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https://doi.org/10.1016/j.gaitpost.2024.07.120

Morphometric analysis of growth-related changes in femoral geometry

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Introduction

Torsional deformities of the femur, common in patients with and without neurological disorders [1,2], can lead to altered gait, increased risk of falls, joint pain, overuse injuries and osteoarthritis [3–6]. Understanding typical growth pattern is essential for clinical assessment of pathological femoral growth [7,8]. So far, most longitudinal evaluations of femoral growth were based on simplified geometrical measures, e.g., anteversion and neck-shaft angle, based on a few ($n < 6$) anatomical landmarks [3,9].

Research Question

Does femoral shape change with size during ontogeny?
Is femoral torsion affected by ontogenetic growth?

Methods

Magnetic resonance images (MRI) of the femur were collected from 10 typically developing children on two occasions, approximately two years apart (age: first session 9.9 ± 0.9 years). For each participant and data collection session, the femoral anteversion (AVA) and neck-shaft angle (NSA) were calculated based on clinical measures from the MRIs [10]. MRIs were segmented using 3Dslicer [11]. On each femur 121 evenly distributed landmarks and semi-landmarks (Fig. 1) were defined and used for geometric morphometric analyses. We used Generalized Procrustes Analyses to obtain centroid size and shape variables [12]. We addressed the research questions using principal components analysis in shape, and form space and regression analyses of shape on size.

Results

During the two-year period, clinical measures showed changes in femoral anteversion and neck-shaft angle from $35 \pm 9^\circ$ to $33 \pm 10^\circ$ and $127 \pm 4^\circ$ to $130 \pm 4^\circ$, respectively. Morphometric analyses revealed a significant relationship between shape and size. A linear model of multivariate regressions explains 12.8% of shape variance ($p = 0.005$) with 1000 permutations. Size differences were highly statistically significant (S1: 1465.5 mm; S2: 1612.2 mm, $p < 0.001$). Shape variation was not very strongly organized by ontogenetic size changes, indicating high inter-individual variation between femurs. Main shape changes (Fig. 1) within the two years included: decrease in the relative anterior-posterior dimension of the lateral condyle and a more curved femoral shaft. Modification of the orientation of the head-neck complex led to a decrease in femoral torsion.

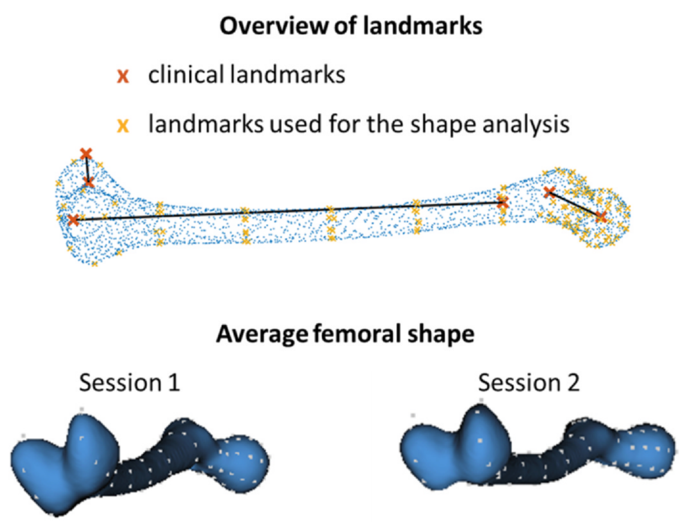

Fig. 1. Overview of landmarks (top subplot) and average femoral shape from the morphometric analysis (bottom subplot).

Discussion

Our results showed that femoral torsion is not simply a mechanical rotation of proximal and distal femur elements along the axis of the shaft, but a complex morphological result of different growth modifications. A recent study [13] showed that some children with cerebral palsy have more bending in the femoral shaft compared to healthy children. Considering that we showed that the shaft curves during growth, the more curved femur in children with cerebral palsy might be caused by modified ontogenetic change of the femur, potentially caused by differences in the biomechanical loading regime [7]. Morphometric analyses in patients might increase our insight in femoral morphology and potentially improve clinical treatment in the future.

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Psychological stress affects trial-to-trial variability of temporal-spatial gait parameters, but not of muscle synergy activation coefficients

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Introduction

The muscle synergy theory posits that a limited set of spatially fixed synergy vectors is activated through central commands – known as activation coefficients [1]. Recent studies showed that the trial-to-trial variability of temporal activation coefficients plays a crucial role in movement control [2, 3].

In everyday life, we face a lot of psychological stressors, commonly induced by situations of social threat [4]. It has been demonstrated that posture and movement are strongly influenced in situations of stress. For instance, acute stress led to freezing gait behaviors [5] and changes of temporal and spatial gait parameters [6]. However, the impact of acute stress on muscle synergies remains uncertain.

Research Question

Is the trial-to-trial variability of temporal-spatial gait parameters and synergy activation coefficients influenced by psychological stress?

Methods

Eight participants (23.7 ± 2.8 years) performed two walking conditions on a treadmill with self-selected and constant velocity in a randomized order: normal walking (NORM) and walking under psychological stress (STRESS). The Paced Auditory Serial Addition Task [7] was employed to induce stress. Electrodermal activity electrodes (Shimmer3 GSR+ Unit) measured tonic skin conductance, force insoles (Novel, Germany) determined foot contacts, and surface electromyography electrodes (Cometa, Italy) recorded the activations of 4–7 muscles on each leg. The participants' stress level was characterized by the averaged z-normalized values of processed (PhysioData Toolbox) tonic skin conductance signals. The stance-phase to gait-cycle ratio was used to determine the temporal-spatial aspect of gait, with the coefficient of variation among steps characterizing trial-to-trial variability. Filtered, rectified, time and amplitude-normalized electromyography signals from both