Length and torsion of the lower limb

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Corrective osteotomies are often planned and performed on the basis of normal anatomical proportions. We have evaluated the length and torsion of the segments of the lower limb in normal individuals, to analyse the differences between left and right sides, and to provide tolerance figures for both length and torsion.

We used CT on 355 adult patients and measured length and torsion by the Ulm method. We excluded all patients with evidence of trauma, infection, tumour or any congenital disorder.

The mean length of 511 femora was 46.3+/- 6.4 cm (+/-2SD) and of 513 tibiae 36.9 +/- 5.6 cm; the mean total length of 378 lower limbs was 83.2 +/- 11.4 cm with a tibiofemoral ratio of 1 to 1.26 +/- 0.1. The 99th percentile level for length difference in 178 paired femora was 1.2 cm, in 171 paired tibiae 1.0 cm and in 60 paired lower limbs 1.4 cm.

In 505 femora the mean internal torsion was 24.1 +/17.4 deg, and in 504 tibiae the mean external torsion was 34.9 +/- 15.9 deg. For 352 lower limbs the mean external torsion was 9.8 +/- 11.4 deg. The mean torsion angle of right and left femora in individuals did not differ significantly, but mean tibial torsion showed a significant difference between right (36.46 deg of external torsion) and left sides (33.07 deg of external torsion). For the whole legs torsion on the left was 7.5 +/-18.2 deg and 11.8 +/- 18.8 deg, respectively (p

These results will help to plan corrective osteotomies in the lower limbs, and we have re-evaluated the mathematical limits of differences in length and torsion.

Anatomical studies1 of the lower limb have established the regularity of the mechanical axis as proved by clinical and radiological studies.2 The ideal mechanical axis is defined by a line between the centre of the femoral head, the knee and the centre of the ankle. Any deviation from this optimal axis is considered to be pathological.3

The geometry of the leg is difficult to define, partly because of the variable terms used to describe rotation. Torsion is the rotation within a bone segment, and varies according to the method of measurement. Rotation is used to describe the range of movement of joints between the segments.

We could find no clear evaluation or definition of the normal values for length and torsion in adults, and therefore aimed to measure and define them.

MATERIALS AND METHODS

From 1991 to 1995 we used CT on 355 patients to determine the length and torsion of the femur and tibia in healthy volunteers and the normal limbs of patients with unilateral fractures of the femur or tibia. All the limbs were asymptomatic in subjects with no history of trauma, tumour or any congenital disorder. There were 231 men and 124 women. All the women were over 16 years of age (mean 35.8; range 16 to 73) and the men were over 18 years of age (mean 32.3 years; range 18 to 78). We have used CT measurement of length and torsion since 1989. Since the radiation exposure by the Ulm method is less than that for corresponding radiological techniques no ethical approval was necessary.

Informed consent of all patients was obtained as for standard radiographic examinations.

We used a GE 9800 Quick CT (General Electric, Milwaukee, Oregon) with highlight detector. The limbs were fixed by a foot-rest mounted on the table, to provide a reproducible position. A scout view allowed the use of standard planes; angles were measured by a standard software program. The technical details and the radiation doses have been reported by Waidelich, Strecker and Schneider.4 We use standard CT to show the centre of femoral head, the centre of the greater trochanter, the dorsal tangent of the femoral condyles and the tibial head and a line across the ankle. Pfeifer et al5 have reported the reproducibility of the method. Internal torsion is shown by a minus sign (-) and external torsion by a plus sign (+).

Statistical analysis. We used the Winstat V 3.1 program (Kalmia Company Inc, Cambridge, Massachusetts). In case of normal statistical distribution data are given as mean +/- 2SD. Other results were expressed as medians with 95th and 99th percentiles. Differences between groups were analysed using a two-tailed t-test. Statistical significance was set at a 99% confidence level (p

RESULTS

Length

Femur. The mean length of 511 intact adult femora (246 left, 265 right) was 46.31 +/- 6.37 cm (37.2 to 54.1; Fig. Ia). The means of 46.28 +/- 6.34 cm for the left side and 46.36 +/6.39 cm for the right side were not significantly different (p = 0.71).

On 178 healthy paired femora, we evaluated individual differences between left and right sides (Fig. lb), but in the absence of a normal statistical distribution, report the data as medians and percentiles. The difference between medians was 0.3 cm. The between-side difference of length was 0.9 cm at the 95th percentile level and 1.2 cm at the 99th percentile level.

Tibia. The 513 intact tibiae had a mean length of 36.98 +/5.62 cm (29.2 to 43.7) with a normal distribution (Fig. 2a), and there was no significant difference between sides (p = 0.98).

In 171 healthy paired tibiae the difference between sides was similar to that for the femora (Fig. 2b). The median of the differences was 0.3 cm, with a difference of 0.8 cm at the 95th percentile level and 1.0 cm at the 99th percentile level.

Lower limb. The mean length of 378 healthy legs was 83.19 +/- 11.37 cm (67.9 to 96.7) with a normal distribution (Fig. 3a) and no significant difference between sides (p = 0.49).

In 60 pairs of normal legs, the median difference in length was 0.6 cm and the 95th percentile level was 1.1 cm (Fig. 3b).

We calculated the ratio of femoral to tibial length using 205 right and 173 left legs. This was 1.26 +/- 0.1 cm (Fig. 3c); there was a trend for greater length on the right side but no significant difference at the level which we set (p = 0.40).

Torsion

Femur. The torsion of 505 intact femora showed a normal distribution (Fig. 4a). The mean value for 263 rightsided femora was -23.77 +/- 18.27 deg and for 242 left-sided femora -24.46 +/- 16.30 deg. There was no significant difference between the sides (p = 0.37). The overall range was -1 deg to -48 deg.

In 172 healthy paired femora (Fig. 4b), the median of the differences between sides was 4 deg. The difference in torsion was 11 deg at the 95th percentile level and 13 deg at the 99th percentile level.

Tibia. The torsion of 504 intact tibiae gave a mean value +34.85 +/- 15.85 deg and showed a nearly normal distribution (Fig. 5a), with a mean torsion of +36.46 deg for the right tibiae and +33.07 deg for the left. This difference was significant (p

In 176 healthy paired tibiae (Fig. Sb) the difference between sides did not show a normal distribution. The median of the differences was 4.9 deg with 13 deg at the 95th percentile level and 14.3 deg at the 99th percentile level.

Lower limb. We measured the torsion angle of 192 healthy right and 160 left legs (mean 9.82 +/- 18.97 deg) with a normal distribution (Fig. 6a). On the right side the mean angle was +11.79 +/- 18.77 deg and on the left +7.46 +/- 18.10 deg which was a significant difference (p

DISCUSSION

We measured length and torsion using the `Ulm method' as described by Waidelich et al.4 The mean values of the length for all right and all left femora were nearly identical, and the mean values for tibial length did not differ significantly. Our results for femoral-to-tibial ratio confirm those of Mikulicz1 who reported a proportion of 5:4 in 60 lower limbs. This is commonly used as the basis for correction of length in lower limbs.

In individual patients, the relative deviation between sides is important, although the variance from the mean value of torsion is of interest only in patients with bilateral injuries or congenital disorders.6 The inward torsion of the femur does not correlate with the ipsilateral external torsion of the tibia, confirming our earlier results on larger numbers of patients.4,7

The mean torsion of left and right femora differed only slightly, but we found a significant difference in tibial torsion. Right tibiae showed an increased mean external torsion of 3.39 deg compared with left tibiae; this agrees with most published data;7-11 only two studies found no difference between sides.12,13 There were different mean values of leg torsion for right (11.8 deg) and left (7.5 deg) sides, but no correlation between right and left sides has been reported.

In line with Braten et al8 our results show a side-to-side individual tolerance of torsion with a maximum of 15 deg. The same holds true for the femur, the tibia and the whole leg.14,15 Moulton and Upadhyay16 reported a maximum of 6 deg in normal subjects, but they studied only 21 patients.

Both general and local conditions must be considered with the full history of any malalignment before treatment decisions are made. In congenital disorders there is some functional accommodation with time, but this does not occur in adults with post-traumatic abnormalities.17 In our opinion, the indication for lengthening osteotomy for congenital shortening of the femur or tibia is a difference greater than 3 cm. For post-traumatic shortening of the lower limb in adults, our indication for lengthening the limb is a difference in leg length of 1.5 to 2.0 cm. Concerning torsional deformities of the lower limb the indication of corrective osteotomy depends basically not only on absolute or relative deviations of the torsion angles but on the inability of full rotation of the adjacent joints according to the neutral zero method.

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