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Effect of compensatory trunk movements on knee and hip joint loading during gait in children with different orthopedic pathologies

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ABSTRACT

Ipsilateral trunk lean toward the affected stance limb has been identified as a compensatory mechanism to unload the hip joint. However, this altered gait pattern increases the lever arm around the knee joint by shifting the ground reaction vector more lateral to the knee joint center, which could be sufficient to deform the lateral compartment of the knee. The purpose of the present study was to show the effect of ipsilateral trunk lean on hip and knee joint moments in the frontal plane in 132 young patients with different orthopedic diagnosis. Linear correlations between ipsilateral trunk lean and the external knee and/or hip adduction moment were detected for patients with Legg–Calvé–Perthes disease (LCPD), arthrogryposis multiplex congenita, myelomeningocele, and unilateral cerebral palsy (CP). In contrast, children with bilateral CP did not show such a relationship due to an increased internal foot placement. In comparison to the hip joint, the effect of ipsilateral trunk lean in patients with LCPD is obviously more pronounced in the knee joint. The valgus thrust of the knee could initiate degenerative changes by placing altered loads on regions of the articular cartilage that were previously conditioned for different load levels. The results suggest that the ipsilateral trunk lean should not be considered and recommended as unloading mechanism for the hip joint on its own but also as a potential increased joint loading of the lateral knee compartment. Therefore, an acceptable therapy concept for limping patients should aim for an inconspicuous gait pattern with a reduced trunk movement.

1. Introduction

Ipsilateral trunk lean toward the affected stance limb (Fig. 1) is a useful substitute for inadequate hip abductors, joint contractures [1] and/or dysfunction of the affected hip [2]. This compensatory gait pattern was first described by Duchenne [2] in patients with paralyzed hip abductor muscles due to poliomyelitis. From a biomechanical point of view, body weight is moved toward the center of the hip joint, which reduces the demand on the weak hip abductor muscles. A recent study has presented a correlation between abductor strength and lateral trunk lean in 375 patients with cerebral palsy (CP) [3]. This suggests that weak hip abductors in patients with CP are accompanied by increased trunk lean to the ipsilateral side.

In addition to neuromuscular considerations, the limping of the hip has been identified as an important compensatory mechanism to unload the hip joint and to relief pain during walking [4–6]. According to Švehlík et al. [5] and Westhoff et al. [6], children with Legg–Calvé–Perthes disease (LCPD) adopted an ipsilateral trunk lean gait pattern with a reduced external hip adduction moment indicating a hip-unloading mechanism. There is also a growing base of knowledge on compensatory angular trunk movements during gait in subjects with osteoarthritis (OA) of the lower limb [7,8]. The ipsilateral trunk lean is considered as a non-invasive intervention for patients suffering from hip pain without a clear indication for surgery [4] or adult patients with medial compartment knee OA [9–11]. Hunt et al. [10] have shown that 13% of the variation in the maximum external knee adduction moment was explained by lateral trunk lean in patients with knee OA. The increased trunk lean reduced medial knee load in a dose–response relationship, with larger lean angles leading to greater reductions in the knee adduction moments [11]. Additionally, Mündermann et al. [12] and Van den Noort et al. [13] have demonstrated that lateral trunk lean has the potential of reducing the knee adduction moment during walking by up to 65% in healthy subjects. Therefore, it appears feasible that older persons [14] and patients with knee OA [15] do adopt a gait pattern that involves increased trunk sway.

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Fig. 1. Ipsilateral trunk lean toward the affected stance limb.

Besides the unloading mechanism for the hip joint and the medial knee compartment of the above described gait pattern, a secondary effect of the ipsilateral trunk lean is valgus of the knee as a result of the laterally displaced weight line. Having in mind that ambulatory load at the knee has been identified as a risk factor for the development and progression of knee OA [16], this could be sufficient to deform the lateral compartment of the knee in young patients with hip abductor weakness or joint contractures. Williams et al. [17] were the first to report that knee OA was present in 24% of their adult myelomeningocele (MMC) patient population. Nevertheless, there is a lack of research on the effect of trunk sway on knee joint loading in young patients without signs of knee OA. Previously published studies investigated the effect of compensatory trunk movements in adult patients [4,7,8,10,11,15] or healthy subjects [9,12–14]. Therefore, the major purpose of the present study was to show the correlation between ipsilateral trunk lean toward the affected stance limb and the knee/hip joint moment in a large group of young children with different pathologies. The second purpose of the present study was to determine kinematic and kinetic differences between patients with natural ipsilateral trunk lean (NTL) and patients with excessive ipsilateral trunk lean (ETL). We hypothesized that ETL might provoke a lateral shift of the ground reaction vector, which could increase lateral tibio-femoral compartment load at the knee joint.

2. Methods

2.1. Subjects

Hip abductor weakness or joint contractures and the resulting ipsilateral trunk lean occur in many types of pathology. This approach was initiated by observations of young patients with a diagnosis of bilateral or unilateral CP, hip disorders (LCPD), congenital joint contractures (arthrogryposis multiplex congenita; AMC), and MMC who were routinely examined in two gait laboratories. A total of 132 patients participated in this multicenter study. Patients were able to walk without assistance or assistive devices. Exclusion criteria were: previous orthopedic surgery in the past two years and morbid obesity with a body mass index $\geq$30. Details on patients' characteristics as well as the prevalence of ipsilateral trunk lean in each patient group are summarized in Table 1.

Twenty typically developed children were recruited as control group (Table 1). None of the control subjects had previously been treated for any clinical spine or lower extremity conditions and none had any activity-restricting medical or musculoskeletal conditions. All subjects and their parents were thoroughly familiarized with the gait analysis protocol. The parents of children provided written informed consent to participate in this study, as approved by the local ethics committee and in accordance with the Helsinki Declaration.

2.2. Data collection

Three-dimensional gait analyses were performed in two different gait laboratories. Comparability between both laboratories was achieved by using the same Vicon motion capture system (VICON Motion Systems, Oxford, UK) operating at a sampling rate of 200 Hz. In both laboratories the level walkway was 15 m long and viewed by eight infrared cameras. AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA, USA) were situated at the mid-point of the walkway to collect kinetic data at 1000 Hz. Prior to the gait analysis, for each subject anthropometric data (Table 1) were collected. The standardized Plug-in-Gait marker set was applied to determine joint centers and kinematic data. Reflective markers were placed on well-defined anatomical points as described in a previous investigation [18] to define the pelvis, thigh, shank, and foot segments. Six additional markers on the left/right shoulder (acromioclavicular joint), clavicle (on the jugular notch where the clavicles meet the sternum), sternum (xiphoid process), C7 (on the spinous process of the 7th cervical vertebra), and T10 (on the spinous process of the 10th thoracic vertebra) were attached to record trunk movements according to an enlarged model, which is part of the VICON software. The consistency between investigators, in particular regarding the marker placement, was achieved by the circumstance that both responsible investigators for the present study