Clinical Biomechanics 28 (2013) 187–192

Contents lists available at SciVerse ScienceDirect

Clinical Biomechanics

journal homepage: www.elsevier.com/locate/clinbiomech

In vitro biomechanical study of femoral torsion disorders: Effect on moment arms of thigh muscles

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ARTICLE INFO

Article history:
Received 26 September 2012
Accepted 12 December 2012

Keywords:
Femoral torsion disorder
Thigh muscles
Moment arms
Femoral osteotomy
Knee osteoarthritis

ABSTRACT

Background: Lower limb torsion disorders have been considered as a factor inducing gonarthrosis and the three-dimensional effect of the surgical correction is not well reported yet. This paper reports an *in vitro* study aiming at quantifying the relationships between experimental femoral torsion disorders and moment arms of thigh muscles.
Methods: Five unembalmed lower limbs were used and fixed on an experimental jig. Muscles were loaded and 6 Linear Variable Differential Transformers were used to measure tendon excursions. Experimental osteotomies were performed to simulate torsions by steps of 6° up to 18°. Moment arms of the main thigh muscles were estimated by the tendon excursion method during knee flexion.
Findings: Moment arms of the tensor of fascia latae, the gracilis and the semitendinosus were significantly influenced by experimental conditions while the rectus femoris, the biceps femoris and the semimembranosus did not show modifications. Medial femoral torsion decreased the moment arm of both the gracilis and the semimembranosus. Opposite changes were observed during lateral femoral torsion. The moment arm of the tensor of fascia latae decreased significantly after 30° of knee flexion for 18° of medial femoral torsion.
Interpretation: Our results showed that medial and lateral femoral torsion disorders induced alterations of the moment arms of the muscles located medially to the knee joint when applied in aligned lower limbs. These results highlight a potential clinical relevance of the effect of femoral torsion alterations on moment arms of muscles of the thigh which may be related, with knee kinematics modifications, to the development of long-term knee disease.

1. Introduction

Knee osteoarthritis (OA) is the most common cause of disability associated with aging and the lower limb deviations in the frontal and sagittal planes have been incriminated as the main factor in the genesis of knee OA. In some cases people may develop an early lateralized and/or medialized gonarthrosis without presenting a lower limb misalignment. Lower limb torsion disorders were mentioned as being involved in lateralized gonarthrosis (Eckhoff, 1994; Maquet, 1985). Other authors also evoked this possibility (Duparc et al., 1992; Goutallier et al., 1997; Takai et al., 1985; Yagi and Sasaki, 1986). Nevertheless, a literature review about the alterations of both the femoro-tibial constraints and the surface areas show contradictory outcomes (Bretin et al., 2011; Goutallier et al., 1997; Kenawey et al., 2011; Krackow et al., 2011; Sobczak et al., 2011a; Takai et al., 1985). Sobczak et al. (2011a) showed that experimental medial femoral torsion (MFT) induced an increase of cancellous bone deformation of the proximal tibial epiphysis below medial chondral tissue, and inversely during lateral femoral torsion (LFT) disorder.

Concerning the knee kinematics, a recent study (Sobczak et al., 2012) observed that LFT deviations induced a significant decrease of adduction and medio-lateral translation and an increase of internal tibial rotation, while MFT deviations increased adduction and medio-lateral translation and decreased internal tibial rotation.

The literature about the modification of moment arms of thigh muscles after lower limb misalignment is scarce, and the influence of femoral torsion disorders on these moment arms has not yet to be investigated. Following the recent kinematic results (Sobczak et al., 2012) it would be interesting to study the behavior of thigh muscle moment arms after experimental femoral osteotomies. To date, only one study (Baillon et al., 2006) reported in-vitro modifications of moment arms of the thigh after high valgus and varus tibial “dome” osteotomy. They observed a significant increase of the maximal peak of the rectus femoris muscle after valgus and varus osteotomies. Concerning posterior thigh muscles, only the semitendinosus muscle

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0268-0033/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.clinbiomech.2012.12.008

was affected by osteotomy conditions with an increase and a decrease after valgus and varus conditions, respectively.

This paper aims at quantifying the modification of the moment arms of most thigh muscles after experimental distal femoral torsion simulation (Sobczak et al., 2011a, 2012) in order to contribute to better understanding of the 3D impacts of surgical osteotomy procedures. Medial torsion (MFT) and lateral torsion (LFT) were performed for various torsion disorder angles from 6° to 18°. Tendon excursions were measured using linear variable displacement transductor (LVDT) and the moment arms were estimated by the tendon excursion method (Spoor and Van Leeuwen, 1992). The objective of this study was to investigate the relationships between femoral torsion disorder and moment arms of thigh muscles. This should enable further development of a new generation of tools that will help surgeons to better appreciate the three-dimensional (3D) aspects of an osteotomy and its consequences.

2. Methods

2.1. Specimens

Five left fresh-frozen lower limbs (mean age: 84 (SD 9) years; 3 males, 2 females) were collected from the ULB Body Donation program. Thawing occurred at room temperature 24 h before the experiment. Each specimen included a full lower limb with its hemi-pelvis. None of the specimens underwent any lower limb surgery prior to this study. Each specimen sustained the following experimental protocol reported in details in a previous study (Sobczak et al., 2012).

The pelvis and femur were rigidly mounted on the experimental jig in an anatomical neutral position. The distal tendons of eight muscles of interest (rectus femoris (RF), vastus lateralis (VL), vastus intermedius (VI), vastus medialis (VM), biceps femoris (BF), semitendinosus (ST), semimembranosus (SM), gracilis (Grac) and tensor fasciae latae (TFL)) were carefully cleaned, cut at their distal musculotendinous junction and attached to a fishing wire (Surflon®, Nylon coated, American Fishing Wire, 90 Lb., USA) following the Bull's method (Amis et al., 2008; Bull et al., 1998). Each wire ran proximally through tunnels drilled into the bone at the level of muscle origin to allow joint loading following physiological muscle lines of action. Total loading was 300 N (RF + VM = 80 N; VL and VI = 60 N each; BF, ST, SM, Grac, and TFL = 20 N each) and was applied by the use of sandbags. One 6 degrees of freedom (DoF) instrumented spatial linkage (ISL) (Salvia, 2004) was used to assess femoro-tibial joint kinematics (data sampling frequency: 200 Hz). Joint kinematics has been assessed as previously described (Sholukha et al., 2004; Sobczak et al., 2012; Van Sint Jan et al., 2002).

2.2. Moment arm measurement

The tendon excursion variations of the RF, BF, ST, SM, Grac and TFL were collected using six Linear Variable Differential Transformer (LVDT, SOLARTRON Inc., AMETEK Advanced Measurement Technology, TN, USA) (Fig. 1A). This indirect method consists of an analysis of the variation of the tendon excursion as a function of angular joint displacement (An et al., 1984; Sobczak et al., 2011b). Range of Motion (ROM) was evaluated using a six-degree-of-freedom Instrumented Spatial Linkage (6Dof-ISL) (Salvia et al., 2003; Sholukha et al., 2004). The base of the 6Dof-ISL (Fig. 1B) was fixed on a Plexiglas® registration block (Fig. 1B) with four calibrated holes attached to the experimental jig. The end of the 6Dof-ISL was fixed to the proximal part of the tibial diaphysis using two Schanz screw pins (∅ 3) (Fig. 1B). To compute knee kinematics, a previously reported registration method was used (Van Sint Jan et al., 2002). The moment arms were assessed during knee flexion.

2.3. In-vitro experimental femoral torsion disorder simulation

In-vitro experimental femoral torsion disorder simulation used a customized experimental control system (CS) (Fig. 2) to apply and measure femoral osteotomy in MFT and LFT. The CS has been described in a previous study (Sobczak et al., 2012). The analyzed torsion disorder simulations of the distal part of the femur were 6°, 12° and 18° for both deviation directions (MFT and LFT). The sequence of deviation conditions was randomized, except for the intact condition.

2.4. Data collection

For each of the above-mentioned torsion deviations, two cycles of three repetitions of knee flexion–extension were performed. Measurement started with the knee in full extension achieved by muscle loading. Flexion was then performed manually with an opened hand pushing the anterior part of the distal shank. Once knee flexion was reached, the shank was released and allowed to move back to full extension thanks to muscle loading. Muscle loading was maintained during the entire measurement session. During data processing, only the knee flexion range from 10° to 90° was considered.

2.5. Statistical analysis

Each motion dataset was segmented in three motion ranges (10°–30°, 30°–60°, 60°–90°) and descriptive statistics were calculated (mean, SD) for each range. A two-way analysis of variance (ANOVA) for repeated measurements was used to investigate effect of deviation conditions, knee flexion range and the interaction between both factors. A post-hoc test (LSD — Fisher's least significant difference) was applied in case of ANOVA significance. Statistical analysis was performed using Statistica© software with a confidence interval of 95%.

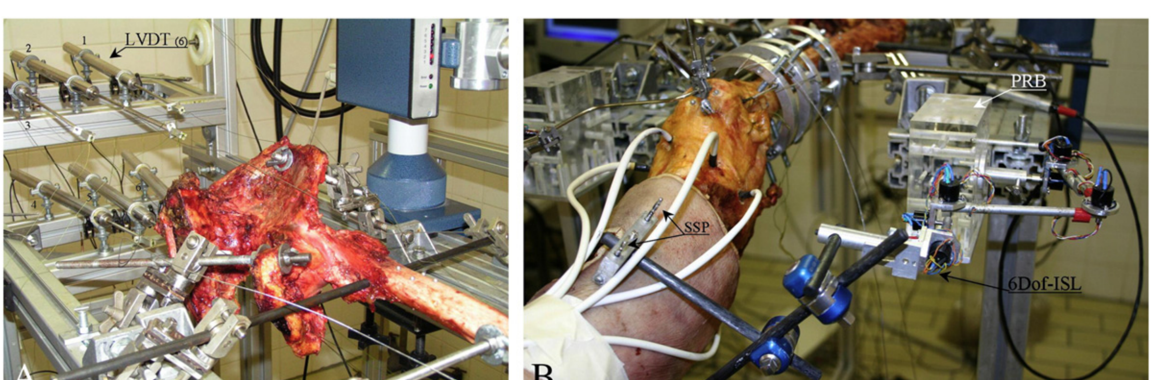

Fig. 1. Experimental setting showing a specimen mounted on the customized jig in anatomical position. A: LVDTs located posteriorly to the lower limb. B: The 6Dof-ISL fixed to the proximal part of the tibial diaphysis using two Schanz screw pin (SSP). PRB: Plexiglas® registration block.