Lower-Extremity Rotational Problems in Children

NORMAL VALUES TO GUIDE MANAGEMENT

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ABSTRACT: We studied 1,000 normal lower extremities of children and adults in order to establish normal values for the rotational profile. The intraterine position of the fetus molds the femur by rotating it laterally and molds the tibia by rotating it medially. These molding effects usually resolve spontaneously during infancy, and then genetically determined individual differences are unmasked.

Rotational problems should be clinically evaluated and the findings compared with the normal values provided by this study. Out-toeing in infants, medial tibial torsion in toddlers, and medial femoral torsion in young children are extremes of a normal developmental pattern. In the vast majority, these rotational variations fall within the broad range of normal and require no treatment.

Variations and deformities of the lower limbs involving rotation in the transverse plane are associated with many clinical problems, ranging from harmless in-toeing in children to disabling osteoarthritis of the hip in adult patients 10,12,21,34,38.

In the past, rotational problems in the transverse plane have often been ignored because they are difficult to assess. This is in contrast to frontal-plane and sagittal-plane deformities, which are easily visualized and measured on conventional radiographs. These difficulties in assessment have led to varied opinions and controversy regarding the evaluation and management of rotational problems. These problems are likely to attract increasing attention because accurate assessment is now possible using computerized transverse-plane tomography and optical and electronic techniques of motion analysis.

For routine clinical evaluation, physical examination remains the primary method for assessment. To be useful, this examination must include measurements of each limb segment and give acceptably reproducible results that can be compared with an established range of normal values. However, previous studies have failed to meet these requirements 6,7,9,14,16,18,22,23,27,31,33.

The present investigation was designed to establish normal values for the rotational profile 29 by studying 1,000 lower limbs of normal subjects of varying ages. Given this information, the clinician could manage the common rotational problems of childhood with more objectivity, and could quantitatively document deformity in the transverse plane when treating serious problems such as congenital dysplasia of the hip, club foot, and neuromuscular disorders.

In this study, we have used the terminology recommended by the Pediatric Orthopaedic Society 39. Normal is defined as that which occurs within two standard deviations of the mean. Rotational problems with values within the normal range are termed “rotational variations”, and those outside the normal range are referred to as “torsional deformities”.

Materials and Methods

The 1,000 limbs included in this study were both lower extremities of 500 subjects (279 female and 221 male) ranging in age from less than one year to seventy years (Fig. 1). These subjects were white and had no history of musculoskeletal abnormality. They were selected from hospital personnel and siblings of children seen in non-orthopaedic outpatient clinics.

The 500 subjects were divided into twenty-two groups based on chronological age (Fig. 1). The first group comprised infants who were less than one year old. Subjects aged one through fourteen were divided into fourteen groups, one for each chronological age; that is, one-year-olds, two-year-olds, and so on. Subjects fifteen through nineteen years old comprised the next group, while those between twenty and sixty-nine years old were divided into five groups, one for each decade. The final group comprised individuals aged seventy and older. The number of limbs in each group ranged from eighteen to ninety-eight (average, forty-five).

The average for both limbs for each subject was used in all measurements. One of us (M. C.) made the following measurements on each of the 500 subjects.

Foot-progression angle: This was defined as the angular difference between the long axis of the foot and the line of progression. In order to assess it, the subjects dusted their feet with chalk and then walked across the study area on a long strip of paper. We measured the angles of six footprints (three from each limb) and recorded the average for each subject. A plus sign denoted an out-toeing angle and a minus sign, an in-toeing angle. Infants were not measured for foot-progression angle.
Hip rotation: This was measured with the patient prone and the knees flexed to 90 degrees. With the pelvis level, the thighs were rotated to the angle that would be maintained by gravity alone. We photographically recorded the positions of the legs using a camera located distally and directed cephalad in line with the axes of the thighs. Medial and lateral rotations were measured with a goniometer on an eight by ten-inch (twenty by twenty-five-centimeter) negative image projected by a photographic enlarger.

Thigh-foot angle and angle of the transmalleolar axis: These were used to determine transverse-plane rotational variations of the tibia and foot. They were measured with the subject prone, the knees flexed to 90 degrees, and the ankles in neutral position. The center point of each malleolus was marked, and these points were joined by a line across the plantar aspect of the heel. This line was used to approximate the transmalleolar axis. A photograph was made with the camera positioned above each foot and aimed in line with the tibiae. The measurements made from the projected photographic negative were as follows: (1) thigh-foot angle — the angular difference between the axis of the foot and the axis of the thigh, and (2) angle of the transmalleolar axis — the angular difference between a line projected toward the heel at right angles to the transmalleolar axis and the axis of the thigh. In-toeing angles were given negative values and out-toeing angles, positive values.

Intra-Examiner and Inter-Examiner Variability

Standard deviations and mean errors were computed to assess the intra-examiner and inter-examiner variabilities in the measurements of medial and lateral rotation of the hip, thigh-foot angle, and angle of the transmalleolar axis made on the photographic negatives and by direct clinical examination (Table 1).

Intra-examiner variability was assessed by one examiner (a pre-medical student), who made photographic measurements of three subjects (a twenty-seven-year-old man, a twenty-two-year-old man, and a forty-six-year-old woman) on three separate occasions over a two-week period. The average standard deviations, in degrees, for the photographic measurements were 2.07 for medial rotation, 1.52 for lateral rotation, 1.67 for thigh-foot angle, and 2.16 for transmalleolar axis. The over-all average standard deviation, in degrees, for all measurements was 1.86. The mean errors for these measurements were 1.48, 1.11, 1.24, and 1.56 for medial and lateral rotation of the hip, thigh-foot angle, and angle of the transmalleolar axis, respectively.

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<td>Photographic</td>
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<tr>
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<td>Thigh-foot angle</td>
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<tr>
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<tr>
<td>Medial rotation</td>
<td>4.90</td>
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<tr>
<td>Lateral rotation</td>
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<tr>
<td>Thigh-foot angle</td>
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<td>transmalleolar axis</td>
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* Intra-examiner variability in clinical measurements was not investigated.

FIG. 1

Distribution of subjects according to the twenty-two age groups studied. There were no subjects between sixteen and twenty years old in the study population. Subjects who were more than twenty years old were divided into six ten-year age groups, as shown.
Inter-examiner variability was assessed by six examiners (the director of the orthopaedic department, two orthopaedic residents, two medical students, and a pre-medical student). Each of the six examiners measured the medial and lateral rotation of the hip, thigh-foot angle, and transmalleolar axis on the same three subjects (a twenty-seven-month-old girl, an eleven-year-old boy, and a forty-one-year-old woman). In addition, we compared the measurements made on the photographic negatives and during the clinical examinations. Clinical measurements of rotation of the hip were made with a gravity goniometer, and the thigh-foot angle and transmalleolar axis were measured with a protractor. The standard deviations and mean errors for the photographic and clinical measurements are shown in Table I. An F test of equality of variances of the photographic and clinical measurements showed no significant differences (p > 0.05). Thus, inter-examiner variabilities in the photographic and clinical measurements were similar.

Figs. 2-A through 2-F: The five measurements plotted as the mean values plus or minus two standard deviations for each of the twenty-two age groups. The solid lines show the mean changes with age; the shaded areas, the normal ranges; the solid circles, the mean measurements for the different age groups; and the open circles, plus or minus two standard deviations for the same mean measurements.

Fig. 2-A: Foot-progression angle.

Fig. 2-B
Medial rotation of the hip in male subjects.
Findings

Data on male and female subjects were compared for each of the five measurements: foot-progression angle, medial and lateral rotation of the hip, thigh-foot angle, and angle of the transmalleolar axis. Medial rotation of the hip was significantly different (p < 0.05) in male and female subjects. Therefore, separate graphs for medial rotation were prepared, one for each sex. For all other measurements there were no significant differences (p > 0.05) between male and female subjects, and their data were pooled for analysis.

For each of the twenty-two age groups we computed the mean and standard deviation of each of the measurements. These calculations were plotted on graphs (Figs. 2-A through 2-F) showing the means and the points for plus and minus two standard deviations as functions of the mean ages for the twenty-two groups. Smooth lines were drawn through the data points by computing quadratic functions using a non-linear least-squares fitting algorithm.

**Fig. 2-C**
Medial rotation of the hip in female subjects.

**Fig. 2-D**
Lateral rotation of the hip in male and female subjects combined.
Foot-progression angle (Fig. 2-A): This angle was greatest and most variable during infancy. During childhood and adult life it showed little change, with the mean remaining approximately +10 degrees and the normal range being between −3 and +20 degrees.

Medial rotation of the hip (Figs. 2-B and 2-C): Since medial rotation was greater in female than in male subjects by a mean difference of 7 degrees, separate graphs for the sexes were constructed. Medial rotation was greatest in early childhood and then declined throughout later childhood and adulthood. From the middle of childhood on, for male subjects the mean was about 50 degrees and the normal range was from 25 to 65 degrees. For female subjects the mean was about 40 degrees and the normal range was from 15 to 60 degrees.

Lateral rotation of the hip (Fig. 2-D): Unlike medial rotation, lateral rotation of the hip showed no sex-related difference, so all values were pooled. Lateral rotation was greatest during infancy, declined throughout childhood, and then remained relatively constant during adult life. From the middle of childhood on, the mean was about 45 degrees and the normal range was from 25 to 65 degrees.

Thigh-foot angle (Fig. 2-E): This angle increased and became less variable throughout childhood. From the middle
of childhood on, the mean angle remained approximately 10 degrees and the range of normal values was from -5 to 30 degrees.

Angle of the transmalleolar axis (Fig. 2-F): The angle of this axis increased and became slightly less variable with age. The mean angles and the normal ranges of the transmalleolar axis were greater than those of the thigh-foot angle. From the middle of childhood on, the mean approximated 20 degrees and the ranges of normal were from zero to 45 degrees.

Discussion

As shown in Table II, the inter-examiner and intra-examiner variabilities, standard deviations, and mean errors were used to compare the examiner variabilities in the current study with the findings in other reliability studies. The findings in our study compare favorably with the values reported in other studies (Table II). For the inter-examiner variabilities in the present study, the ov-all average standard deviation was within the range of the average standard deviations in other studies (1.0 to 3.7). The mean error values for these variabilities were also within the range of 0.6 to 3.3 found in Low's study. For the inter-examiner variabilities in the current study, the ov-all average standard deviations were within the range reported in other studies (over-all average standard deviations ranging from 2.9 to 8.4), and the mean errors were within the range of 3.3 to 6.3 reported by Low. As would be expected, in the present study the inter-examiner variabilities were greater than the intra-examiner variabilities, a finding that was consistent with those in previous studies.

Table II: Ranges and Averages* for Inter-Examiner and Intra-Examiner Variabilities in Measurement (in Degrees) Determined in This and Other Studies

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<td>Photographic</td>
<td>3.81±4.25</td>
<td>2.65±3.48</td>
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<td></td>
<td>(3.94)</td>
<td>(3.08)</td>
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<tr>
<td>Clinical, over-all</td>
<td>4.90±8.90</td>
<td>3.33±6.78</td>
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<td></td>
<td>(6.48)</td>
<td>(4.91)</td>
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<tr>
<td>Other studies</td>
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<tr>
<td>Ashton et al.†</td>
<td>6.01±1.10</td>
<td>0.21±1.4</td>
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<tr>
<td></td>
<td>(8.40)</td>
<td>(1.0)</td>
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<td>Boone and Azem et al.</td>
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<td></td>
<td>1.5±4.6</td>
<td>0.6±1.4</td>
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<td></td>
<td>(2.9)</td>
<td>(1.0)</td>
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<td>Boone et al. †</td>
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<td></td>
<td>4.4±7.7</td>
<td>3.3±6.3</td>
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<td>(5.6)</td>
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* Averages are in parentheses.

The data for the foot-progression angle in the current study were consistent with those in previous reports. Scrutton and Robson, in their study of fifty normal children, found that in 94 per cent of the children who were one to three years old the mean was +6 degrees and the range was from -5 to +15 degrees, while in the children who were older than four the mean was 4 degrees and the range was from -2 to +12 degrees. Eighteen per cent of these fifty children had in-toeing on one side. Schwartz et al., in a study of adults, found that the mean was between 5 and 9 degrees, with more out-toeing occurring in subjects who were more than sixty years old.

The foot-progression angle may be normal in patients with torsional deformity because medial femoral torsion is often associated with compensating lateral tibial torsion. This association was found by Fabry et al. in 30 per cent of the patients in their series and it was also found by Kobyliansky et al. in their study of dried tibiae and femora from the same limbs.
**Femur**

Our study showed that in early infancy lateral rotation of the femur is greater than medial rotation, but that with advancing age lateral rotation decreases while medial rotation increases (Figs. 2-B, 2-C, and 2-D). The findings in this study were consistent with previous findings for mean values during childhood⁶⁻⁹, 13, 15, 26, but in addition provided a range of normal values. This normal range is great at all ages, with the upper limit of medial rotation being about 65 degrees in male subjects and 60 degrees in female subjects (Figs. 2-B and 2-C). The lower limit of lateral rotation is about 25 degrees for both sexes.

Severity of medial femoral torsion may be graded as follows: *mild* if medial rotation is between 70 and 80 degrees and lateral rotation is between 10 and 20 degrees (two or three standard deviations from the mean), *moderate* if medial rotation is between 80 and 90 degrees and lateral rotation is between zero and 10 degrees (three or four standard deviations), and *severe* if medial rotation is greater than 90 degrees and no lateral rotation is possible (more than four standard deviations). The degree of joint laxity influences these values, and both medial rotation and lateral rotation will be increased in a child with joint laxity.

The relationship between rotation of the hip and radiographically measured femoral anteverision was studied by Staheli et al. ³². A reasonable correlation was found, although other factors, such as acetabular inclination, can affect rotation of the hip.

**Tibia**

Tibial rotation is defined as the relationship between the axis of rotation of the knee and the transmalleolar axis of the tibia. In 1909, le Damany measured the rotation in 100 dried tibiae ³⁳. In the newborn, the average angle of the transmalleolar axis was 4 degrees of medial rotation. Thereafter, lateral rotation gradually increased throughout childhood until the mean rotation was 23 degrees of lateral rotation, with a range of zero to 40 degrees in adults.

Later studies confirmed this early work. Nachlas observed that medial rotation of the tibia is common in the orangutan and gorilla, and suggested that medial tibial torsion is an atavistic variation ³⁵. Hutter and Scott measured forty adult skeletons and found that the mean lateral tibial rotation was 21 degrees on the right and 19 degrees on the left ³⁴. They then studied fifty children, two to three years old, and found that 30 per cent had in-toeing, usually due to medial tibial torsion. The prevalence was 8 to 10 per cent in the five to seven-year age group and 8 to 9 per cent in early adolescence, with a nearly equal sex distribution. They also found that 3 per cent of 200 adults whom they studied showed persistence of significant medial torsion, but this was not defined. They considered this to be a serious problem in about 1 per cent.

Wynne-Davies, using a special caliper to measure tibial rotation in normal adults ³⁶, found that it ranged from zero to 40 degrees of lateral rotation, the mean being 20 degrees. Khermosh et al. studied tibial rotation in 230 children in infancy and early childhood and found that the mean lateral rotation was 2 degrees at birth and 10 degrees at the age of five years ³⁶. Staheli and Engel used a caliper method to survey 160 normal children ³⁷. They found a gradual increase from 5 to 14 degrees of lateral rotation between the ages of one and thirteen years, while Ritter et al. found the increase to be from 4 degrees at birth to 11 degrees at two years ³⁸. Malekafzali and Wood, in 200 adult subjects, found the normal range to be from 7 to 20 degrees of lateral rotation, with a mean of 14 degrees ³⁹.

The current study demonstrated that the angle of the transmalleolar axis and the thigh-foot angle become progressively larger lateral angles throughout growth (Figs. 2-E and 2-F). The findings relative to the angle of the transmalleolar axis were comparable with those found in other studies. From the middle of childhood through adult life,
the normal range is from about zero to 45 degrees of lateral rotation, with a mean of 25 degrees.

The thigh-foot angle is a composite measurement that reflects rotation of both the tibia and the hind part of the foot\(^1\). This angle roughly parallels the angle of the transmalleolar axis, but its mean value is lower (Fig. 3).

The thigh-foot angle is easier to measure than the angle of the transmalleolar axis and is the most practical measurement of the usual torsional deformity. However, for more complex torsional deformities, such as the torsion associated with a club foot, measurements of both the transmalleolar axis and the thigh-foot angle are useful. These measurements clarify the anatomical location of the deformity. Thus, torsional deformity of the tibia is assessed by the angle of the transmalleolar axis; deformity of the hind part of the foot is assessed by the difference between the angle of the transmalleolar axis and the thigh-foot angle; a combined deformity of both the tibia and the hind part of the foot, by the thigh-foot angle; and finally, deformity of the middle and distal portions of the foot, by the difference between the clinical measurements of the hind and fore parts of the foot.

**Foot**

Deformities of the foot were not assessed in this study. The most common foot deformities affecting the rotational profile are metatarsus adductus producing in-toeing and the hypermobile flat foot producing out-toeing.

Lateral rotation caused by eversion of the foot is secondary to joint laxity or muscle imbalance. Such foot deformities are detectable during the physical examination and should be the last entries in the rotational profile.

**Conclusions**

During infancy, the rotational profile appears to be influenced by the effects of intrauterine molding. The hips are flexed and laterally rotated in utero, resulting in greater lateral than medial rotation of the hips and femora. The feet are medially rotated, producing medial rotation of the tibia and sometimes metatarsus adductus. The spontaneous resolution of molding results in equalization of medial and lateral rotation of the hip, lateral rotation of the tibia, and decreasing variability in the foot-progression angle during the second year of life.

Genetic factors effect the rotational profile during early childhood. Medial femoral torsion becomes evident at the age when medial rotation is greatest. Continued lateral rotation of the tibia corrects residual medial tibial-torsion angulation.

During late childhood, medial rotation of the hip diminishes, correcting in-toe due to femoral torsion. Continued lateral rotation of the tibia, however, may aggravate a lateral tibial-torsion deformity. During adult years, the rotational profile is relatively constant except for medial rotation of the hip, which decreases, presumably due to a generalized loss of joint mobility with age.

The graphs showing normal values for the rotational profile of the lower limbs will allow the clinician to determine the location and severity of torsional problems. In the past, many infants and children with normal rotational values were treated with splints, braces, exercises, or even surgery.

Such treatment is both harmful to the child and expensive for the parents.

In evaluating children with torsional deformity, the potential for long-term disability in the absence of treatment and the risks of treatment should be weighed. Non-operative treatments are usually ineffective. Rotational osteotomies of the femur or tibia are effective but are associated with significant complication rates.

**References**