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A Comparison of Three Methods of Measuring Tibial Torsion in Children with Myelomeningocele and Normally Developing Children

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Abstract

INTRODUCTION—Abnormal tibial torsion is a common pediatric problem, and there are many existing measurement methods. The purpose of this study was to compare three methods of measuring tibial torsion for its evaluation: computed tomography, physical examination, and motion capture.

MATERIALS AND METHODS—Twenty healthy children and 20 children with myelomeningocele underwent measures of tibial torsion bilaterally. Measurements were compared using correlation and Bland-Altman plots of the difference between measurements.

RESULTS—All three measurements were moderately correlated in controls ($r = 0.49$, $p = 0.002$) and in patients ($r = 0.51$, $p = 0.001$). In controls, the motion capture measurements were on average 2° more lateral than the clinical measurements whereas motion capture and clinical measurements were 13° and 15° more medial than CT measurements, respectively. Similarly for patients, motion capture measurements were on average 5° more medial than clinical measurements, and motion capture and clinical measurements were 26° and 22° more medial than CT measurements.

CONCLUSIONS—The approximate 20° difference between the clinical or motion capture measures and the CT measure suggests that clinical evaluation identifies different axes than those defined based on skeletal anatomy. Clinical or motion capture methods may be used in lieu of imaging methods for measuring tibial torsion with the knowledge that these methods provide less lateral measurements than measurements obtained using CT.

Keywords

Tomography, X-Ray Computed; Physical Examination; Pediatrics; Meningomyelocele

Introduction

Abnormal tibial torsion is a common problem that may significantly impact muscle lever arms and force production, particularly in patients with neuromuscular disorders such as

cerebral palsy and spina bifida. Measurement of tibial torsion helps to determine the extent of torsional deformity and direct treatment decision-making including the need for derotational osteotomy (Davids and Davis, 2007; Hazlewood et al., 2007; Milner and Soames, 1998). While various methods exist to measure tibial torsion, imaging using computed tomography (CT) or magnetic resonance imaging (MRI) offers the greatest objectivity because it provides three-dimensional (3D) data that allows the determination of appropriate anatomic axes (Eckhoff and Johnson, 1994; Jakob et al., 1980). However, CT and MRI are expensive, inconvenient, may not be readily accessible and, in the case of CT, may not be appropriate for routine clinical use as it requires radiation.

Other methods used to measure tibial torsion include ultrasound and clinical protocols. Ultrasound is an attractive alternative due to its lack of radiation exposure. However, this imaging method still requires special equipment, which may not be readily accessible or cost effective, and ultrasound data are difficult to reconstruct (Butler-Manuel et al., 1992). Several clinical methods that require minimal equipment, making them more practical, are frequently used such as the Staheli and Engel method (Davids and Davis, 2007; Staheli and Engel, 1972); however, clinical methodologies require a high level of expertise to obtain reliable results. Careful positioning of the leg and goniometer is necessary, and individual judgment is relied on for identification of anatomical landmarks to define rotational axes. Consequently, the accuracy and reliability of these clinical measures has been questioned (Davids and Davis, 2007; Lee et al., 2009; Milner and Soames, 1998; Stuberg et al., 1991).

Motion capture provides another alternative method to measure tibial torsion. Motion analysis systems are currently used to measure kinematics and kinetics during walking and other activities (Mündermann et al., 2008; Schache et al., 2006; Stebbins et al., 2006) and can also provide estimates of tibial torsion and other angular offsets based on the placement of skin-mounted markers. Motion capture is safer than CT, as it does not use radiation, but it requires the use of a motion analysis system and is dependent on proper identification of anatomical locations for marker placement. Motion capture measurement of tibial torsion is similar to clinical measurement, except that the torsion angle is automatically calculated rather than requiring goniometric measurement.

Previous studies have compared CT and clinical measures of tibial torsion in children (Lee et al., 2009; Stuberg et al., 1991), but to our knowledge no study has examined the use of motion capture in addition to clinical examination to measure tibial torsion in pediatric patients and typically developing children. Therefore, the purpose of this study was to compare three methods of measuring tibial torsion in children with myelomeningocele and typically developing children: an imaging method using CT, a clinical method based on physical examination, and a computational method using 3D motion capture technology. It was hypothesized that motion capture and clinical methods would produce similar measurements to CT and could therefore be used in lieu of CT methods in pediatric patients.

Methods

Data from 20 typically developing children (14 males, 6 females; ages 6–16 years; mean age 10.8 (SD 2.8) years) and 20 children with myelomeningocele (9 males, 11 females; ages 6–

13 years; mean age 9.9 (SD 2.8) years) were included in this study. Myelomeningocele is the most common and severe form of spina bifida where the spinal column fails to close properly and completely in utero resulting in varying degrees of functional impairment. Children with myelomeningocele often have abnormal lateral tibial torsion, sometimes leading to the need for tibial derotation surgery (Dias et al., 1984). The distribution of lesion levels for the participants with myelomeningocele, based on the International Myelodysplasia Study Group (IMSG) criteria (Wright, 2001), was 4 sacral level, 8 low lumbar level, and 8 mid lumbar level and above. Participants were part of a larger study in which CT, clinical, and motion capture data were being collected. Written informed consent was obtained from participants and guardians, and all protocols were approved by our Institutional Review Board (IRB).

Participants underwent a CT scan of the legs while lying supine. All scans were performed on the same scanner (Philips Gemini GXL, Philips Medical Systems Inc., Cleveland, OH) by the same certified radiology technologist. The scanning parameters (90 kVp, 32 mA, 1 sec rotation time) were set to minimize radiation exposure (estimated to be <0.05 mSv). To measure tibial torsion from the 1 mm axial CT images, the angle was measured between a posterior tibial axis at the proximal tibia and a bimalleolar axis at the distal tibia (Fig. 1). The posterior tibial axis was drawn tangent to the posterior aspect of the tibial plateau, in the first image slice just below the articulating surface of the knee where the tibial plateau was fully visible. The bimalleolar axis was drawn bisecting the medial and lateral malleoli, just above the articulating surface of the ankle where both malleoli were most prominent. Two observers made three measurements each per subject per side, and the average measurement across the two observers was used for comparison with the clinical and motion capture measurements.

For the clinical method, subjects lay prone with the knee flexed to 90° and the ankle in neutral position. Tibial torsion was measured as the angle between a line connecting the centers of the medial and lateral malleoli (transmalleolar axis, TMA) and a line perpendicular to the long axis of the thigh (Fig. 2) (Sankar et al., 2009).

Motion capture measurements were extracted from 3D marker locations recorded (Vicon Motion Systems, Oxford, UK) while subjects stood still with retro-reflective markers placed on four anatomical landmarks: the medial and lateral femoral epicondyles corresponding to the knee flexion axis, and the medial and lateral malleoli at points corresponding to the transmalleolar axis. Vicon Workstation software was used to calculate the angle of the ankle axis projected onto the plane formed by the knee axis and the long axis of the tibia (Fig. 3).

For all measurements, negative values denote lateral rotation and positive values denote medial rotation. Measurements were compared using correlation coefficients and Bland-Altman plots. Bland-Altman plots show the difference between two measurements against the mean of the two measurements, illustrating systematic differences (offsets) between methods and variability in the agreement between methods despite possible offsets (Bland and Altman, 2010). Threshold lines indicate the mean difference between two measures and limits of agreement two standard deviations above and below the mean.

Results

The measurements from the three different methods were moderately correlated for both controls and patients (Table 1). In controls, the strongest correlation was between motion capture and CT, followed by clinical and CT, then clinical and motion capture. For patients, clinical and CT measures had the strongest correlation, followed by clinical and motion capture, then motion capture and CT.

Summary statistics (Table 2) and Bland-Altman plots (Fig. 4) indicated close agreement between the clinical and motion capture measurements, but systematic differences between these measurements and the CT measures. The clinical and motion capture measurements had little offset between them (mean difference 2.1° for controls and -4.8° for patients) whereas both had sizeable offsets with the CT measurements (mean difference 15.0° for clinical and 13.0° for motion capture in controls; 21.6° for clinical and 26.4° for motion capture in patients) (Table 3 and Fig. 4). The 95% limits of agreement were larger for patients than for controls.

Discussion

To our knowledge, this is the first study to report values for tibial torsion in typically developing children and children with myelomeningocele comparing motion capture, clinical, and CT methods. In this study, we found that clinical and motion capture measurements were similar to each other, but differed from the CT measurements by approximately 20° . This discrepancy is consistent with past research. Milner et al. used four clinical methods on cadavers, all of which underestimated lateral rotation compared to direct measurements of the bones (Milner and Soames, 1998). Tamari et al. found that clinical methods differed from true tibial torsion measured with MRI in healthy adults. In particular, the Wynne-Davies' method, which estimates a line parallel to the posterior surface of the tibial condyles for the proximal reference, significantly underestimated lateral rotation by approximately 20° (Tamari et al., 2005).

The difference between the CT and indirect measures is likely due to rotation of the tibia relative to the femur within the knee. Tibial torsion is a physical property of the bone denoting rotation between the proximal and distal ends (as measured using imaging). However, clinical measurements typically assess rotation of the distal tibia relative to the knee flexion axis and therefore includes knee rotation. Knee rotation depends on subject posture (e.g., knee flexed vs. extended, weight bearing vs. non-weight bearing) since the knee does not rotate about a fixed axis (Asano et al., 2005; Churchill et al., 1998; Hollister et al., 1993; Walker et al., 1972). Knee flexion is often accompanied by approximately 20° of medial tibial rotation (Iwaki et al., 2000; Victor et al., 2009), which could explain the difference between the clinical and CT measurements. However, this would not explain the difference between the motion capture and CT measurements, as bearing weight has little effect on knee rotation when the knee is extended (Dyrby and Andriacchi, 2004; Johal et al., 2005; Victor et al., 2009). The main difference is likely due to different definition of the proximal axis, as the functional axis of the knee identified clinically and in motion capture appears to differ from the anatomical axis along the posterior aspect of the tibial plateau by

approximately 20°. This offset needs to be considered when comparing tibial torsion measured using different methods since a 20° difference is clinically significant.

In general, our clinical and CT measurements were consistent with values from previous work. We observed clinical measures ranging from 5–30° lateral (mean 14.9°) for controls and from 10° medial to 40° lateral (mean 14.5° lateral) in patients. Previous studies using goniometric measures in children have reported tibial torsion values ranging from 0–45° lateral for typically developing children (Staheli et al., 1985; Staheli and Engel, 1972; Stuberg et al., 1991). In children with myelomeningocele, previous studies have observed lateral rotation ranging from 25° to 60° and medial rotation ranging from 20° to 90° (Dias et al., 1984; Fraser and Menelaus, 1993). Because tibial torsion increases with age until it peaks in adulthood (Kristiansen et al., 2001; Staheli et al., 1985), our values may vary slightly from other studies due to differences in age. We observed CT measures ranging from 13.1–45.4° lateral (mean 29.9°) in controls and 11.7–67.3° lateral (mean 36.0°) for patients. Previous studies reported average values of approximately 40° for typically developing children (Krishna et al., 1991; Kristiansen et al., 2001) and 55° for children with spina bifida (Joseph et al., 1987). As with Lucareli et al., who measured tibial torsion using motion capture and goniometry in healthy adults, our tibial torsion measures from motion capture were similar to our clinical values (Lucareli et al., 2014).

This study has several limitations. The data were obtained from a larger study in which measures were only taken once, so we could not evaluate repeatability of the motion capture and clinical measurements or the CT image acquisition. Repeatability should be evaluated in future work to determine which methods are most reliable. Also all three methods consider rotation only in the transverse plane. Positioning in the coronal and sagittal planes may affect these measurements, particularly when knee rotation is involved.

In conclusion, clinical or motion capture methods can be used in lieu of imaging methods for measuring tibial torsion, but it is important for clinicians to be aware that these methods provide tibial torsion measurements that are less lateral than measurements obtained using CT likely due to the inclusion of rotation within the knee. Clinical decision-making must therefore be based on consistent methodology, with tibial torsion measurements being evaluated using appropriate normative values obtained using a similar technique.

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Figure 1.

To measure tibial torsion from axial CT images, the angle was measured between the posterior tibial axis at the proximal tibia (dashed line; A) and a bimalleolar axis at the distal tibia (B). *A*: The posterior tibial axis was drawn tangent to the posterior aspect of the tibial plateau, just below the knee. *B*: The bimalleolar axis was drawn bisecting the medial and lateral malleoli, just above the ankle.

Figure 2. Clinical tibial torsion was measured between the line connecting the medial and lateral malleoli and a line perpendicular to the long axis of the thigh.

Figure 3.

For the motion capture measurements, markers were placed on four anatomical landmarks: the medial and lateral femoral epicondyles corresponding to the knee flexion axis, and the medial and lateral malleoli corresponding to the transmalleolar axis. Vicon Workstation software was used to calculate the angular offset between the two axes defined by the knee and ankle markers, indicated by the arc in the transverse and sagittal views.

Figure 4. Bland-Altman plots comparing clinical, motion capture, and CT measurements of tibial torsion for controls (left) and patients (right).

Table 1
Correlation coefficients and p-values between the techniques for patients and controls

		Controls				Patients			
		Clinical		Motion Capture		Clinical		Motion Capture	
		r	p	r	p	r	p	r	p
Motion Capture		0.49	0.002			0.64	<0.001		
	CT	0.63	<0.001	0.65	<0.001	0.79	<0.001	0.51	<0.001

Table 2

Comparison of measurements among the 3 techniques for patients and controls

Method	Controls		Patients	
	Mean (SD)	Range	Mean (SD)	Range
CT	-29.9 (6.9)	-45.4 to -13.1	-36.0 (13.3)	-67.3 to -11.7
Clinical	-14.9 (5.7)	-30.0 to -5.0	-14.5 (11.3)	-40.0 to 10.0
Motion Capture	-16.9 (6.9)	-32.9 to -5.8	-9.7 (13.6)	-42.7 to 17.4

All measurements in degrees

Table 3

Mean difference and limits of agreement from Bland-Altman plots

	Clinical - Motion Capture		Clinical - CT		Motion Capture - CT	
	Mean difference	Limits of agreement	Mean difference	Limits of agreement	Mean difference	Limits of agreement
Controls	2.1	-10.9 to 15.0	15.0	4.0 to 26.0	13.0	1.4 to 24.5
Patients	-4.8	-26.3 to 16.7	21.6	5.3 to 37.9	26.4	-0.2 to 52.9

All measurements in degrees