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Balimore Group Simplifies Leg Length Prediction

Prediction of Limb Length Discrepancy Using a Simple Mathematical Formula

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Limb length discrepancy (LLD) in children is generally progressive until skeletal maturity. Treatment considerations depend on the predicted LLD at skeletal maturity (LLDsm). Shapiro identified five different patterns of progression of LLD in children. Current methods of prediction of LLDsm are only applicable to the

Shapiro type one linear progression method. LLD of types 2-5 has periods of acceleration or deceleration of progression of the LLD and therefore cannot be predicted.

The current method of predicting LLDsm for Shapiro type 1 is based on the longitudinal data of Green and Anderson. This data gives the length of the femur and tibia from age 1 to skeletal maturity for the 5th to the 95th percentiles. Prediction of length with this data is based on the comparison between the predicted length of the long leg versus the short leg at skeletal maturity. The length of the normally growing long femur and tibia at present is extrapolated to give the predicted length at skeletal maturity. The predicted length is determined by following the growth curve to skeletal maturity along the percentile of the individual. For leg length discrepancies present at birth the predicted length of the short leg is determined based on the assumption that the percentage growth inhibition remains the same until skeletal maturity. For Shapiro type 1 conditions that do not have LLD present at birth (e.g.- growth arrest, polio), LLD prediction is based on the difference between the predicted length of the long leg at skeletal maturity LLsm and the predicted length of the legs at the age of onset of the LLD and the subsequent rate of inhibition.

A refinement of the Green and Anderson method is the Moseley graph which employs the same data presented graphically for extrapolation of the length of the long and short legs. The advantage of the Moseley method is for long term follow up of LLD and as a good method to record progression. It allows for refinement of prediction since the percentile of the patient is not just based on one measurement. Both the Green and Anderson and the Moseley methods require the availability of the tables and graph respectively. Neither method can be used for children under one year of age and therefore prediction in the first year or two of life is difficult. The purpose of this study is to develop a simple mathematical.

To create a single equation that represents the lower limb growth curve would require a complex exponential function. Since the growth rate remains fairly linear during the three intervals outlined above three separate linear formulae could be derived to approximate the femoral and tibial growth from birth to skeletal maturity. The assumptions used to derive these formulae are that femoral and tibial growth ceases at skeletal age 14 in girls and 16 in boys (based on the Green and Anderson data). Growth continues until the end of the 1 4th and 1 6th year respectively in girls and boys but the growth rate in the last two years is only half that previously. Therefore by considering growth completed by skeletal age 14 and 16 the last year of growth 13-14 & 15-16 is equivalent to the amount of growth

that occurs between skeletal age 13-15 in girls and 15-17 in boys respectively.

The Green and Anderson data displays Skeletal Age (SA) on the x-axis and femur and tibia length on the y-axis. A linear relationship between SA and Limb Length (LL) (femur + tibia length) can be written as LL = mSA + b(y=mx + b). Knowing two points on the line (SA=3, LL= 1/2 LLsm) & (SA=14, LL=LLsm) for girls and (SA=3, LL= 1/2 LLsm) & (SA=l4, LLD=LLsm) for boys the equation can be solved. The formula for girls skeletal age 3 through 14 is:

$$LLsm = 22\ LL/\ SA + 8.$$

The formula for boys skeletal age 4 through l6 is:

$$LLsm = 24\ LL/\ SA + 8.$$

The same analysis is carried out for girls and boys aged 1-3 and 1-4 respectively. The two points on the line are line (SA=l, LL= 1/3 LLsm) & (SA=3, LL=l/2 LLsm) for girls and (SA=l, LL= 1/3 LLsm) & (SA=4, LL=l /2LLsm) for boys. The formula for girls skeletal age 1 through 3 is:

$$LLsm = 12\ LL/\ SA + 3$$

The formula for boys skeletal age 1 through 4 is:

$$LLsm = 18\ LL/\ SA + 5.$$

The same analysis is carried out for girls and boys aged 0-1. The two points on the line are line (SA=O, LLD= 1/4 LLDsm) & (SA=1, LLD=1/3 LLDsm) for girls and boys. The formula for girls and boys skeletal age O through 1 is:

$$LLDsm = 12\ LLD/\ SA + 3.$$

The formula for girls aged 0-1 is the same as for girls aged 1-3 indicating that the growth rate in girls between age 0-3 can be represented by a single straight line equation.

Application of the equations for the prediction of LLD

Prediction of LLD using the equations can only be done if one assumes that the increase in LLD is directly proportional to the increase in leg length until skeletal maturity. These types of LLD conform to Shapiro's type 1 pattern. They can be classified into two types: type 1a) LLD developed in utero present at birth; type lb) LLD developed after birth. Prediction of LLDsm in type 1a can be done by changing the variable LL in all the equations to LLD (present limb length discrepancy) and the variable LLsm to LLDsm. The LLDsm can be calculated directly from the formulae for type 1a LLD. For boys and girls at birth or age 1 the LLD can be multiplied by 4 or 3 respectively to quickly calculate the predicted LLDsm. The LLD at age 3 in girls and 4 in boys can be multiplied by 2 to calculate the predicted LLDsm.

Type 1b LLD is not present at birth. It is therefore necessary to know the age of onset of the LLD. This is usually known for conditions such as post traumatic growth arrest or polio. The formulae are used to calculate the predicted length of the long leg at skeletal maturity and the predicted length of both legs at the age of onset of the LLD condition. The difference between the two is the limb length growth remaining that was effected by the growth inhibition (LLgr). To calculate the LLDsm the percentage inhibition needs to be known. This can be calculated by knowing the percentage of lower limb growth from an individual growth plate in the case of a growth arrest. Alternatively the percent inhibition can be calculated from bilateral lower limb length measurements carried out at two different time intervals. The LLDsm is calculated as the product of the percentage inhibition and LLgr.

Accuracy of Prediction

To be useful the formulae should be as accurate as Green and Anderson and the Moseley method of LLD prediction. We compared the predicted LLDsm obtained using the formulae and the Moseley method. It was not necessary to do the same with the Green and Anderson method since the Moseley method gives the same result. The assumption was made that the skeletal age of the patient remained in the same percentile all throughout growth. Therefore if a patients long leg length line intersected the skeletal age line at the 50th percentile then the patients predicted long leg length was determined by line extended from the skeletal maturity skeletal age line at the 50th percentile. In this manner the Moseley graph could be used to predict LLDsm from a single measurement of LLD. We checked the predilection for various percentiles ranging from 5th to 95th. We found that

formula method produced the same result as the Moseley graph. We can therefore conclude that this method is as accurate as the Moseley and Green & Anderson methods for prediction of LLDsm based on a single LLD measurement.

Clinical Applicability

Most LLD are treated from a young age by limb lengthening, amputation and prosthetic fitting, or at an older age by epiphyseodesis. Very few ever reach skeletal maturity without intervention. We were therefore unable to test the accuracy of prediction in patients. Such testing has also not been carried out for the other methods although they are accepted as accurate methods for prediction of LLD. The limiting factor for accuracy is the single data point and not the formula itself. As with the other methods the more data points that are available over a longer period of time the more accurate the prediction can be.

With the advent of limb lengthening more patients are undergoing lengthening at young ages frequently before they have 3 to 4 measurements of LLD performed at different skeletal ages. The formula method allows a quick calculation of the predicted LLDsm at the time of the initial consultation without having to leave the room and look for the Moseley or Green & Anderson graphs. This is very convenient to the clinician and very impressive to the patient. We have found it a very handy tool for predicting LLDsm and thereby planning our limb length equalization strategy.

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