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Improving greater trochanteric reattachment with a novel cable plate system

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ABSTRACT

Cable-grip systems are commonly used for greater trochanteric reattachment because they have provided the best fixation performance to date, even though they have a rather high complication rate. A novel reattachment system is proposed with the aim of improving fixation stability. It consists of a Y-shaped fixation plate combined with locking screws and superelastic cables to reduce cable loosening and limit greater trochanter movement.

The novel system is compared with a commercially available reattachment system in terms of greater trochanter movement and cable tensions under different greater trochanteric abductor application angles.

A factorial design of experiments was used including four independent variables: plate system, cable type, abductor application angle, and femur model. The test procedure included 50 cycles of simultaneous application of an abductor force on the greater trochanter and a hip force on the femoral head.

The novel plate reduces the movements of a greater trochanter fragment within a single loading cycle up to 26%. Permanent degradation of the fixation (accumulated movement based on 50-cycle testing) is reduced up to 46%. The use of superelastic cables reduces tension loosening up to 24%. However this last improvement did not result in a significant reduction of the grater trochanter movement.

The novel plate and cables present advantages over the commercially available greater trochanter reattachment system. The plate reduces movements generated by the hip abductor. The superelastic cables reduce cable loosening during cycling. Both of these positive effects could decrease the risks related to grater trochanter non-union.

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1. Introduction

With our aging population, the number of patients requiring hip replacement surgery is increasing rapidly. One of the common complications of hip replacement surgery (3–7%) is the fracture of the greater trochanter (GT) [1]. In addition, an intentional osteotomy of the GT is often performed to provide better surgical exposure during complicated primary hip arthroplasty or revision surgeries.

Stabilization of the greater trochanter continues to offer one of the greatest challenges in revision of total hip arthroplasty. Several techniques using monofilament wires were developed to achieve secure fixation of the GT fragment on the femur [2] but the advent of the Dall–Miles cable plate system in the early 1980s [3] spurred a host of cable-plate systems. Nowadays, the most widely used greater trochanteric reattachment (GTR) systems consist of a plate, which hooks over the GT, combined with cable fixation (Zimmer Cable-Ready®, Warsaw IN & Dall-Miles Stryker, Mahwah, NJ, USA) (Fig. 1a).

These fixation systems are considered to provide the best performance [4,5] but, despite the many improvements in the past few decades, they have been deemed responsible for a high rate of post-operation complications: cable breakage, pain, bursitis and non-union [6–11]. Some of these complications result in considerable GT fragment migration.

It should be noted that the current systems essentially resist the forces generated by the hip abductor muscles acting in the cranial direction. However, these forces are most likely to displace the GT when the hip is in a flexed position, as in the movement of rising from a chair [12].

Furthermore, a high rate of cable breakage [10–19%] and non-union [9–31%] has been reported with the existing systems [6,9]. One possible source of such a high failure rate is cable loosening and its effect on system integrity. Finally, pain and bursitis can be due to irritation of the surrounding sensitive soft tissues caused by a bulky fixation system.

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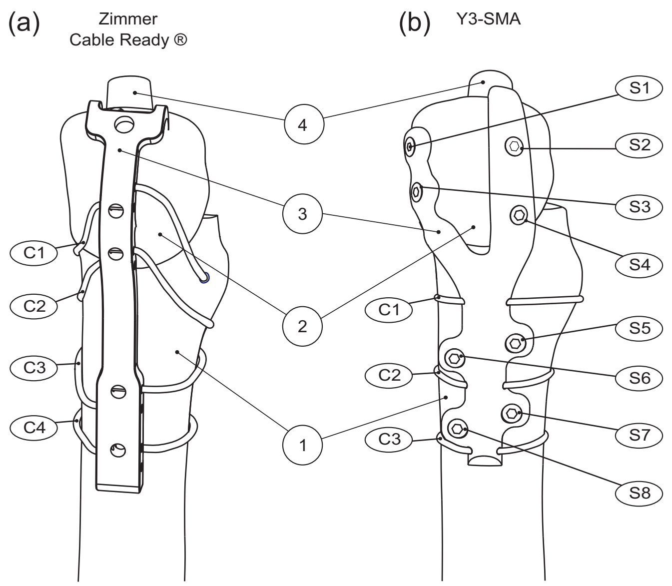

Fig. 1. Greater trochanter reattachment systems: (a) Zimmer Cable-Ready® and (b) Y3-SMA. The illustrated parts are the femur model (1), the GT fragment (2), the plates (3), the cables (C), and the screws (S).

A novel GTR system proposed based on clinical experience [13] and protected by two complementary patent applications [14,15] is studied in this work. The proposed GTR system (further referred to as Y3-SMA) consists of a fixation (Y3) plate with a general Y shape which hooks over the greater trochanter [15] shown in Fig. 1b. It is fixed with a combination of superelastic SMA cables [14] and locking screws which are inserted into the GT and into the femur.

The particular asymmetrical Y shape of the Y3 plate is designed to resist abductor and flexor muscles while having a low-profile design to reduce irritation of the surrounding soft tissues. The anterior and lateral trochanteric branches of the Y3 plate are designed to provide a solid fixation of the greater trochanter using self-locking screws. Moreover, the anterior trochanteric branch allows intraoperative contouring to accommodate the specific geometry of a patient's femur. The femoral branch accommodates a combination of unicortical locking screws and cables. The tubular-shaped cables are braided using NiTi superelastic filaments, a material used in numerous medical applications [16]. The SMA cable used as a binding element provides two novel features for bone fixation. Firstly, it prevents cable loosening even though the cerclage geometry varies, for example as a result of bone remodeling. Secondly, it flattens out when in contact with bones to provide a better force distribution at the bone–cable interface and to reduce the risk of cutting through the bone. Dynamic testing of these cables when used for sternal closure resulted in bone binding compression forces 20% higher than provided by standard stainless steel sutures [17]. The ability of SMA cables to maintain higher compression forces on the implant is expected to maintain the GT fragment stability during repetitive loading.

The objective of this study is to evaluate the effectiveness of the novel Y3-SMA cable plate system to prevent GT fragment displacements and to maintain cable tension as compared to a standard cable grip system. A biomechanical testing experiment, using a Box et al. [18] fractional factorial design of experiment (DoE), was designed to evaluate individual impacts of the Y3 plate and the SMA cables, as well as their synergistic effect on the improvement of the GTR system stability.

2. Materials and methods

The models used for experimentation include artificial femurs and GT fragments as well as GTR systems. The models are installed in the testing rig, which applies loading and records data.

2.1. Testing models

The testing models consist of four parts to be assembled (Fig. 1): the plates, the cables, the screws, the GT fragment and the femur model.

Two different plates were compared to reattach the GT to the femur. The first plate is an integral long GT reattachment device of the Cable-Ready® cable grip system (Zimmer Inc., Warshaw, IN, USA). The second plate is the novel Y3 plate made of titanium alloy (Ti6Al4V) by means of electron beam melting at the IREQ (Hydro-Québec Research Institute, QC, CA) facilities. Final processing included drilling and the insertion of copper–zinc alloy inserts for the bone screws.

Two types of GTR cables were also compared. The standard cables are 1.8 mm Cable-Ready® cobalt–chrome cables. The 48-filament superelastic cables were braided from the as-drawn 0.15 mm diameter filaments of BTR-BB (Ti–50.8 at% Ni) alloy (Memory Corp., Bethel, CT, USA) using a Wardwell (Central Falls, RI, USA) braiding machine on a 3 mm diameter core, heat treated at 350 °C (15 min) and then water quenched to ambient temperature.

Two types of Zimmer 3.5 mm diameter screws were used depending of their location on the Y3 plate holes: 12–20 mm locking screws on the GT and the mid-femoral branch and 14 mm standard cortical screws on the femoral branch extremities.

A large left fourth-generation composite femur model (Sawbones©, Pacific Research Laboratories, Vashon Island, WA, USA) was used to reduce specimen intervariability. The mechanical behavior of this femur model is reputed as being closer to human bone [20] than the previous-generation femur model used in biomechanical studies of post-osteotomy GT fixation [21,22]. The greater trochanter was cut according to the methodology presented in Section 5.

2.2. Testing apparatus

The femur and greater trochanter fixation system assemblies were placed in a custom-made testing apparatus (Fig. 2) previously described and validated [23].

Two simulated physiological forces were applied on the femoral implant (P1) and the GT (P2). The forces P1 and P2 were recorded in real-time by load cells (2224 N, LC101-500 and 4448 N, LC101-1k, Omega Engineering Inc, Stamford, CT, USA, instrument repeatability: ±0.01%) and the pulling cables were redirected by pulleys and guides to modify the forces' directions. Through-hole load cells (889 N, LC8100-200-5, Omega Engineering Inc, Stamford, CT, USA) were installed on each GTR cable to allow real time tension monitoring.

A dedicated motion analysis video system was used to follow the GT fragment's in-cut planar displacements and rotations, as illustrated in Fig. 2a. This view-point was chosen based on previous work showing it is the best of 3 candidate camera positions [23]. This single-camera testing approach was found appropriate within the framework of a comparative study with expected measurement errors of less than 0.38 mm in displacements and 0.5° in rotation [23].

2.3. Specimen preparation

For the specimen preparation, similar to the method described in Bredbenner et al. [24], a customized jig and a hand saw were used

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