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THE ACCURACY OF ORTHOROENTGENOGRAPHIC MEASUREMENTS

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During the past 20 years orthoroentgenographic methods have been widely employed for accurate measurement of lower extremity length in orthopaedic and paediatric clinics and in anthropometric studies. The method of measurement have been commonly accepted as completely reliable, and attempts to evaluate the accuracy of the method in practical use do not seem to have appeared in the literature.

The accuracy of the measurements is of special interest in scientific evaluation of the results of operative procedures for correcting leg length inequalities. For practical purposes, the term "anisomelia", devised by *Bertelsen* (1955) to cover the Anglo-saxon: "inequality of leg length", will be used, as it is thought to be shorter, more precise and better suited for international use.

Errors in orthoroentgenographic measurement may arise from distortion due to inaccurate focusing over the ends of the measured bones. Film alterations due to shrinkage and to thermal and humidity expansion may play a role. Finally complete immobility between the exposures, and exactly identical positioning of the legs at serial examinations is indispensable for the comparability of the measurements.

Green, Wyatt & Anderson (1946) devised a method for orthoroentgenographic measurement. They compared their results of X-ray measurement to direct measurement in one leg post mortem. The tibial lengths were equal. The femur was 2 mm. shorter on the X-ray than the actual length.

Goldstein & Dreisinger (1950) described a spot-orthoroentgenographic method, where each joint was exposed separately. The error due to distortion was computed to maximum 1.3 per cent. A mean error of 0.25 per cent by storage shrinkage was estimated. Humidity and thermal

expansion was negligeable. It exceeded 0.11 and 0.06 per cent, respectively, only in extreme cases.

These investigators, however, do not pay attention to the most probable sources of error, namely movements between the single exposures in each examination and variations in alignment of the extremities between serial examinations.

OWN MATERIAL

During the 10-year period from 1952 to 1961 orthoroentgenographic examinations were performed on 841 children at the Orthopaedic Hospital in Copenhagen. A modified Goldsten & Dreisinger technique was used: The patient is placed supine on the X-ray table. Hip, knee and ankle-joints are marked on the skin. To secure correct marking a test exposure is made of the hip joints. Thereafter a 40 $\times$ 90 cm. casette is placed under the legs. The feet are tied to a wedge-shaped support placed between the medial borders of the feet to secure a standard slight inward rotation. No further fixation is used.

6 separate exposures are made over the joints of the lower extremities with a tube-to-film distance of 100 cm. Proper focusing on the skin markers is secured by the aid of the light diafragm. No tubus is used.

Femoral and tibial length is measured between tangents—perpendicular to the border of the film—to the top of the femoral head, the lowest point on the medial femoral condyle, and the highest point in the groove lateral to the medial malleolus on the distal tibial joint surface in order to avoid inaccuracy from use of different rulers. The same ruler was used for measurement in all cases.

Among the examinations all those cases were selected, in which two or more measurements had been performed after completion of growth. Two cases were added, which had been measured twice with an interval of 5 days and 7 days, respectively.

In all cases with completed growth, epiphyseal closure was completed at the first of the two pictures. Films were stored and measured under equal conditions.

Two successive measurements of the same patient, in which bone length should theoretically be equal, were thus obtained in 29 patients. In 2 of these cases the femoral length, and in one case the tibial length in the two measurements were not comparable due to surgical interventions between the measurements. This makes it possible to compare femoral length in 52 cases, tibial length in 56 cases, length of single

bones in 108 cases, and length of lhe whole lower extremity in 50 cases. Comparison of two measurements of the anisomelia can be performed in 25 cases, and the difference between single bone pairs in 54 cases.

RESULTS

The results of this investigation are given in Table 1.

Cases, where the second measurement exceeds the first, are given as + variations and vice versa.

The means ($\bar{x}$) do not deviate significantly from zero in any group.

The standard deviations (s_x) are almost equal at femoral and tibial measurements ($\pm$ 1.84 mm. and $\pm$ 1.90 mm.), while the standard deviation between measurements of the whole lower extremity is considerably greater ($\pm$ 2.86 mm.) than at isolated femoral and tibial measurement.

The greatest deviations between measurements of whole lower extremities equal twice the standard deviation ($\pm$ 5.72 mm.). Mean length of the lower extremities in the material was 762 mm. The maximum deviations thus amount to $5.72 \times 100/762 = 0.75$ per cent.

The focusing can be read directly from the film. The inaccuracy of focusing did not exceed 1.5 cm. in any case. From this a maximum error can be computed due to distortion of approximately 1.7 mm. at each end of the femur and proximal end of the tibia, and of approximately 1.0 mm. at the distal end of the tibia.

DISCUSSION

In some cases the errors were greater than the maximal distortion. If inaccurate focusing was a major source of error one should expect greater inaccuracy in femoral than in tibial measurement, as accurate focusing is most difficult, and the object-film distance is greatest at the hip joint. If inaccurate focusing at the knee joint was of major importance for the error, femoral and tibial inaccuracy would be oppositionally directed and therefore diminished when added to give whole lower extremity length.

This investigation, however, showed no difference in accuracy between femoral and tibial measurements and a tendency to addition of deviations on femoral and tibial measurements in whole leg length measurements. As other sources of error such as thermal and humidity expansion have been omitted, these findings seem to indicate that

TABLE 1
Distribution of results.

Diff. between measurements mm.	−6	−5	−4	−3	−2	−1	0	+1	+2	+3	+4	+5	+6	Total nos. obs.	Mean $\bar{x}$ mm.	Standard deviation s^x mm.
Nos. obs. femora	–	1	3	3	6	8	15	7	6	2	–	–	1	52	—0.29	±1.84
Nos. obs. tibiae	–	–	2	4	10	6	13	7	9	2	3	–	–	56	—0.05	±1.90
Nos. obs. single bones	–	1	5	7	16	14	28	14	15	4	3	–	1	108	—0.17	±2.02
Nos. obs. whole lower extrem.	2	1	2	8	6	5	7	6	2	5	5	–	1	50	—0.30	±2.86
Nos. obs. anisomelia	–	–	2	4	2	5	4	3	2	1	–	1	1	25	—0.52	±2.33
Nos. obs. diff. between single pairs of bones	1	–	4	4	8	9	9	7	5	3	1	2	1	54	—0.22	±2.50

movements of the legs between single exposures and inaccuracy of positioning at separate examinations are the major sources of error.

The results of the investigation show that orthoroentgenographic measurement of the lower extremities is sufficiently exact for clinical use. The margin of error should, however, be kept in mind, when scientific results are based upon such methods.

SUMMARY

Orthoroentgenographic double-measurements of the lower extremities without intervening growth were collected from 29 patients. The standard deviations (s_X) between the two measurements were almost equal at femoral and tibia measurements ($\pm$ 1.84 mm. and $\pm$ 1.90 mm.) and considerably greater between measurements of the whole lower extremity ($\pm$ 2.86 mm.).

Movements of the legs between single exposures and inaccuracy of positioning at separate examinations seemed to be the major sources of error.

Orthoroentgenographic measurement is sufficiently exact for clinical use, but the errors may influence scientific results.

RESUME

Une double mensuration orthoradiographique des extrémités inférieures sans qu'une croissance soit intervenue a été enregistrée chez 29 malades. Les déviations standard (s_X) entre les deux mensurations ont été pratiquement égales aux mensurations fémorales et tibiales ($\pm$ 1,84 mm et $\pm$ 1.90 mm) et considérablement plus élevées entre les mensurations de toute l'extrémité inférieure ($\pm$ 2,86 mm.).

Les mouvements des jambes entre les différentes expositions et le manque de précision de la position aux examens séparés semblent être les principales sources d'erreurs.

Les mensurations orthoradiographiques sont suffisamment exactes pour usage clinique, mais les erreurs peuvent exercer une influence sur les résultats scientifiques.

ZUSAMMENFASSUNG

Orthoröntgenographische Doppelmessungen der unteren Gliedmassen ohne intervenierendes Wachstum wurden von 29 Patienten gesammelt. Die Standardabweichungen (s_X) zwischen den beiden Messungen waren

fast die gleichen bei Femur- und Tibiamessungen (± 1,84 mm und ± 1,90 mm) und bedeutend grösser zwischen Messungen der gesamten unteren Gliedmasse (± 2,86 mm.).

Bewegungen der Beine zwischen den einzelnen Belichtungen und Ungenauigkeit der Lagerung bei den unterschiedlichen Belichtungen scheinen die hauptsächlichen Fehlerquellen darzustellen.

Orthoröntgenographische Messung ist hinreichend genau für die klinische Verwendung, aber die Fehlermöglichkeiten können wissenschaftliche Ergebnisse beeinflussen.

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