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Biomechanical changes associated with femoral derotational osteotomy

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ABSTRACT

Torsional deformities of the femur in children may occur as a result of either idiopathic or neuromuscular disorders and may be corrected with derotational osteotomies. Regardless of the underlying etiology, neither the effects of the torsional pathologies nor the alterations resulting from corrective osteotomies are well understood. A study of children with isolated femoral anteversion undergoing a single corrective procedure may assist in understanding the biomechanics of the pathology and the efficacy of surgical correction. A multicenter retrospective study included 25 subjects with idiopathic femoral anteversion who underwent femoral derotational osteotomy and had completed pre and postoperative gait analyses. Both changes with surgery and comparisons to typically developing controls were analyzed. Reduced gait pathology and expected improvements in hip rotation and foot progression were found with derotational osteotomy. Overall gait pathology and pathological differences in pelvic tilt, hip flexion moment and knee adduction moment were found comparing anteversion subjects with typically developing subjects. Following surgery, only hip rotation was significantly and clinically different from typically developing subjects, changing from relatively inward to outward. Idiopathic femoral anteversion creates multifaceted and significant alterations to normal gait and should not be considered solely a cosmetic issue. Additionally, the efficacy of derotational osteotomy is illustrated and may be more broadly applied to other conditions where pathologic femoral anteversion is present.

1. Introduction

Femoral anteversion is a common bony deformity in which the normal alignment of the knee joint axis relative to the hip joint axis is rotated inward due to excessive twist in the femur [1]. Abnormal femoral anteversion may be present secondary to cerebral palsy [2,3], myelomeningocele [4] or Down syndrome [5]. It may also be associated with Perthes' disease [6], flat foot [7], developmental dysplasia of the hip [8] or can occur idiopathically.

Typical gait requires normal alignment of the knee for proper biomechanics of the hip, knee and ankle joints. If transverse plane knee alignment is significantly inward, as can be the case with excessive femoral anteversion, knee flexion and the knee moments are not aligned with the sagittal plane of the body and the direction of progression, thereby creating out of plane motions and forces. The alignment of the foot with the ground can also be compromised resulting in a reduced ankle plantar flexion moment, which also reduces the knee extension moment. In the absence of this functional relationship, knee extension must be augmented by the quadriceps and perhaps hip extensor musculature. In addition to a reduction in knee extensor moment, the malaligned foot may impart abnormal frontal and rotational plane moments about the knee joint [9,10].

Numerous techniques have been employed to measure femoral anteversion, including radiography, CT, MRI, fluoroscopy, ultrasound and physical examination [11–15]. Pathologic femoral anteversion can be corrected surgically by an osteotomy of the femur which may be performed either proximally or distally [16–

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18]. Proximal osteotomies may be performed either at the subtrochanteric or intertrochanteric level [19,20].

While the documentation and pathomechanics of femoral anteversion and outcomes of corrective osteotomies have been studied in cerebral palsy [21,22] and Down syndrome [5], the idiopathic [23,24] population has been less researched. Femoral anteversion tends to be recognized and treated in those individuals with underlying problems and identifiable etiologies because they are more likely to be followed closely by specialists who are aware of the presentation and the association with the primary diagnosis. We believe, however, excessive anteversion is often overlooked when it occurs idiopathically. This population may only seek treatment after lower extremity (hip, knee or ankle) pain has set in.

1.1. Rationale

The current study evaluated subjects with isolated, idiopathic femoral anteversion (IFA). This population allows the effects of the pathology and the changes occurring with femoral derotational osteotomy to be studied without the additional influences of neurological deficits, spasticity, muscle contractures, or concomitant surgeries.

1.2. Aims and hypotheses

The aims of this study are to determine (1) the biomechanical pathology associated with increased femoral anteversion during walking and (2) the biomechanical changes associated with femoral derotational osteotomy (FDRO). We hypothesized that (1) sagittal plane pelvic kinematics, tri-planar hip kinematics, hip flexor and abductor moments, frontal plane knee moments, and ankle power would be significantly different from an age matched typically developing (TD) population. We further hypothesized that (2) each of these variables would show significant changes toward typically developing values following FDRO.

2. Methods

Isolated idiopathic femoral anteversion (IFA) is a relatively rare presentation as a clinical referral for a movement analysis assessment. This may be due to a combination of factors including low prevalence of the disorder, the deformity goes unrecognized or is not considered to be of concern, or that orthopedists treating the condition do not commonly refer this group of subjects for computational gait analysis as the treatment options are clear. Likely a combination of these factors are at play. To identify a sufficient number of subjects for analysis, a multi-center retrospective study was undertaken in three laboratories within the Shriners Hospitals for Children system (Greenville, Salt Lake City and Spokane), each with over fifteen years of clinical data. IRB approval was obtained locally at each site. The database in each laboratory was searched to identify patients with a diagnosis of IFA who had undergone unilateral or bilateral FDRO between the ages of 8 and 18 and had undergone instrumented gait analysis both within 18 months prior to FDRO and within 3 years (36 months) after FDRO. Additionally, after these subjects were identified, only subjects with femoral anteversion confirmed by physical examination reported inward hip rotation of $\geq 60^\circ$ and with tibial torsion $\leq 30^\circ$ outward and $\geq 5^\circ$ inward assessed by goniometric thigh-foot angle [25] were included. This last criterion excluded subjects with miserable malalignment: excessive femoral anteversion combined with excessive tibial torsion. Subjects were excluded if any concomitant surgery occurred or had any history of major lower limb skeletal trauma or orthopaedic procedures other than subsequent removal of FDRO hardware. The three participating labs utilized similar hardware and software (Vicon, Centennial, CO), gait model [26], and data reduction software to compute joint kinematics and kinetics. All sites, including principle investigators, had participated in previous education and training sessions designed to increase reliability between laboratories [27]. Data post-processing was performed in a single lab using custom software to extract variables.

Due to the explorative nature of this research, a number of single time point, average and range of motion parameters were evaluated to investigate the variable profiles under hypothesis. Additionally, the gait deviation index (GDI), a summary metric of nine gait kinematic profiles [28], and a novel scaled and normalized pelvis and hip index which considered the three planes of pelvis and hip kinematics, three planes of hip moments, and hip power was developed using established techniques [29]. Both indices are normalized and scaled such that typically developing control means $\pm$ one standard deviation are 100 ± 10.

Two basic types of statistical comparisons were performed. Both pre- and post-operative data were compared to a set of age matched typically developing children by Student's *t*-tests to assess how increased femoral anteversion alters gait biomechanics and to assess the outcomes of FDRO. Pre-operative data were compared to post-operative data by paired Student's *t*-tests to directly assess the changes that result from FDRO surgery. The exploratory nature of this work involved testing 30 gait parameters along with the two indices. Statistical significance level was set at alpha = 0.05, however clinically meaningful changes were designated as those which both reached statistical significance and exhibited mean changes greater than one standard deviation of the TD cohort.

3. Results

Twenty five subjects (20 females, 5 males) were identified meeting all inclusion and exclusion criteria. Twenty-two subjects had bilateral surgery and three had unilateral, and one limb was excluded due to excessive tibial torsion leaving a total of 46 limbs for analysis. The majority of subjects having bilateral corrections (19/22) underwent single event surgery. The remaining subjects (3/22) had the surgery staged with an average of 6 (4–9) months between procedures. Surgical site of the FDO was generally at the

Table 1
Subject characteristics. BMI centiles computed from http://nccd.cdc.gov/dnpabmi/Calculator.aspx. Inward hip rotation was measured by physical exam with a goniometer or inclinometer. The typically developing population was not measured but normal values are considered to be 45° [25].

	Pre-Op		Post-Op		Typical	
	Mean	SD	Mean	SD	Mean	SD
Age (years + months)	12 + 0	2 + 8	13 + 6	2 + 7	11 + 10	2 + 11
Height (cm)	151.2	13.6	157.3	11.9	149.4	14.9
Weight (kg)	48.4	21.3	55.7	6.8	40.3	13.1
BMI	20.3	6.1	21.8	6.8	17.6	2.8
%BMI	57.0	34.4	59.2	33.7	46.4	30.7
Inward Hip Rotation Physical Exam (deg)	75	10	48	12		