \times 40 \times 20\ mm^3$ polyethylene specimens of each type, each with a 6 mm metric screw clearance hole in its center. We use block-shaped specimens rather than actual tibial inserts to focus the study on the relationship between creep and the resulting torque needed for screw loosening, apart from a specific insert design. Notwithstanding, the block thickness of 20 mm is relevant to revision tibial inserts, which often are thicker than primary inserts. Fig. 2 shows the experimental setup. The polyethylene specimens are affixed to an aluminum base with a 6 mm stainless steel metric screw, similar to a typical locking screw used in commercial implants (Fig. 2(b)). We use a digital torque wrench (AC Delco ARM601-3, accuracy $\pm 2\%$) to fasten the

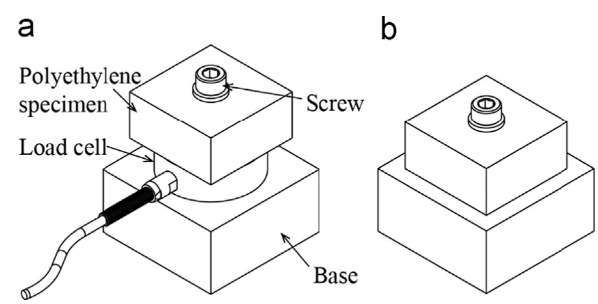

Fig. 2 – Schematic of the experimental setup (a) measuring the bolt preload with a load cell (one specimen), and (b) without load cell (remainder of specimens).

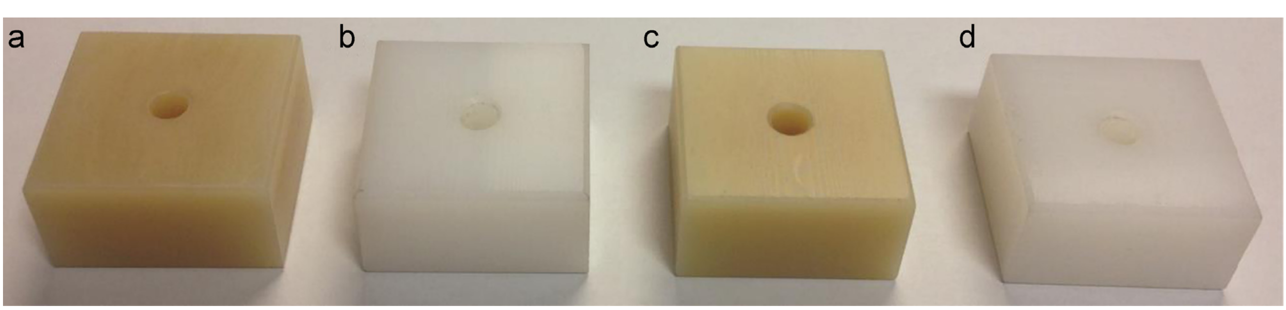

Fig. 1 – Different types of polyethylene used in this study (a) ultra-high molecular weight polyethylene (UHMWPE) GUR 1020 blended with vitamin E, (b) UHMWPE GUR 1020, (c) Vitamin E-blended cross-linked polyethylene (XLPE) GUR 1020 (75 kGy gamma radiation), and (d) XLPE GUR 1020 (75 kGy gamma radiation, remelted).