Journal of Biomechanics 44 (2011) 1354–1360

Contents lists available at ScienceDirect

Journal of Biomechanics

journal homepage: www.elsevier.com/locate/jbiomech
www.JBiomech.com

The effect of valgus braces on medial compartment load of the knee joint – *in vivo* load measurements in three subjects

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ARTICLE INFO

Article history:
Accepted 3 January 2011

Keywords:
Knee joint
Braces
Forces
Valgus
Medial load

ABSTRACT

Knee osteoarthritis occurs predominately at the medial compartment. To unload the affected compartment, valgus braces are used which induce an additional valgus moment in order to shift the load more laterally. Until now the biomechanical effect of braces was mainly evaluated by measuring changes in external knee adduction moments. The aim of this study was to investigate if and to which extent the medial compartment load is reduced *in vivo* when wearing valgus braces.

Six components of joint contact load were measured *in vivo* in three subjects, using instrumented, telemeterized knee implants. From the forces and moments the medio-lateral force distribution was calculated. Two braces, MOS Genu (Bauerfeind AG) and Genu Arthro (Otto Bock) were investigated in neutral, 4° and 8° valgus adjustment during walking, stair ascending and descending.

During walking with the MOS brace in 4°/8° valgus adjustment, medial forces were reduced by 24%/30% on average at terminal stance. During walking with the GA in the 8° valgus position, medial forces were reduced by only 7%. During stair ascending/descending significant reductions of 26%/24% were only observed with the MOS (8°).

The load reducing ability of the two investigated valgus braces was confirmed in three subjects. However, the load reduction depends on the brace stiffness and its valgus adjustment and varies strongly inter-individually. Valgus adjustments of 8° might, especially with the MOS brace, not be tolerated by patients for a long time. Medial load reductions of more than 25% can therefore probably not be expected in clinical practise.

1. Introduction

Osteoarthritis (OA) is the most common joint disease, associated with pain and loss of mobility. When the knee joint is highly loaded, e.g. during the stance phase of gait, most of the axial force is transmitted by the medial compartment (Hsu et al., 1990; Johnson et al., 1980; Morrison, 1970; Shelburne et al., 2005; Zhao et al., 2007). This fact is believed to be responsible for the observation that gonarthrosis predominately starts at the medial compartment (Hernborg and Nilsson, 1977; Jackson et al., 2004).

Besides surgical treatments, several conservative methods, such as lateral shoe wedges, the use of crutches, weight reduction and valgus bracing are common to reduce the axial tibial force and/or to shift it laterally. Reduced loading of the affected compartment is related to pain reduction and improved function, and may thus delay the need for joint replacement. Valgus braces induce an additional external valgus (abduction) moment at the knee joint, which counteracts the external adduction moment (EAM) in order to shift the axial force from the medial knee compartment towards the lateral one. A correlation between the medial contact force and peak EAMs was found analytically and measured *in vivo* in one subject (Shelburne et al., 2008; Zhao et al., 2007).

In previous studies the load reducing effect of braces was predicted by brace and EAM measurements. Reductions of peak EAMs of about 10–15% were reported when walking with valgus braces (Lindenfeld et al., 1997; Self et al., 2000). Studies have furthermore predicted that larger valgus angulations of the brace lead to higher load reduction of the medial compartment. Reductions of peak EAMs of up to 15% and 19% were reported when walking with a brace adjusted in 4° and 8° valgus positions, respectively (Fantini Pagani et al., 2010). Using an analytical model, Pollo et al. (2002) estimated a medial load reduction of 11% when the brace was adjusted in a 4° valgus position, and 17% for the 8° valgus position. Furthermore, several clinical studies

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doi:10.1016/j.jbiomech.2011.01.014

have shown that the use of braces leads to reduced pain and improved function (Kirkley et al., 1999; Lindenfeld et al., 1997; Pollo et al., 2002; Richards et al., 2005).

Up to now no direct measurement of the medial contact force (F_{med}) has been performed to confirm the unloading effect of valgus braces. The aim of this study was therefore to investigate the ability of valgus braces to reduce the medial compartment load, by taking measurements directly in the knee joint. Knee contact loads (3 forces and 3 moments) were measured using instrumented knee implants with telemetric data transmission. Medio-lateral load distribution was determined during the most frequent strenuous activities of daily living: walking, stair ascending and descending.

2. Methods and materials

2.1. Investigated braces

Two braces with monocentric joints were investigated: MOS (MOS Genu, long version, Bauerfeind AG, Germany) and GA (Genu Arthro, Otto Bock HealthCare GmbH, Germany) (Fig. 1A, and B). Both braces are designed to apply an external valgus moment about the knee through a three-point bending system. Whereas the GA is a unilateral brace, the MOS has a bilateral frame.

The braces were adjusted by skilled orthopaedic technicians. The joints were aligned with Nietert's (1976) compromise axis . The braces were first fitted to the leg in a neutral position to examine whether the brace itself already has an influence on joint loading. After performing the activities with the brace in neutral position, additional valgus angles of 4° (MOS) and 8° (MOS and GA) were adjusted. The valgus adjustment of MOS is set by scaled, eccentric screws while the brace is still attached to the leg. The GA has to be removed from the leg to set the additional valgus angle.

When fixing the brace at the leg, it is bent in varus direction until it reaches its final position (Fig. 1C). This back-bending causes the required valgus moment M_b. The magnitude of M_b depends not only on the adjusted angle, but also on the stiffness of the brace.

2.2. Instrumented implant

An instrumented tibial tray with telemetric data transmission (Fig. 2) was developed to measure the 6 components (3 forces and 3 moments) of the knee contact load *in vivo* (Heinlein et al., 2007). It is based on the INNEX FIXUC total knee system (Zimmer GmbH, Winterthur, Switzerland) with a standard femoral component and a standard ultra-congruent tibial insert. The custom-made tibial component has a stem-in-stem design. Six semiconductor strain gauges (KSP 1-350-E4, Kyowa, Japan) measure the strains in the inner stem and deliver, via a 6×6 calibration matrix, the 6 load components. The signals are multiplexed by a custom-made telemetry chip and transferred via an antenna to the external receiver (Graichen et al., 2007). The electronics are powered inductively by an external magnetic field.

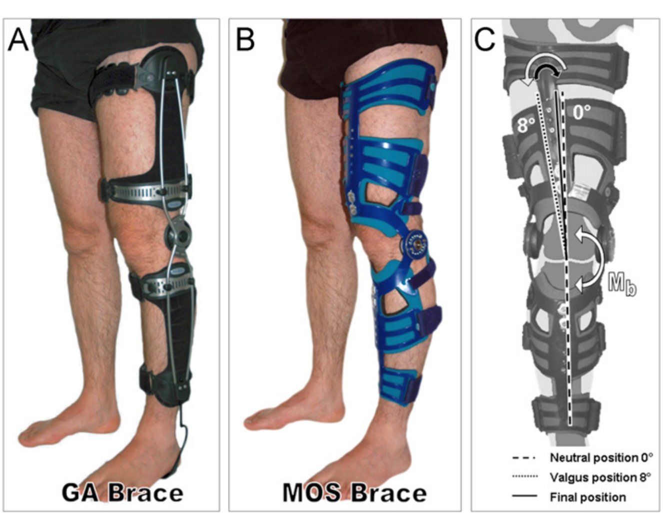

Fig. 1. Investigated braces GA (A) and MOS (B) and schematic illustration of brace adjustment (C). The braces are adapted in neutral position (0°) and then adjusted in 4° or 8° valgus position (grey arrow). When fixing the braces at the leg, they are bent back (black arrow) and thereby apply an external moment M_b.

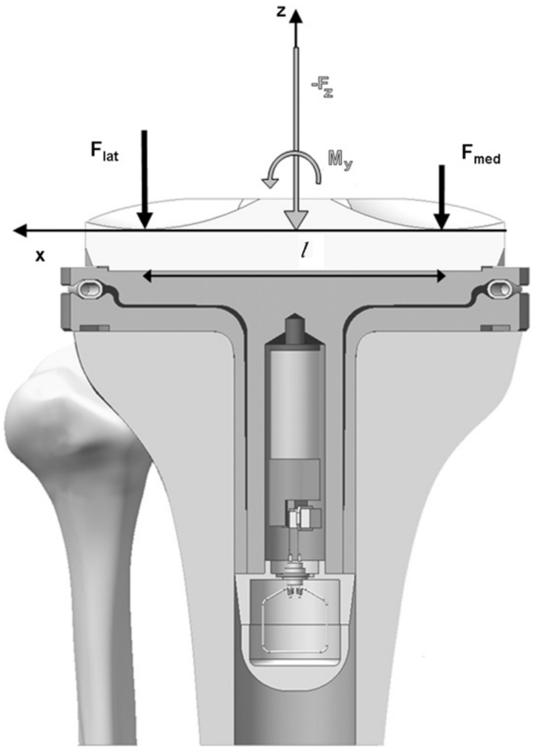

Fig. 2. Coordinate system of the instrumented tibial tray in the frontal plane. The axial force $-F_z$ is the sum of the medial and lateral force (F_{med}+F_{lat}) acting on the tray.

Table 1
Subject data.

Subject	K1L	K3R	K5R
Age (years)	64	71	60
Body mass (kg)	103	96	96
Height (cm)	177	175	175
Time post-op (months)	23	12	6
Mechanical axis angle (°)	3 varus	4 varus	1 varus

2.3. Coordinate system

The right-handed coordinate system of the implant is fixed at the right tibia (Fig. 2). Its origin lies on the extended stem axis at the height of the lowest part of the tibial insert.

The force components $+F_x$, $+F_y$ and $+F_z$ act in lateral, anterior and superior directions, respectively. The moments $+M_x$, $+M_y$, $+M_z$ act in the sagittal, frontal and horizontal plane of the tibia, respectively and turn right around their belonging axes. The negated moment $-M_y$ counteracts the external adduction moment, i.e. it attempts to abduct the tibia.

2.4. Subjects and activities

After approval by the ethics committee and the patients' informed consent, three male patients obtained an instrumented implant after medial compartment osteoarthritis (Table 1).

The knee alignment in the frontal plane was determined from radiographs during two-legged stance. The mechanical axis angle was defined as the angle formed by the mechanical axes of femur (hip to knee centre) and tibia (Specogna et al., 2007). All subjects showed a slight varus alignment.

Three activities of daily living were investigated: walking at a self selected speed on level ground, ascending stairs, and descending stairs (stair height: 200 mm). All subjects performed the activities fluently and free of pain.