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In vitro biomechanical study of femoral torsion disorders: Effect on femoro-tibial kinematics

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ABSTRACT

Background: Gonarthrosis is a degenerative disease mainly found in elderly persons. Frontal plane deviations are known to induce lateral and medial gonarthrosis. Nevertheless, patients suffer from gonarthrosis without frontal deviations. Lower limb torsions disorders have been considered as a factor inducing lateral and medial gonarthrosis. This paper reports an *in vitro* study aiming at quantifying the relationships between experimental femoral torsion disorders and femoro-tibial kinematics.
Methods: Five fresh-frozen lower limbs were used. Specimens were fixed on an experimental jig and muscles were loaded. A six-degree-of-freedom Instrumented Spatial Linkage was used to measure femoro-tibial kinematics. Experimental femoral osteotomies were performed to simulate various degrees of medial and lateral torsion. Internal tibial rotation, abduction/adduction and proximo-distal, medio-lateral and antero-posterior translations were measured during knee flexion.
Findings: Internal tibial rotation and abduction/adduction were significantly influenced ($P<0.001$) by femoral torsion disorder conditions. Medial femoral torsion increased tibial adduction and decreased internal rotation during knee flexion. Opposite changes were observed during lateral femoral torsion. Concerning translations, medial femoral torsion induced a significant ($P<0.05$) decrease of medial translation and inversely for lateral femoral torsion. No interactions between femoral torsion disorders and range of motion were observed.
Interpretation: Our results showed that medial and lateral femoral torsion disorders induced alterations of femoro-tibial kinematics when applied in normally aligned lower limbs. These results highlight a potential clinical relevance of the effect of femoral torsion alterations on knee kinematics that may be related to the development of long-term knee disease.

1. Introduction

Knee osteoarthritis (OA) is a common degenerative pathology found generally in an elderly population. Frontal plane deformities are directly related to lateralised and medialised gonarthrosis (Sharma et al., 2001). Nevertheless, patients may develop early lateralized gonarthrosis without presenting a deformation in the frontal plane. The association of lower limb torsion disorders was mentioned as being a factor inducing a 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). For the majority of these authors an increase of medial femoral torsion may induce lateral gonarthrosis but Takai et al. (1985) found no femoral torsion difference between medial and lateral femoro-tibial OA groups. Recent in vitro studies showed that lower limb malrotation induces variations of femoro-tibial contact pressure (Bretin et al., 2011; Kenawey et al., 2011). Bretin et al. (2011) observed a significant valgus deviation of the mechanical axis and a shift of the centre of force towards the lateral condyle after experimental internal femoral torsion and inversely after external femoral torsion. The results were however collected in knees after medial and lateral menisectomies. For Kenawey et al. (2011) the femoro-tibial contact area was not affected by femoral and tibial mid-shaft rotational osteotomies, but medial compartment contact pressure increased with external and decreased with internal femoral or tibial malrotations while lateral pressure was not affected. 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. A recent in vivo study (Krackow et al., 2011) reported that medial loading could be predicted by the mechanical axis and the foot progression angle. Patients with medial knee osteoarthrosis and an apparent torsion deformity had a significant greater mechanical axis varus and knee varus moment compared to a control group and a group of patients with medial knee osteoarthrosis without apparent torsion deformity. This literature review shows

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contradictory results and there is a paucity of data concerning the relationships between bone alignment, osteotomy surgery, local joint pressure, joint kinematics and moment arm of thigh muscles. Moreover, the influence of femoral torsion disorders on knee joint kinematics has not been reported yet.

This paper aims at quantifying knee joint kinematics following experimentally induced distal femoral torsion in order to contribute to better understanding of the 3D impacts of surgical osteotomy procedures on femoro-tibial kinematics. Medial torsion (MFT) and lateral torsion (LFT) were performed for various torsion disorder angles from 6° to 18°. Knee kinematic were analyzed using a six degrees of freedom-Instrumented Spatial Linkage (6Dof-ISL). The objective of the study was to contribute to a better insight into the relationships between femoral torsion disorder and knee joint kinematics. 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 kinematics consequences.

2. Methods

2.1. Specimens

Five left fresh-frozen lower limbs (mean age: 84 (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 specimen underwent any lower limb surgery prior to this study. Each specimen was submitted to the following experimental protocol (Sobczak et al., 2011a, 2011b). The degree of osteoarthrosis was evaluated by macroscopic evaluation using Debouck's classification (Debouck and Rooze, 1995). The median degree of lesion was a stage II (ulceration). Computed tomography (CT, Siemens SOMATOM, helical mode, slice thickness = 0.5 mm, inter-slice spacing = 1 mm) was performed in anatomical neutral position to evaluate the lower limb alignment, and occurrence of deviation in the frontal and transversal planes (Table 1). Lower limb alignment was estimated as previously reported (Goutallier et al., 1997; Sobczak et al., 2011a). Femoral torsion was evaluated by the angle between the proximal and distal femoral axes: the proximal axis was the line joining the centre of the femoral head and the middle part of the femoral neck and the distal axis was the tangent to the most posterior part of the femoral condyles. Tibial torsion was evaluated by the angle formed between the proximal and distal tibial axes: the proximal axis was the tangent to the posterior border of the tibial epiphysis and the distal axis passed through the centre of articular surface of the medial and lateral malleoli. Frontal alignment was evaluated by the angle formed by the femoral and tibial both mechanical and anatomical axes.

The pelvis and femur were rigidly mounted on the experimental jig in an anatomical neutral position (Fig. 1). This position is defined by the alignment of 3 anatomical landmarks in the sagittal plane

Table 1
Average (standard deviation) of physiological lower limb alignment of the specimens used in this study prior to femoral torsion disorder simulation. Frontal plane: a negative and a positive sign described varus and valgus alignment, respectively. Transverse plane: femoral torsion is negative (−FT) and tibial torsion is positive (+TT) by convention. FTindex = (−FT) + (+TT).

	Frontal plane		Transversal plane		
	Mechanical axis (°)	Anatomical axis (°)	Femoral torsion (°)	Tibial torsion (°)	FT index (°)
S1	2	5	−6	35	29
S2	1	6	−20	31	11
S3	2	3	−20	28	8
S4	0	5	−15	27	12
S4	3	8	−18	36	18
X	2 (1)	5 (2)	−18 (2)	31 (4)	16 (8)

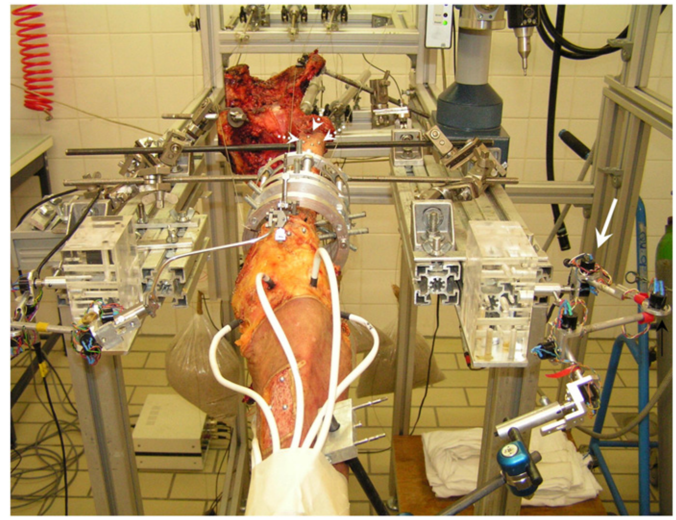

Fig. 1. Experimental setting showing a specimen mounted on the customized jig in anatomical position. The arrow shows the 6Dof-ISL fixed to the proximal part of the tibial diaphysis using two Schanz screw pin and proximal femoral technical landmarks.

(the centre of the greater trochanter, the center of lateral malleolus and the top of the lateral edge of the pattelar surface of the femur). The eight muscles of interest were carefully cleaned and cut at their distal musculotendinous junction. Care was taken to preserve the anatomical relations with the knee joint and the distal part of these tendons and insertions. Dissected muscles were: 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). Special care was given to respect the integrity of hip and knee joint capsule and ligaments. A fishing wire (Surflon®, Nylon coated, American Fishing Wire, 90 Lb., USA) was attached to each tendon by a trained orthopaedic surgeon (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). Muscle loading was applied by the use of sandbags. Loads were selected to respect the proportional forces that each muscle can generate considering muscle volume and muscle pennation angle (Klein Horsman et al., 2007). One 6 degrees of freedom (DoF) instrumented spatial linkage (ISL) (Salvia, 2004, see below) was used to assess femoro-tibial joint kinematics (data collection frequency: 200 Hz). Validation of this instrument is reported elsewhere (Sholukha et al., 2004). To express anatomical landmarks coordinates and kinematics, clusters of four technical markers (TM) made of aluminium balls were glued on the distal epiphysis of the femur and on the diaphysis of the tibia (Van Sint Jan et al., 2002). Spatial location of each TM was computed using a 3D digitizer (Faro arm, model 08 Bronze, USA, point probe, accuracy = 0.305 mm).

2.2. Kinematics measurement

Femoro-tibial kinematics were assessed by analysing motion related to anatomical planes based on the joint coordinate system defined by flexion-extension around the femoral fixed axis linked to the femur (e1 — transepicondylar axis), tibial rotation around the moving axis linked to the tibia (e2 — tibial anatomical axis) and abd-adduction around the floating axis (e3) or the node line perpendicular to both previous axes (Grood and Suntay, 1983).

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 was fixed on a Plexiglas® registration block