The straight line graph in limb length inequality

A new design based on 182 Dutch children

Annechien Beumer[1], Harald I H Lampe[1], Bart A Swierstra[1], Ad F M Diepstraten[1] and Paul G H Mulder[2]

Moseley's Straight Line Graph (M-SLG), which is based on growth data obtained in the 1940s and 1950s, is helpful for the timing of physiodesis. We investigated whether current growth data could improve this graph. We estimated growth curves based on recent data on 182 Dutch children, collected between 1979 and 1994, using repeated measure analysis of variance. In both boys and girls, the mean femur and tibia length had increased, when compared to the data collected by Anderson et al. (1964). Based on our growth data, a new straight line graph (Rotterdam Straight Line Graph; R-SLG) was created. Its value was assessed by comparing the difference between the predicted length of the short (i.e., not operated) limb at maturity with the final limb length. In a group of 34 children who underwent physiodesis up to 10 years ago, the R-SLG gave better prediction of limb length at maturity than the M-SLG did in 22 of 34 cases and equal results were obtained in 5 cases. We conclude that our updated SLG can improve the prediction of final limb length and thus also the timing of physiodesis.

Departments of [1]Orthopedics, Sophia Children's Hospital, University Hospital and [2]Epidemiology and Biostatistics, Erasmus University, Rotterdam, The Netherlands. Correspondence: Dr. B.A. Swierstra, Department of Orthopedics, University Hospital Dijkzigt, Dr. Molewaterplein 40, NL-3015 GD, Rotterdam, The Netherlands
Tel +31 10-4639222. Fax-4634611. E-mail: swierstra@ortd.azr.nl
Submitted 95-12-27. Accepted 97-04-22

The result of physiodesis for inequality of limb length (LLI) is determined by the timing of the operation. For that purpose Moseley (1977) developed a straight line graph (M-SLG). The use of M-SLG has been reported by several authors (Timperlake et al. 1991, Dewaele and Fabry 1992, Lampe et al. 1992). Apart from failures not related to the use of M-SLG itself, discussion on the accuracy of this method focuses on the data about which M-SLG was based—i.e., measurements of North American children in the 1940s and 1950s (Anderson et al. 1964). Regional and present-day differences in skeletal maturation (Porat et al. 1991) as well as the tendency of people in industrialized countries to become taller (Van Wieringen 1987) affect the use of M-SLG.

We actualized the straight line graph with recent growth data on Dutch children acquired in our limb length clinic and evaluated it.

Patients and methods

Between 1979 and 1994, 226 children (94 girls) were seen at our limb length clinic. Most of them were followed until maturity. After exclusion of 44 children (12 girls) for various reasons, such as systemic disease or treatment affecting both limbs, abnormalities or operations on both limbs and incomplete measurements, 182 children were included in this study (Table). In every child, length of the normal limb was measured. For example, in case of hemihypertrophy we measured the short limb, and in case of hemihypotrophy we measured the long limb. Measurements were done with orthoradiographs, as described by Taillard (1956). In all children, the femur was measured from the most cranial point of the femoral head to the most distal point of the medial condyle. The tibia was measured from the eminentia intercondylaris medialis to the most proximal point of the talus. Total limb length was measured from the head of the femur to the talus. In total, we performed 596 measurements (280 in girls), mean per child 3.3 (2–14). Skeletal age was determined according to the atlas of Greulich and Pyle (1959), by one of two available radiologists. The limb length was considered as a function of calendar age and skeletal age. Growth curves were estimated with the help of multivariate regression analysis, using Biomedical Computer Programs (BMDP) software (module 5V: unbalanced repeated measure models, with the covariance matrix defined as first-order autoregressive). Using these data, we constructed a new straight line graph (Rotterdam Straight Line Graph, R-SLG), similar to Moseley's (1977) method.

The construction of the straight line graph can be

Etiology of limb length inequality

	All children (n 182)	M-SLG compared to R-SLG (n 34)
Congenital		
proximal femoral focal deficiency	1	
congenital short femur	9	
coxa vara	2	
congenital longitudinal deficiency of the fibula	4	1
congenital longitudinal deficiency of the tibia	1	
posteromedial angulation of the tibia and fibula	7	3
congenital pseudarthrosis of the tibia	1	1
skeletal dysplasia	4	1
congenital dislocated hip	9	3
clubfoot	2	
congenital constriction band syndrome	1	1
Vascular malformations		
popliteal stenosis	1	
Infections		
metaphyseal osteomyelitis of the femur	1	
metaphyseal osteomyelitis of the tibia	1	
septic arthritis of the hip	10	1
septic arthritis of the knee	4	
septic arthritis of the hip and knee	1	
Neurological disorders		
hemiplegia	17	
poliomyelitis	8	
myelocele	1	
Trauma		
fractured femur	6	1
fractured tibia	4	1
fractured femur and tibia	4	3
epiphyseal injuries	2	
Tumor and tumor-like conditions		
multiple exostosis	1	1
Ollier's disease and related disorders	4	
Anisomelia		
hemihypertrophy	11	1
Klippel Trénaunay syndrome	11	3
Beckwith Wiedemann hemiatrophy	2	1
hemiatrophy	16	
Miscellaneous		
Legg-Calvé-Perthes	1	
arthrogryposis	1	
Idiopathic	34	12

explained by the following model. The way in which the mean limb length (L) increases with age (a) is described as:

$L(a) = L_o + s\,F(a)$, with

$L(a)$ = mean limb length at a certain age

L_o = mean limb length at birth

$F(a)$ = a monotonically increasing function of age

s = slope

The formula above represents a straight line (slope s) of the mean limb length with F(a). Hence F(.) can be considered a transformation of the age-axis that distorts distances between adjacent ages on this axis, whilst keeping the ordering intact. This transformation may be nonparametric. (Moseley has chosen s = 1 in M-SLG. For practical reasons, we have chosen s = 0.6 in the R-SLG).

The growth curve of an individual (i) child's limb is denoted as $L_i(a)$ which is defined as: $L_i(a) = C_i L(a)$ with C_i a positive factor typical for an individual child. The mean of the C_i's for all children in a population is 1, describing the mean growth curve L(a). For the individual child, the growth curve ($L_i(a)$) is also drawn as a straight line with a slope of 0.6 but drawn against the C_i F (a)-axis. This C_i F (a)-axis applies to the individual child and is parallel to the mean skeletal age axis (F (a)-axis). This C_i F (a)-axis becomes longer than the F (a)-axis when C_i is larger than 1 (i.e., when the child's normal leg is longer than the mean limb length at a certain skeletal age), the axis becomes shorter when C_i is smaller than 1. The former gives a C_i F (a)-axis that is drawn above the F (a)-axis, whereas the latter is drawn below the F (a)-axis. Hence, for an individual child, the age-axis, which already is transformed by transformation F(.) is also rescaled by a factor C_i (Figure 1).

The actual slope of the skeletal age lines in the nomogram is unimportant, it is the relative slope of these lines to the others that is important. The line that is located most to the right is the maturity line. This line is placed at a slope of 1 to reduce errors in drawing both horizontal and vertical lines to it. The other lines are placed in a way that the ratio of its X-coordinate to the X-coordinate of the maturity line at the same Y-coordinate is equal to the proportion of adult growth achieved by that skeletal age as derived from the mean values in the tables of Anderson et al. (1964) for boys and girls. In other words, if the maturity line slope is 1 ($X = 1, Y = 1$), then a skeletal age line with a slope of 1.4 ($X = 0.7, Y = 1$) shows that given a specific skeletal age, 70% of the total growth of the limb is achieved.

The mean differences in skeletal lengths between the Dutch population and that described by Anderson et al. (1964) were compared by means of a t-test ($p < 0.05$ significant). The differences in skeletal age at the

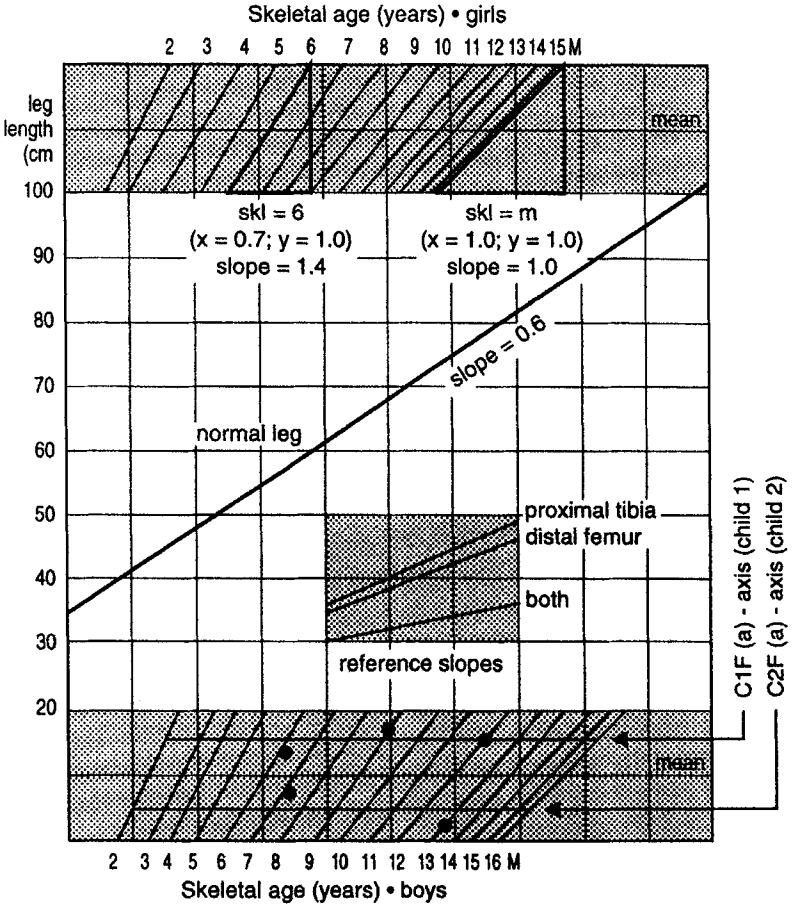

Figure 1. The Rotterdam Straight Line Graph, for explanation see text.

various calendar ages were compared with a Z-test having the same significance.

To compare the value of the R-SLG with M-SLG, the length of the short limb (not always a normal limb) at maturity was predicted with the help of both R-SLG and M-SLG in 34 of the 182 patients. These 34 children (14 girls) underwent physiodesis up to 10 years ago (Table). 17 patients were also included in a former study (Lampe et al. 1992). The time of the prediction was just after the last measurement before physiodesis. Measurements were always done with orthoradiographs. When using M-SLG, total limb length was calculated by adding lengths of femur and tibia; when using R-SLG, total limb length was calculated by measuring the length from the femoral head to the talus. The mean number of radiographic measurements was 4 (2–8). The two methods were compared by calculating the difference between predicted and final limb lengths (paired t-test).

Results

At most ages, Dutch children had longer femora and tibiae than in the data of Anderson et al. (1964). This increase was statistically significant for the femur in girls aged 8–9 years and in boys aged 10–15 years, and for the tibia in girls aged 6–16 years and in boys aged 6–16 years. In both sexes, the length of the tibia increased more than that of the femur (Figure 2). Although not significant, in general the mean skeletal age was slightly lower than the mean calendar age, except for girls between 9 and 11 years (Figure 3). With these data, we created the R-SLG, as shown in Figure 1.

Prediction of the short limb length at maturity with the R-SLG was statistically significant better than with M-SLG. The mean difference between M-SLG and R-SLG was 1.0 cm (95% confidence interval 0.5/1.5 cm). Better results were obtained in 8 of 14 girls and 14 of 20 boys, equal results were obtained in 2 girls and 3 boys (Figure 4).

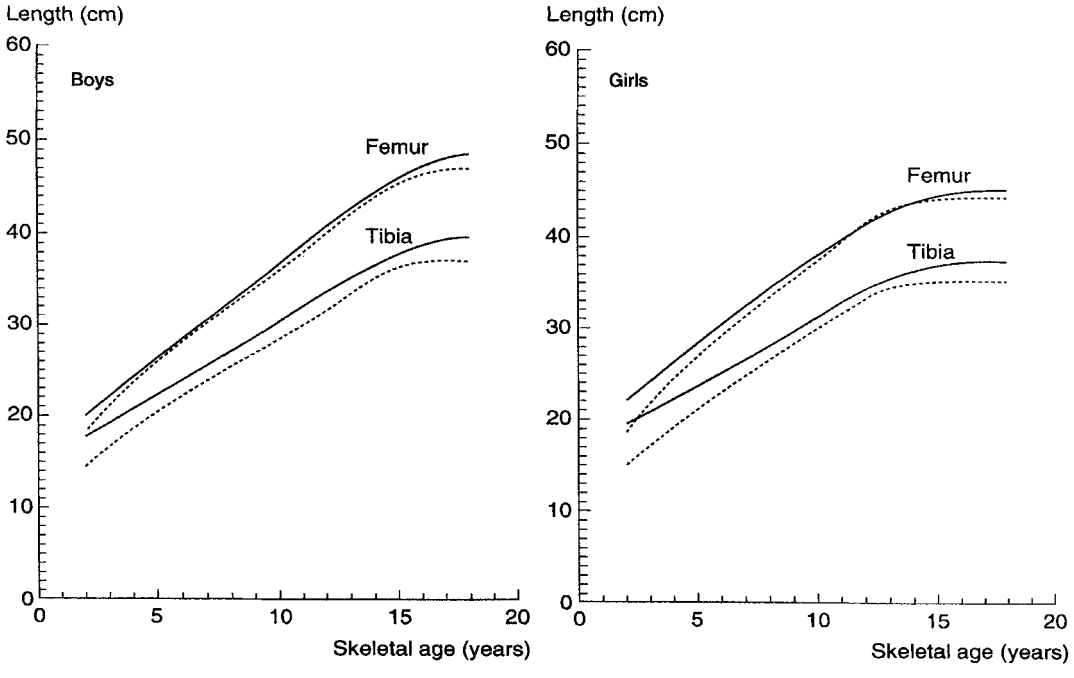

Figure 2. Lengths of femur and tibia. Dutch data (——) compared to those of Anderson et al. (- - -; 1964).

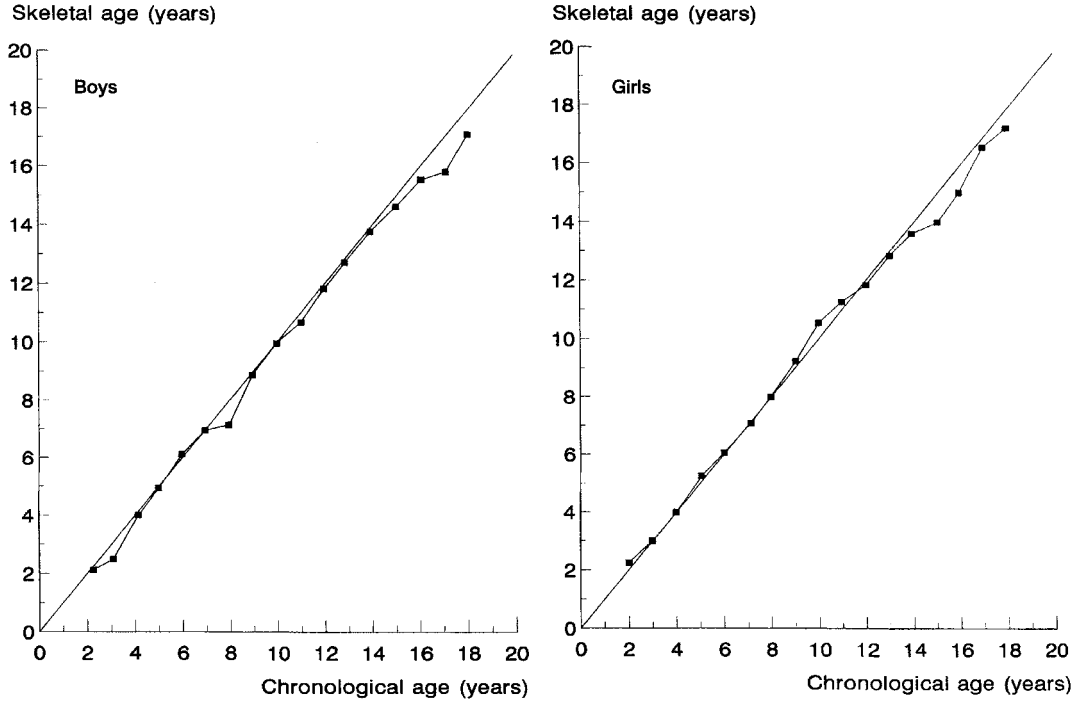

Figure 3. Mean skeletal age versus calendar age in Dutch children.

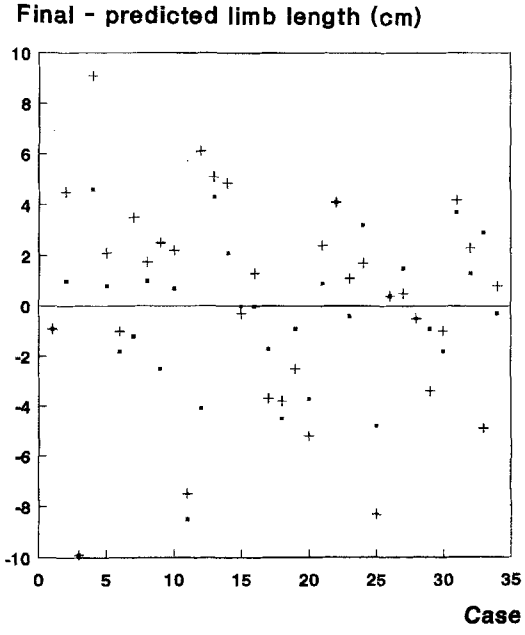

Figure 4. Difference (cm) between final and predicted length of the short limb at maturity for + M-SLG and • R-SLG.

Discussion

The consequences of the secular trend are illustrated by the differences we found in the length of the femur and tibia of Dutch children and those measured by Anderson et al. (1964). Some differences exist in measurement technique. The most important is the use of teleroentgenography by Anderson et al. (1964) in younger children. The enlargement factor caused by teleroentgenography (although used with mathematical correction) might have led to overestimation, and in any case less accurate measurement of length of the tibia and femur in younger children. The differences in limb length in young children, as found in our study and that of Anderson et al., are therefore underlined. Furthermore, small differences exist as regards the points of reference with use of orthoradiography. We believe that these do not explain the differences found in length of the femur and tibia but are a result of the secular trend. Therefore we created a new straight line graph. The problem of points of reference will probably also be encountered by future investigators, who choose other measurement techniques, such as computer tomography or ultrasound.

The graphic method, the straight line graph created by Moseley (1977), was based on the growth data of Anderson et al. (1964), to predict final LLI and to determine the limb length at which physiodesis should be performed. This method is based on two concepts. First, growth of the limb is represented by a straight line after rescaling the abscissa by means of an 'empiric transformation', a nonparametric transformation independent of the nature of the data involved. Secondly, the growth percentile of the child is taken into account in determining limb length at maturity, by means of an age nomogram.

There are several differences between the R-SLG and M-SLG. In the R-SLG, total limb length is measured from the femoral head to the talus, instead of the sum of the femur and tibia lengths, as in M-SLG. In M-SLG this results in relatively longer limb length at younger ages than at older ages, because there is an overlap between the femur and tibia on radiographs at older ages. M-SLG therefore tends to predict limb length longer than that achieved. Because the overlap is the same for both limbs, it does not affect the prediction of LLI by either M-SLG or R-SLG.

Another difference is the primary use of skeletal age in the R-SLG, as mean skeletal age seemed to differ from mean calendar age in our population, although not significantly. When Anderson et al. presented their data in 1964, calendar age might have been considered the same as skeletal age. Some differences already existed in those days and were also noted by Little et al. (1996). The assumption made in the construction of M-SLG, which is based on the data of Anderson et al. (1964), of calendar age being equal to skeletal age might thus be a possible source of error. With the primary use of skeletal age in the R-SLG, we further eliminated age-related errors in M-SLG.

Finally, in the R-SLG, a different slope (0.6) was chosen than in M-SLG (1.0) for the straight line, presenting growth of the long limb. This was done by an adaptation of the abscissa to facilitate its use. The reference lines, representing growth after physiodesis, have been adjusted accordingly.

The better results in the prediction of final limb length with R-SLG, as compared to M-SLG, reflect the necessity to update the growth data on which M-SLG is based. It may thus help to improve timing of physiodesis.

With the adaptations mentioned above, we believe we have improved M-SLG for use in our clinic. However, this method may not be superior in a population different from ours. The same is probably true of M-SLG, but this did not prevent its widespread use. However, despite the use of an "optimal straight line graph", changes in the pattern of maturation, due to increasing deceleration of growth, inaccuracy in determining skeletal age or manual drawing of the lines in a straight line graph, may reduce the accuracy of this method (Green and Anderson 1957, Blair et al. 1982, Cundy et al. 1988, Lampe et al. 1992).

References

Anderson M T, Messner M B, Green W T. Distributions of lengths of the normal femur and tibia in children from one to eighteen years of age. J Bone Joint Surg (Am) 1964; 46: 1197-202.

Blair V P, Walker S J, Sheridan J, Schoenecker P L. Epiphysiodesis: a problem of timing. J Pediatr Orthop 1982; 2: 281-4.

Cundy P, Paterson D, Morris L, Foster B. Skeletal age estimation in leg length discrepancy. J Pediatr Orthop 1988; 8: 513-5.

Dewaele J, Fabry G. The timing of epiphysiodesis. A comparative study between the use of the method of Anderson and Green and the Moseley chart. Acta Orthop Belg 1992; 58: 43-7.

Green W T, Anderson M. Epiphysial arrest for the correction of discrepancies in length of the lower extremities. J Bone Joint Surg (Am) 1957; 39: 853-72.

Greulich W, Pyle S I. Radiographic atlas of skeletal development of the hand and wrist. Stanford University Press, Stanford, 2nd ed, 1959.

Lampe H I H, Swierstra B A, Diepstraten A F M. Timing of physiodesis in limb length inequality. Acta Ortop Scand 1992; 63: 672-4.

Little D G, Nigo L, Aiona M D. Deficiencies of current methods for the timing of epiphysiodesis. J Pediatr Orthop 1996; 16: 173-9.

Moseley C F. A straight line graph for leg length discrepancies. J Bone Joint Surg (Am) 1977; 59: 74-9.

Porat S, Peyser A, Robin G C. Equalization of lower limbs by epiphysiodesis: results of treatment. J Pediatr Orthop 1991; 11: 442-8.

Taillard W. Die röntgenologischen Methoden Zur Messung der langen Röhrenknochen. Z Orthop 1956: 88: 151-8.

Timperlake R W, Bowen J R, Guille J T, Ho Choi I. Prospective evaluation of fifty-three consecutive percutaneous epiphysiodeses of the distal femur and proximal tibia and fibula. J Pediatr Orthop 1991; 11: 350-7.

Van Wieringen J C. Secular growth changes. In: Human growth (Eds. Falkner F, Tanner J M). Plenum Press, New York, 1987; 2; 445-73.