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Loads in the hip joint during physically demanding occupational tasks: A motion analysis study

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ABSTRACT

Epidemiologic studies of osteoarthritis of the hip indicate a possible connection between work related activities and the pathogenesis of the disease. This study investigated the hip joint contact forces for physically demanding occupational tasks (lifting, carrying, transferring of a weight (mass: 25 kg, 40 kg and 50 kg); stair climbing without and with additional load of 25 kg; ladder climbing) and compared these with everyday activities (level gait, sitting down and getting up). The hip joint contact force was calculated with the human multibody simulation software AnyBody employing motion capture and ground reaction force measurements by force plates and an instrumented staircase and ladder. Although the results for 11 male test subjects showed individual variations, a general trend could be observed in regards of force curves' characteristics and maxima. The largest joint contact forces calculated were (637 ± 148)%-body weight for horizontal transfer of a 50 kg weight. For several of the occupational activities the computed hip joint contact forces were significantly larger compared to the investigated examples of activities of daily living. This study provides original data of simulated hip joint contact forces for physically demanding activities.

1. Introduction

Hip osteoarthritis is a disease with detrimental consequences for the musculoskeletal system. Patients experience severe limitations in daily and work life (Bolen et al., 2010). For adults it is one of the leading causes of disability (Chu et al., 2014; Ma et al., 2014) with a prevalence of 10.9% (Pereira et al., 2011). Additionally, osteoarthritis is a socioeconomic burden because of lost workdays (Kotlarz et al., 2010; Piscitelli et al., 2012; Rabenberg, 2013). Several factors (e.g. genetic, metabolic) influence the etiology of arthritis including mechanical stress (also influenced by bony abnormalities) (Felson, 2004). Based on epidemiologic studies a general association between occupational tasks and the development of hip osteoarthritis has been previously suggested (Sulsky et al., 2012) and potentially risk associated occupational activities were identified.

However, little knowledge exists on the mechanical impact of these activities. In vivo data from direct measurement with instrumented prostheses are available for walking, stair climbing, sitting down/getting up and carrying of 24 kg (Bergmann, 2008). An alternative approach for the determination of joint contact forces is their numerical calculation by multibody simulation and inverse dynamics (Damsgaard et al., 2006). Some activities, like sitting down or squatting (Kunze et al., 2012; Weber et al., 2014) and of course level gait, have been simulated by multibody dynamics (Correa et al., 2010; Hornová and Daniel, 2013; Lenaerts et al., 2009; Manders et al., 2008). Different lifting techniques and their muscle activation were investigated but without exploring the hip joint contact forces (Mirakhorlo et al., 2014). The carrying of greater weights as well as ladder climbing have not yet been addressed and none of the previous studies had an occupational background.

This study aims to analyze the hip joint contact force (HJCF) for different occupational activities and compare these to HJCF occurring in everyday activities, hypothesizing that significantly higher forces occur in the work related tasks.

2. Materials and methods

2.1. Design

Motion capture and ground reaction force data of selected occupational and everyday activities were assessed and subsequently used in human multibody simulation to compute HJCF and kinematic parameters.

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2.2. Test persons

11 healthy male individuals without known diseases or pain of the hips were recruited. The test persons obtained detailed information regarding the study and gave their informed written consent. Their average ($\pm$standard deviation) height and weight were (1.81 ± 0.07) m and (91 ± 19) kg, resulting in a mean body mass index of (28 ± 5) kg m^{-2}. The test persons were aged (42 ± 12) years, with (23 ± 12) years of professional experience in blue collar jobs. All activities were performed in working clothes and with safety shoes to be in compliance with safety regulations and to reflect typical working conditions.

2.3. Motion capture

For marker based motion capture a 12 camera Vicon system (M2 cameras, Vicon Motion Systems Ltd., Oxford, GBR) was employed. The ground reaction forces were measured by two force plates (Kistler Instrumente AG, Winterthur, CH). Additionally force plate instrumented staircase and ladder were used to detect reaction forces during one step in the middle of the climb (Kistler Instrumente AG, Winterthur, CH). The Plug-In Gait marker protocol was used (Vicon Motion System Ltd., Oxford, GB). Additional markers were placed on the most lateral points of the iliac crests as redundant points for the pelvis reconstruction. The markers were attached using the Vicon Quick Suit (Vicon Motion System Ltd., Oxford, GB). The Vicon Quick Suit consists of neoprene parts and straps that allow a tight fit to the body, decreasing the movement of the clothing and providing a surface for the markers to be placed upon. The kinematic and kinetic data were stored in C3D-files which were subsequently used for the multibody simulation.

To give an idea about the differences to a test setup where the markers are placed on the skin, preliminary trials conducted without working clothes (in underwear) and without the additional weights were compared to the actual trials. These preliminary trials were conducted by student volunteers ($n = 3$) who were not part of the actual study group. The lifting of 25 kg for the study group, which includes high ranges of motion, was compared to an equivalent squatting motion without the additional weight for the students. The coefficients of variation for the distance between the markers on the right and left iliac crest were determined and considered as a measure of potential inaccuracies resulting from marker placement.

2.4. Activities

The test persons conducted a series of everyday and occupational activities. Each activity was performed three times and the movement execution was self-selected. The occupational activities were as follows:

- lifting, carrying and horizontal load transfer of weights (masses: 25 kg, 40 kg and 50 kg),
- stair climbing (without weight and with a weight (mass: 25 kg)) and
- ladder climbing (angle of 70° and 90°).

A cylinder with interchangeable masses (for a total mass of 25 kg, 40 kg and 50 kg, respectively) was used for all activities which included a weight. This cylinder had two handles aligned symmetrically (180° displacement, 0.4 m distance) with a height of 0.53 m for load transfer and 0.34 m for the other activities involving the weight (lifting, carrying and stair climbing with a weight). A marker was placed on the top of the cylinder to measure the height to which it was raised for lifting, carrying and load transfer.

The lifting activity consisted of picking up a weight from the floor and subsequently putting it down. The weight was lifted similar to a deadlift exercise with extension of legs, hip and back and little flexion in the arms. There was no significant pause between picking up and putting down. The carrying motion constituted of two steps with a weight in both hands. Horizontal load transfer was to pick up the weight placed laterally to one side of the body and subsequently, while keeping the feet in place, to put it down laterally on the other side of the body (Fig. 1). The test persons were required to use their hands for safety and support during ladder climbing.

The maximum resultant HJCF of the work related activities were compared to those of level gait as an example for everyday movement. A second everyday activity was sitting down on and subsequently getting up from a chair. The seat height was adjusted in such a way that approximately 90° knee joint flexion resulted in the seated position. No support (e.g. armrest) was used. For sitting, periods with a contact between buttocks and chair were excluded from calculation. Every activity was performed at self-selected speed. All activities were carried out in a single measurement session in the order they have been mentioned above (i.e. first lifting 25 kg, lifting 40 kg, lifting 50 kg, then load transfer of 25 kg, etc.). Fatigue was not a significant issue because of the test person's physical condition and sufficient resting periods between the different activities (measurement of a single test person took about 5 h). Trials in which the force plates were hit incompletely were excluded. As the test persons were made aware of the force plates this occurred only in approximately one out of 10 trials.

2.5. Multibody simulation

The multibody simulation was conducted with AnyBody Modeling System 6.0.1 (AnyBody Technologies A/S, Aalborg, DK). AnyBody calculates the HJCF based on inverse dynamics and muscle recruitment optimization algorithms. From the model repository version 1.6 the “MocapModel” was employed with its polynomial

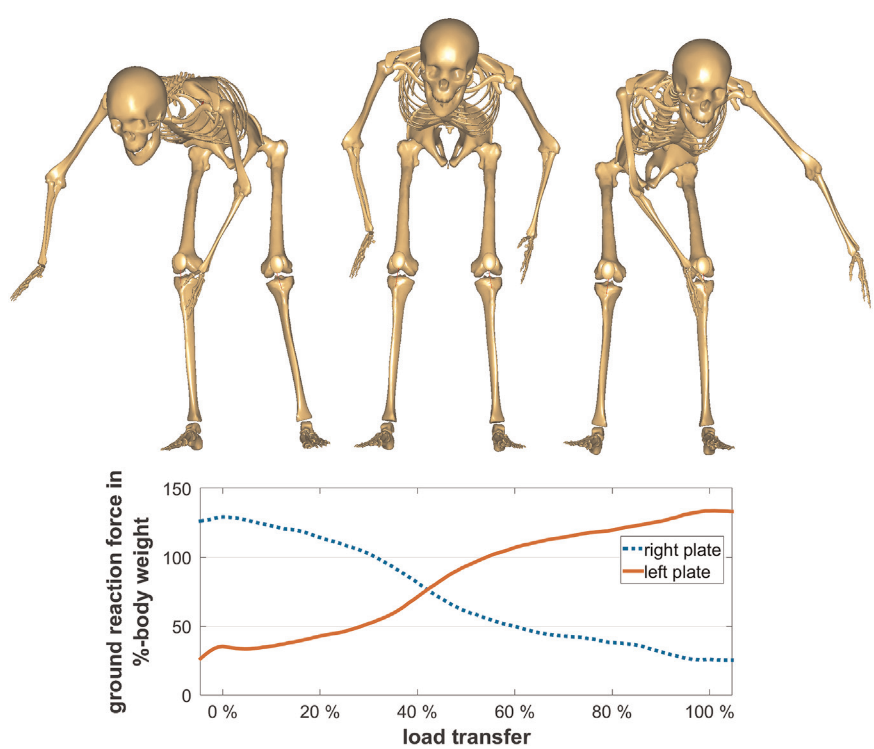

Fig. 1. Horizontal load transfer (without showing the weight for better visibility). The load was transferred from one site to the other in a forward bend posture. The graph shows exemplary data (transfer of 50 kg, single trial of a single test person) for the progression of the vertical ground reaction force for the plates under the right and the left leg in %-body weight.

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