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A comparison of four in vivo methods of measuring tibial torsion

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ABSTRACT

Tibial torsion, twisting of the tibia about its longitudinal axis, varies during development and early childhood. Knowledge of the normal range of tibial torsion at various ages and its accurate clinical measurement is important in the assessment of the extent of a torsional deformity. To evaluate tibial torsion a reliable technique for its measurement in vivo is therefore required. The aim of this study was to determine which of 4 existing in vivo methods of measuring tibial torsion was the most accurate and had the highest repeatability, by comparing them with direct measurement of the tibia. A wide range of mean values for tibial torsion was observed, using the various techniques, with none of the indirect techniques employed having a strong correlation with direct measurement of tibial torsion. The repeatability of the indirect techniques was observed to be low both in cadavers (n = 4) and the living (n = 3). Since none of the in vivo techniques appear to measure true tibial torsion or be of a reasonable repeatability, alternative easy to use and inexpensive methods need to be developed. Accurate clinical measurement of tibial torsion is important in the assessment of the extent of a torsional deformity. It is recommended that data gained using the methods reviewed here are interpreted with caution.

Key words: Skeleton; tibial torsional deformity.

INTRODUCTION

Tibial torsion was first described by Le Damany (1903); it is the twisting of the tibia about its longitudinal axis, resulting in a change in alignment of the planes of motion of the proximal (knee) and distal (ankle) articulations (Hutter & Scott, 1949). The difference between torsion and rotation has been highlighted by Rosen & Sandick (1955), torsion being described as a twisting in the axis of the same unit, while rotation is a turning of one unit about another.

The degree of tibial torsion varies during development and early childhood. In utero, it is internal (medial), mainly due to the space constraints placed upon the fetus. Derotation occurs after birth so that in the new-born the axes of the knee and ankle are parallel, i.e. torsion is neutral. External torsion then develops during the first few years of life as a firm walking base develops, resulting in an average external (lateral) torsion of 20° in normal adults (Le Damany, 1903).

Knowledge of the normal range of tibial torsion at various ages and its accurate clinical measurement is important in the assessment of the extent of a torsional deformity before corrective surgery is undertaken. Furthermore, the accurate determination of less extreme tibial torsion deformities is important in the evaluation of conditions such as chondromalacia patellae (Butler-Manuel et al. 1992). It is particularly important that tibial torsion can be accurately determined in children, in order to reduce lower-limb rotational defects such as in-toeing and out-toeing in adults. However, the accurate determination of tibial torsion in vivo is relatively difficult as there are no obvious relevant landmarks that can be used as reference points. Consequently, several techniques have been suggested using various mechanical, radiological, computed tomography and ultrasound methods.

To study and evaluate tibial torsion an effective and reliable technique for its measurement in vivo is required. Taking into account factors such as cost,

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ease of use, safety and availability, a review of the relevant literature identified 4 techniques that were appropriate for detailed investigation. The techniques chosen were those developed by Staheli & Engel (1972) and Malekafzali & Wood (1979) to measure tibial torsion, Ritter et al. (1976) to measure tibio-fibular rotation and Staheli et al. (1985) to measure the angle of the transmalleolar axis. The aim of this study was to determine which of these methods was the most accurate and which had the highest repeatability, by comparison with direct measurement of the tibia.

MATERIALS AND METHODS

The following descriptions of the methodology employed are based on the descriptions provided by the investigators whose techniques were used; apparatus was constructed as described by the authors where necessary.

Details of techniques evaluated

In the first technique (Staheli & Engel, 1972) the subject was seated with the thigh directly in front of the hip, the heel placed against a flat vertical backboard and the forefoot held perpendicular to the backboard in both the horizontal and sagittal planes. If forefoot adduction was present, the hindfoot was used as the source of reference. The malleoli were then marked with a pen at the centre of their broadest point. With the heel resting comfortably against the backboard the distance between the mark on each malleolus and the backboard was recorded to the nearest mm. The width of the ankle was then measured to the nearest mm using callipers and the angle of the transmalleolar axis determined by simple trigonometry and not from the conversion grid given by Staheli & Engel (1972).

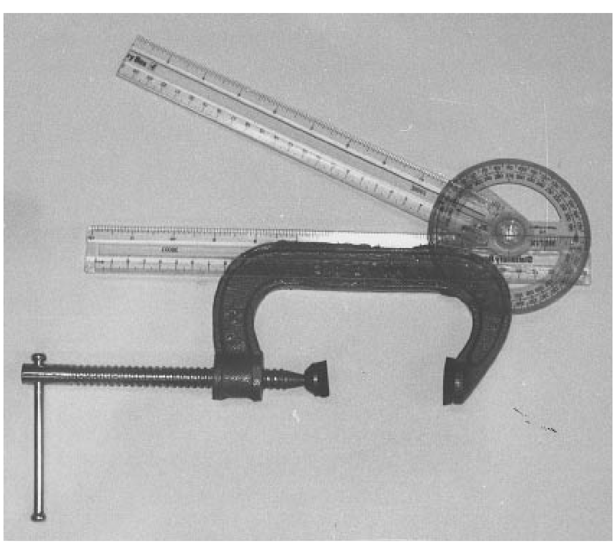

Fig. 1. Apparatus used in technique 2 (Ritter et al. 1976).

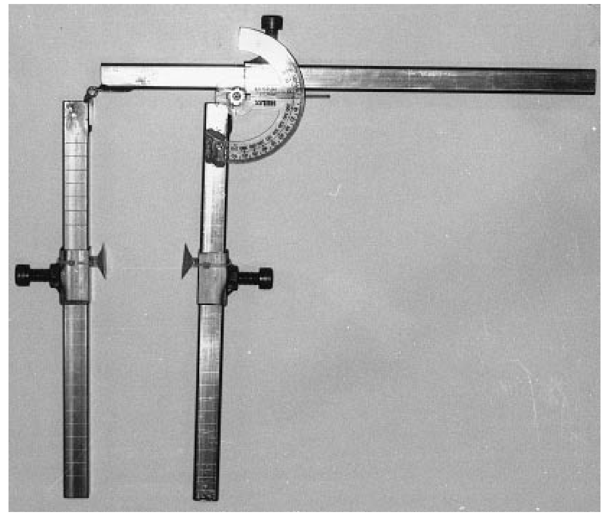

Fig. 2. Apparatus used in technique 3 (Malekafzali & Wood, 1979).

In the second technique (Ritter et al. 1976) the subject lay supine with both the hip and knee each flexed to 90° and the leg in neutral rotation (i.e. with the tibial tubercle pointing directly up and appearing to extend the long axis of the femur). A C-clamp, with a goniometer attached to the long axis of the C (Fig. 1), was placed over the most prominent aspect of each malleolus. The moveable arm of the goniometer was adjusted until it was perpendicular to the long axis of the femur, the angle indicated on the goniometer was then recorded. The angle measured was that between a line passing through the malleoli and a line perpendicular to the long axis of the femur, the latter representing the proximal transverse axis of the tibia.

In the third technique (Malekafzali & Wood, 1979) the measuring apparatus consisted of a goniometer attached to 2 hinged arms, held parallel to each other (Fig. 2). The malleolar cups were placed equidistant from the hinged end of each of the arms; their position being adjustable to accommodate different limb sizes. The A-arm of the goniometer was 'fixed parallel and in congruity with the axis of rotation of the knee joint with the knee in 90° of flexion' (p. 155). This was interpreted as meaning that the A-arm of the goniometer was held parallel to the apparent axis of rotation of the knee joint, determined visually, with the knee flexed to 90° and represented a consistent reference line to the transcondylar axis of the tibia. The malleolar cups were placed over the malleoli, keeping the A-arm in position and the 2 arms parallel

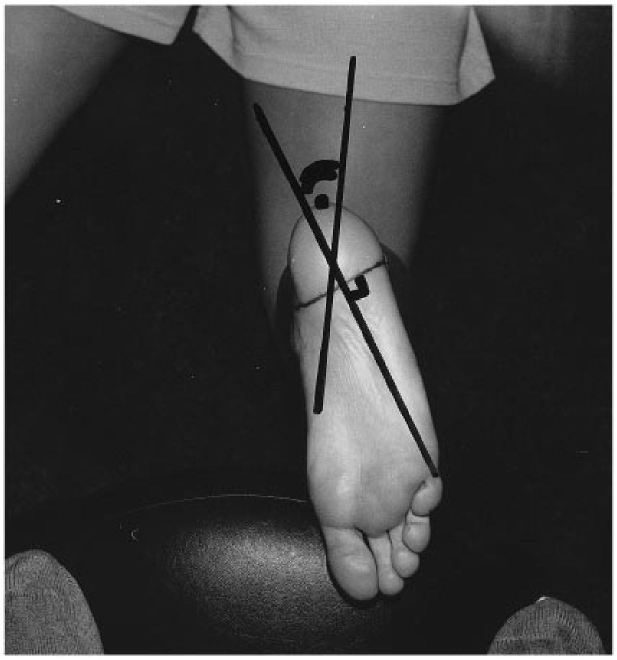

Fig. 3. Position of subject and determination of angle of torsion in technique 4 (Staheli et al. 1985).

to each other. The degree of rotation of the A-limb indicated the angle formed by the intersection of the transmalleolar and transcondylar axes of the tibia; this angle was recorded.

In the final technique used (Staheli et al. 1985) the angle of the transmalleolar axis to a line perpendicular to the long axis of the thigh represented the transverse plane rotation of the tibia. It was measured with the subject lying prone, the knees flexed to 90° and ankle neutral. The centre point of each malleolus was marked and the 2 points joined by a line across the plantar aspect of the heel; this line approximated the transmalleolar axis (Fig. 3). A photograph was taken with the camera positioned above the foot in line with the long axis of the tibia. From the projected photographic negative, the angle between a line perpendicular to the transmalleolar axis and the long axis of the thigh was measured, in-toeing angles being negative and out-toeing angles positive.

Assessment of techniques

Each technique was performed as described once on both lower limbs of 10 cadavers (mean age 84 y, range 66–99 y). Prior to the techniques being carried out the muscles crossing the knee and hip were sectioned to allow unrestricted movement of the limb during measurement. Each of the techniques was then repeated 10 times on both limbs on a random selection of 4 of the cadavers. The order in which the techniques were performed, and also in which the cadavers were measured, was also randomised to reduce any possible effects that the order of measurement may have had. Repeat measurements were made nonconsecutively on the cadavers, with all 4 techniques being carried out on all 4 cadavers before any repeat measures were taken. To eliminate the potential problem of inter-observer error, all measurements were undertaken by the same investigator.

The tibiae were then dissected from the cadavers and the angle of tibial torsion measured directly using the method described by Butler-Manuel et al. (1992). The tibia was placed supine on a flat, horizontal surface, such that it rested proximally on the posterior edge of the tibial plateau and distally on the posterolateral aspect of the tibia. A photograph of the distal end of the tibia was then taken, with the camera positioned with the centre of the lens at the same vertical height as the centre of the distal articular surface and perpendicular to the long axis of the bone. The angle of tibial torsion was calculated as the angle between the distal transverse axis of the tibia and the horizontal. The distal transverse axis was represented by a line joining the 2 points on the posterior tibial border where it turns sharply anteriorly to join (1) the medial malleolus and (2) the lateral tibial border. A line joining the most posterior points of the tibial condyles represented the proximal axis. In the present study the technique was modified to take advantage of advances in technology. Rather than photographing the distal end of the tibia and measuring the angle manually, an image of the distal tibia was captured by a CCD camera linked directly to a PC. The angle of tibial torsion was then determined directly using TAS image analysis software (Aaron et al. 1993), using the same reference points as previously.

To ensure that the bones always had the same orientation with respect to the camera and that the centre of the camera lens was at the same height as the centre of the articular surface, a rig was constructed (Fig. 4). Prior to measuring the tibiae removed from the 10 cadavers, the direct measurement technique was developed using dry bones. To enable the precision of direct measurement to be determined, the technique was repeated 10 times on the tibiae of the same 4 cadavers that had been used to test the repeatability of the other techniques. The data were analysed and the repeatability of the technique determined together with its relationship with the indirect measurements of tibial torsion, i.e. the 4 previous techniques.

To ensure that the use of cadaver limbs was not a limiting factor in the reliability of the different techniques employed, e.g. due to the sectioning of the

Fig. 4. Apparatus used to align the tibia and camera for the direct determination of the angle of tibial torsion.

muscles, all 4 techniques were repeated 10 times on both lower limbs of 3 volunteers. These data were then included in the analysis to determine if there were any significant differences between the reliability of the 2 sets of data. However, data from the in vivo study could only be used to compare the reliability of the indirect techniques with each other and to make comparisons with the cadaver data set.

RESULTS

A wide range of mean values for the torsion measured on the cadavers was observed in the present study using the various direct and indirect measurement techniques (Table 1), highlighting the fact that each technique uses different reference axes in the determination of torsion. The correlation coefficients presented in Table 2 show that none of the indirect techniques employed had a strong correlation with

Table 1. *Mean and standard deviation* (S.D.) *for tibial torsion* (°) *determined using indirect and direct measurement techniques on 10 cadavers* (*n* = 20)

Technique	Mean	S.D.	Range
Indirect			
1. Staheli & Engel (1972)	17	6.35	6–29
2. Ritter et al. (1976)	21	8.63	5–40
3. Malekafzali & Wood (1979)	24	4.05	17–32
4. Staheli et al. (1985)	21	10.51	5–45
Direct			
5. Butler-Manuel et al. (1992)	35	7.42	21–47

Table 2. *Correlation coefficient* (*r*) *between each of the indirect measurement techniques and direct measurement of tibial torsion on 10 cadavers* (*n* = 20)

Technique	r
Staheli & Engel (1972)	0.15
Ritter et al. (1976)	0.48
Malekafzali & Wood (1979)	−0.21
Staheli et al. (1985)	0.33

Table 3. *Coefficient of variation* (*CV*) *for 10 repeated measurements of tibial torsion obtained for each technique in the current study*

Technique	CV	
	Cadavers (n = 8)	In vivo (n = 6)
Indirect		
1. Staheli & Engel (1972)	0.12	0.17
2. Ritter et al. (1976)	0.15	0.14
3. Malekafzali & Wood (1979)	0.23	0.17
4. Staheli et al. (1985)	0.20	0.19
Direct		
5. Butler-Manuel et al. (1992)	0.03	—

Table 4. *Comparison of previously published repeatability (% within 2° of the mean) of the indirect and direct measurement techniques for tibial torsion with those observed in the present study*

Technique	Repeatability (% within 2°)		
	Previously published	This study	
		Cadaver[d]	In vivo[e]
Indirect			
1. Staheli & Engel (1972)	72[a]	46	37
2. Ritter et al. (1976)	92[b]	31	24
3. Malekafzali & Wood (1979)	—[c]	26	33
4. Staheli et al. (1985)	—[f]	21	39
Direct			
5. Butler-Manuel et al. (1992)	—[c]	97	—

[a] 25 pairs repeated twice; [b] 50 pairs repeated twice; [c] no repeats; [d] 4 pairs repeated 10 times; [e] 3 pairs repeated 10 times; [f] repeatability given as standard deviation; 2.16 (compare with 3.4 (cadaver) and 4.8 (in vivo) in present study).

direct measurement of tibial torsion. It can be seen from Tables 3 and 4 that the repeatability of the different indirect techniques was low in the present study, both in cadavers and in the living, much lower than that stated by the authors of some of the indirect methods. The repeatability of the direct measurement technique, however, was excellent (Table 4).

DISCUSSION

The main problems encountered during evaluation of the various techniques employed, except direct measurement, were due to their subjective nature. They relied on individual judgement rather than truly objective criteria in positioning the apparatus on the subject. However, this appears to be unavoidable due to the lack of suitable landmarks on the leg. In addition, the methods used to approximate the proximal and distal axes of the tibia may not be representative. Even with direct measurement of the proximal and distal tibial axes using predetermined anatomical landmarks, considerable variability was observed resulting in a large range of tibial torsion. Nevertheless, the technique employed was highly repeatable.

With all 4 of the indirect techniques, it is assumed that the landmarks used are directly related to tibial torsion. However, no comparisons with direct measurement of torsion had been made. If these assumptions were correct the measurements obtained, if not reflecting the precise degree of tibial torsion, would have at least borne a consistent relationship to direct measurement. This would allow the calculation of true tibial torsion once the relationship were known. If this were the case, a good correlation between the direct measurement of tibial torsion on the cadaveric tibiae and the indirect measurements made would be expected. However, as can be seen from Table 2, the correlation with direct measurement was very low for all of the indirect measurements. This suggests that the indirect techniques either did not measure tibial torsion, but some other angular variable of the lower limb, or provided inconsistent measures. Consequently, these techniques are unsuitable for determining tibial torsion in vivo. This lack of correlation between indirect and more direct methods, where landmarks on the bone itself are used, has also been noted by Joseph et al. (1987).

In all 4 indirect methods the distal axis was approximated by the transmalleolar axis, which may not accurately reflect the tibial axis, due to the influence of the position of the fibular. The proximal axis was either perpendicular to the long axis of the thigh with the leg neutral (Staheli & Engel, 1972; Ritter et al. 1976), parallel to the axis of the knee joint with the limb flexed to 90° (Malekafzali & Wood, 1979), or parallel to the backboard in a horizontal plane (Staheli & Engel, 1972). All these representations of this axis appear reasonable and it might therefore be expected that the results obtained based on them would be highly correlated with the direct measurement of torsion, such that a conversion factor could be applied to determine the degree of true tibial torsion. The poor correlation of the indirect techniques with direct measurement suggests that these representations of the various axes are not consistently related to tibial torsion. The results of this investigation clearly highlight the fact that assumptions cannot be used as the basis for developing a measurement technique without adequate testing.

Comparing the error associated with each of the different techniques employed was difficult as each study calculated this in a different way. An attempt was made to convert the data available to a common form in order to allow more meaningful comparisons both between the different techniques and also between the published errors and those found in this study (Table 3).

The apparent repeatability of the indirect techniques was low, much lower than that stated by the authors in those cases that included repeatability data. Only one technique was found to have a reasonable coefficient of variation in this study: that of Ritter et al. (1976) (15%). The reason why the repeatability was so much lower than expected is unclear. It may be due to the much more rigorous repeatability testing carried out in this study—10 repeats per ankle—compared with only 2 or 3 in the original studies. The smaller number of specimens on which repeat measurements were carried out (8 limbs) would not be expected to contribute to the decrease in repeatability. It is also possible that the investigator (CEM), who performed all measurements, was not sufficiently experienced in the different techniques, although all were practised before data collection began. However, the repeatability of the direct measurement was excellent (3 %), suggesting that sufficient experience of the various techniques had been gained prior to data collection.

The high reliability of the direct measurement technique is almost invariably due to the more objective identification of relevant landmarks that was possible. This is in direct contrast to the indirect methods, which require a certain amount of subjective judgement as to the precise positioning of the apparatus.

In addition, more specific difficulties were encountered with the individual techniques. The conversion grid presented by Staheli & Engel (1972) is incorrect; the angle of torsion was, therefore, calculated by simple trigonometric calculation. Also, it was suggested by Ritter et al. (1976) that only one examiner was necessary to perform the measurement on children up to 2-y-old, however; it was found during this investigation that an assistant was necessary to perform the measurement on adults. It was also relatively difficult by visual examination to be certain when the long arm of the goniometer was perpendicular to the long axis of the thigh. The detail regarding measurement technique provided by Malekafzali & Wood (1979) was minimal, consequently several assumptions had to be made. For example, the A-limb is described as being 'fixed parallel and in congruity with the axis of rotation of the knee joint'. This was interpreted as placing the A-limb parallel to the apparent axis of the knee joint when the knee is flexed to 90°. The A-limb cannot be placed parallel to the true axis of the knee joint as the axis itself is constantly changing throughout its range of motion (Palastanga et al. 1994).

The original aim of this study was to determine which of the 4 indirect methods of measuring tibial torsion was the most accurate and repeatable, by comparing them with direct measurement of the tibia itself. Since none of the in vivo techniques appear to measure true tibial torsion or be of a reasonable repeatability, alternative methods must be developed. It is recommended that data gained using the methods reviewed here be interpreted with caution.

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