Stress distributions in the proximal femur during gait in healthy and spastic diplegic children
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INTRODUCTION
Cerebral palsy (CP) is a non-progressive neuromuscular motor disorder that affects the motor control of skeletal muscles. Children with spastic diplegic CP walk with an altered gait due to muscle contractures and increased muscle tone. Spastic diplegic gait is often characterized by in-toeing, walking on the toes, and crouching. Children with spastic diplegia also suffer a range of bone deformities including femoral anteverision and coxa valga.

We hypothesize that the altered gait in CP children places extra demand on the muscles, and therefore changes the stress distributions in the femur during walking compared to healthy children.

The objectives of this research were to:
1. estimate femoral muscle loads and contact forces from gait analysis of CP and healthy children;
2. determine how the loading conditions of different gait patterns alter the stresses in the bone.

This research is the first step towards determining the relationship between abnormal gait and bone deformities of the proximal femur.

METHODS
One healthy child and two spastic diplegic children with different gait abnormalities, one with jump knee gait pattern (increased knee flexion at the foot contact with the floor) and one with pelvic rotation and obliquity, were considered for this study.

Three-dimensional gait analysis (Vicon 370 - Vicon Motion Systems, Oxford, UK) was performed for each child to determine ground reaction forces and kinematics. A subject specific child musculoskeletal model was created by scaling a generic adult deformable model. The model included 43 muscles and 16 degrees of freedom and was based on marker positions measured during a static pose. In a first inverse dynamics (SIMUM, MusculoGraphics, Inc., Santa Rosa, CA), kinematics and external forces (ground reaction forces, inertial forces and gravity) from the gait analysis were imposed on the model to estimate joint moments, joint forces, maximal muscle force and muscle moment arms for each muscle over the gait cycle. Muscle activation patterns of 43 muscles were computed over the gait cycle, using a static optimization algorithm, minimizing the sum of the muscle activations [1]. In a second analysis, the muscle forces resulting from the calculated muscle activation patterns, as well as the external forces were imposed and the hip contact forces were calculated.

A three-dimensional finite element model representing the proximal femoral geometry was generated based from the generic adult femoral geometry used in the musculoskeletal model (Rhinoceros, McNeek, Barcelona, Spain; Truegrid, XYZ, Scientific Application, Inc., Livermore, CA) and then scaled down according to each child’s body weight. Cortical (E = 20 GPa, ν = 0.3) and trabecular (E = 500 GPa, ν = 0.3) bone were assumed to be homogeneous, isotropic and linear elastic.

FE analysis was performed for all the children at 10%, 30%, 45% and 70% of gait cycle applying the hip joint contact forces as well as the muscles forces obtained from the musculoskeletal model (Figure 1).

RESULTS
Figure 2 shows the maximum principal stress distribution in a mid-coronal slice through the femur for the three children at the four instances of gait cycle. Because this is a subject specific study, the magnitude of applied loads was different (the children weighed different amounts) and the modeled femurs were different sizes. It is therefore not possible to compare stress magnitude but only stress patterns.

Stress patterns in the femoral neck seem to be quite similar for the healthy and the CP child with a jump knee gait pattern, especially at 30% and 70% of the gait cycle. These children have large compressive stresses on medial side of the neck and large tensile stresses in the lateral side of the neck. Considerably different stress distributions are seen for the CP child with pelvic rotation and obliquity. The femoral neck is mainly in compression at 10% and 30% of gait cycle. At 45% and 70% there are compressive stresses in the medial side and tensile stresses in the lateral side, but the area of compressive stresses is definitely smaller than in the healthy child.

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REFERENCES