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Partial weight bearing of the tibia

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ABSTRACT

Introduction: Partial weight bearing is part of treatment schemes in orthopedic surgery and traumatology. The aim of the present study was to explore to what degree ground reaction forces during partial weight bearing of the lower leg are related to given instructions and to tibia deformation.
Materials and methods: Tibia deformation (torsion, medio-lateral and anterio-posterior bending) was measured for rear foot and forefoot loading, 10 kg, 20 kg and half body weight instructions compared to full loading in five healthy male subjects using the "Optical Segment Tracking" approach, a motion-capturing based method that uses monocortically fixed bone screws.
Results: 1. Ground reaction force was a good indicator of tibia deformation. 2. Participants significantly under-loaded during half-body weight instructions ($P < 0.001$) while they overloaded when loading the forefoot only. 3. Partial-loading instructions led to a highly significant and systematic reduction in peak ground reaction force (GRFpk) in all three types of tibia deformation with substantial variation between measurements. 4. Forefoot usage was associated with significant, albeit moderate increases in GRFpk ($P = 0.0031$), in AP-bending ($P = 0.0027$) and in torsion ($P < 0.001$), compared to rear foot loading.
Discussion: These findings result in the following clinical "lessons learned": 1. GRF is a good reflection of loading-induced deformation of the tibia. 2. GRFs are hard to control by subjects/patients. 3. The expectation that forefoot-loading results in larger tibia deformation could not be confirmed in our study. 4. When aiming at a reduction in tibia deformation, rear-foot loading is more preferable than forefoot loading.

Introduction

In Orthopedic Surgery and Traumatology, partial weight bearing (PWB) is part of treatment schemes for a number of conditions. PWB is frequently applied in fracture treatment, after surgery, especially after fracture osteosynthesis, joint replacement, and corrective osteotomies, as well as in pseudarthrosis, to only mention a few indications [1–3]. Loading schemes may include rear- or forefoot/toe-touch-loading, and usually comprise a percentage of body weight or a number of kilos or pounds, e.g. 10 or 20 kg [1,2]. The rationale for partial loading schemes is to improve the biological process of fracture healing: While certain forces are required for fracture healing, excessive movement is known to delay the healing process compared to a more rigid situation [4]. Axial forces are necessary for the healing process [5]. Shear forces, however, rather delay healing and may increase the likelihood of nonunion [5]. Accordingly, PWB regimens aim at a reduction of force application and ultimately at delivering a certain dose of mechanical stimulation. However, how well this 'dosage' can be defined is unclear and seems to depend on the individual situation. Thus, it is known patients frequently over-load the target-weight in PWB [6–8]. Hustedt et al. have shown that a higher body-mass-index and male gender were predictive of worse compliance and heavier weight bearing [2,9]. Some studies have tried to improve the instructions to patients and evaluated the use of biofeedback-methods in addition to verbal instruction and a bathroom scale [2,10]. In patients with tibia osteotomies who were treated with Ilizarow ring fixators, Duda et al. showed that there is

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no direct relationship between tibia interfragmentary movement magnitudes and ground reaction force. They found the same movement magnitudes in exercises that included muscle contractions only, standing up and walking [1]. Duda et al. concluded that PWB could not reliably reduce loading of a healing zone, while it may increase patient awareness [1]. Weight bearing schemes are mainly empiric and differ widely between institutions and “schools”. In biomechanical theory, the lever arm of the ankle joint would cause much greater bending moments on the tibia in forefoot loading as compared to rear-foot loading. In reality, however, the complex anatomy of the food and ankle consists of a number of bones and ligaments and is influenced by the pull of several muscles. Calf muscles work against a short lever, and internal tibia forces therefore mostly on muscle contractions and not so much upon tibia inertial loading or ground reaction forces [11]. In the literature, it has not yet been addressed whether, as one would expect on biomedical grounds, forefoot loading does actually lead to higher bone deformation than rear-foot loading, and to what extent this might be affected by PWB. We recently showed that the torsional deformation angle during both stair ascent and running was larger with forefoot strike than rear foot strike [12]. During isometric plantar flexion, tibia deformation regimes were characterized more by torsion than bending, which leads to the conclusion that tibia torsional deformation is closely related to calf muscle contractions. The question is now what happens during PWB.

Our group has recently developed a method that allows in vivo measurements of human bone deformation during exercise, called “optical segment tracking (OST)” [12–16]. Motion Capture is used to track markers mounted on screws that are mono-cortically inserted into the bone (e.g. tibia) to accurately measure bending and torsion during exercise and locomotor activities. The experiment presented here was part of the MUST-study (Ethical approval by the ethics committee of North Rhine Medical Association No. 2011306 and by the ethics committee of Cologne University Hospital No. 12-007).

The aim of this specific experiment was to explore to which degree ground reaction forces during PWB of the lower leg are correlated with tibia deformation. Moreover, we were interested to see whether fore-foot loading would lead to increased tibia deformations compared to rear-foot loading.

Materials and methods

Study design and setting

Subject selection including in- and exclusion criteria has previously been described in detail [13]. Five healthy male human subjects were selected to participate in the study. The low number of subjects was chosen for ethical reasons due to the invasiveness of measurements. Informed consent was obtained from all subjects. Subjects were trained and familiarized for the actual study during dry runs using sham-markers. To minimize risk of infection, experiments were carried out in two operation theatres, one used for screw implantation and explantation, and another to conduct the experiments. Stryker Asnis Micro 3.0 mm cannulated titan screws (self cutting screw, 3.0 mm, 24 mm total length, 6 mm thread length, Stryker Leibinger GmbH & Co. KG, Duisburg, Germany) were used for marker cluster fixation. The experiment described in this manuscript was part of a larger protocol that included other tests such as walking, running on a treadmill, jumping, squatting, a three-point bending test and others. Screws were implanted at 8 am and explanted before or at 6 pm on the same day. Details of the screw implantation and handling have also been published before [13]. During the exercises, trajectories of the marker clusters attached to the screws were captured with a Vicon MX motion capture system (eight Vicon F40 cameras, Vicon Motion System Ltd., LA, USA) at 300 Hz, capturing infrared light (Fig. 1). Tibia deformation angles (bending and torsion) were calculated from the relative translation between markers in the same way as in our previous publications [12–16]. Matlab (The MathWorks, Inc. Version 7.9.0 R2009b) routines were written to process the marker's trajectories and calculate the deformation angle from the relative displacement between marker clusters. Ground reaction forces were recorded using a force plate (AMTI OR-6-6-2000, Advanced Mechanical Testing Inc., MA, USA) in the ground (Fig. 1). The resolution, accuracy and precision of the optical approach for tibia deformation recording have been assessed previously [15,16]. In detail, the optical system is capable of recording at least 20 μm movement of the retro-reflective markers with high accuracy and repeatability [15]. In terms of deformation angles, the potential recording error, e.g. accuracy of the present optical approach was as low as 0.012°, which was lower than the reported deformation angle by two orders of magnitude [16]. Our previous results also showed that the repeatability of the optical method is approximately 0.04° [14]. With the above-mentioned investigations, the optical method was therefore capable of recording minute tibia deformations in the present study with sufficient performance.

Subject testing and instructions

For the PWB-experiment, an experienced physiotherapist gave instructions and a short training was performed (approximately 15 min). The procedure was conducted in exactly the same way as with patients in everyday clinical practice, including verbal instructions, the use of a bathroom scale and biofeedback with a curve projected to the wall. First, the physiotherapist explained and practiced the use of typical forearm crutches with the subject until he felt comfortable with them, and until the usage was appropriate. Next, an analogue bathroom scale was applied to practice loading of the foot with 10 kg, 20 kg and 50% of body weight, using the forefoot and the rear foot separately for each weight level (Fig. 1). Subjects were asked to gradually progress the weight posed on the foot to develop a feeling for the weight applied, while watching the display of the scale. The next step was to try to reach the three weight levels with the fore and rear foot separately. When this aim was accomplished, participants were asked to make a step onto the scale while using the crutches to learn how much weight they actually put on the scale. Once the participants were able to properly apply all weight levels, and when the physiotherapist felt they were ready for the experiment, testing was started. To make this decision, the physiotherapist was instructed to decide in the same way as in the hospital when instructing patients. Subjects then performed several runs of each of the three different partial loading levels with fore- and rear-foot loading each, and in addition with full weight bearing (minimum number of runs per tested loading level: 3). In each run, participants were asked to accelerate over 3–4 gait cycles, then to achieve contact on the ground force plate and to walk on for at least another 1–2 cycles after touching the plate.

Data processing

The largest peak (GRFpk) was identified in the ground reaction force (GRF) data for each touchdown of the foot. The reported tibia deformations are measurements at the times of largest GRFpk. Ground reaction forces were normalized to body weight and are thus given in *g*. The coefficient of variation (CV) was computed in percent as $100 \times$ SD/mean.