RESEARCH ARTICLE

A Method of Time Prediction in Epiphysiodesis for Limb Length Discrepancy Based On Multiplier

Reza Abdi, MD; Omid Shahpari, MD; Farshid Bagheri, MD; Ramin Zargarbashi, MD

Research performed at Orthopedic Research Center, Ghaem Hospital, Mashhad University of Medical Sciences, Mashhad, Iran

Received: 27 August 2022 *Accepted: 4 September 2023*

Abstract

Objectives: The most critical step in the calculation of final limb length discrepancy (LLD) is estimating the length of the short limb after skeletal maturity(Sm). Paley's multiplier method is a fast, convenient method for calculating Sm and LLD after skeletal maturity; nonetheless, the calculation of the process of Sm and LLD in acquired type cases is complex in contrast to congenital type in this method. Notwithstanding, the multiplier method uses a variable called "growth inhibition" for the calculation process in acquired type LLD; however, its mathematical proof has not been published yet. The present study aims to find out whether there is an alternative way to estimate the length of Sm and LLD in skeletal maturity without using growth inhibition (GI) and its complex calculation process in acquired type LLD.

Methods: We used trigonometric equations to prove the GI concept and conducted proportionality analysis to calculate the length of short limbs and LLD in skeletal maturity without using GI.

Results: Based on the results, the following proportionality can estimate the length of the short limb in skeletal maturity. ($\Delta Lm/\Delta L = \Delta Sm/\Delta S$)

Conclusion: The GI concept can be proved trigonometrically; nonetheless, its numerical value is not necessary for estimating the length of the short limb in skeletal maturity. Instead, a simple proportionality analysis serves the purpose of calculation.

Level of evidence: II

Keywords: Limb length discrepancy, Method skeletal maturity, Paley's multiplier

Introduction

Before the full growth span, epiphysiodesis of normal limbs is the treatment of choice for children suffering from a predictable 2 to 5-centimeter LLD in skeletal maturity. Nevertheless, short limb lengthening is recommended for larger discrepancies.[1,2] Therefore, the precise estimation of LLD in skeletal maturity is a basic prerequisite for deciding whether to lengthen the short limb or use epiphysiodesis of a normal limb at the appropriate time. Paley's Multiplier Method is a convenient approach to estimating LLD in skeletal maturity by using one multiplier table and chronological age.[3,4] The multiplier method uses the GI variable in its calculation process of Sm and LLD; however, the mathematical basis of the GI has not been published yet; moreover, the calculation of GI and its related formula is difficult to understand and memorize. To address this problem, we proved the GI concept by relying on trigonometric tools. Alternatively, we introduced a simple proportionality in the multiplier method to calculate Sm and LLD without the need for calculating GI.

Materials and Methods

Based on Paley's multiplier method, limb length discrepancies are divided into two categories: congenital and developmental.4 One measurement of the limb length in the congenital type and two measurements of limb length in the developmental type are prerequisites for calculating the final LLD (Δm). However, as Paley et al. recommended, the

Corresponding Author: Omid Shahpari, Orthopedic Research Center, Ghaem Hospital, Mashhad University of Medical Sciences, Mashhad, Iran

Email: omidshahparidr@gmail.com

THE ONLINE VERSION OF THIS ARTICLE ABJS.MUMS.AC.IR

results will be more precise if the calculation process in the congenital type is carried out as the developmental type.[4] the following basic variables must be measured in congenital and developmental limb length discrepancy.

Congenital type

L: Current length of normal limb
S: Current length of short limb
Lm: Estimated length of normal limb in skeletal maturity
Sm: Estimated length of short limb in skeletal maturity
M: Multiplier Coefficient, the value extracted from the table for each specific age

Developmental type

We need two consequent limb length measurements, 8-12 months apart.
L': Previous (first-time measurement) length of normal limb
S': Previous (first-time measurement) length of short limb
L: Current length (second time measurement) of normal limb
S: Current length (second time measurement) of short limb
Lm: Estimated length of normal limb in skeletal maturity
Sm: Estimated length of the short limb in skeletal maturity
M: Multiplier Coefficient, the value extracted from the table for each specific age
ΔLm=Lm-L, ΔL=L-L'
ΔSM=Sm-S, ΔS=S-S'

The calculating process of the length of a normal limb in the skeletal maturity (Lm) in both types of LLD is the same (Lm=M*L) [4]. Nonetheless, the calculating process of the short limb (Sm) is different in congenital versus developmental LLD.[4,5]

Trigonometric proof for calculating Sm in congenital type

The tangent of an angle is defined as the ratio between the adjacent side and the opposite side of a right triangle containing that angle. The starting point of discrepancy (Σ point) is located on the zero point of the time-axis (X-Axis) in congenital LLD [Figure 1]. The growth slop of the two limbs is different (α ≠β); however, the growth ratio (coefficient of proportionality) called multiplier is constant for both limbs.
(Lm/L=Sm/S=M, Lm=M*L, Sm=M*S)

Trigonometric proof for the estimation of Sm is demonstrated in Figure 1. Sm can be calculated by using the following proportionality [Figure 2].
Lm/L=Sm/S

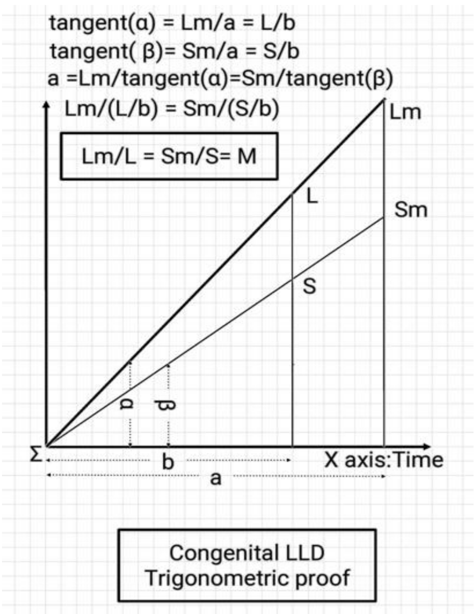

Figure 1. Trigonometric proof in congenital LLD

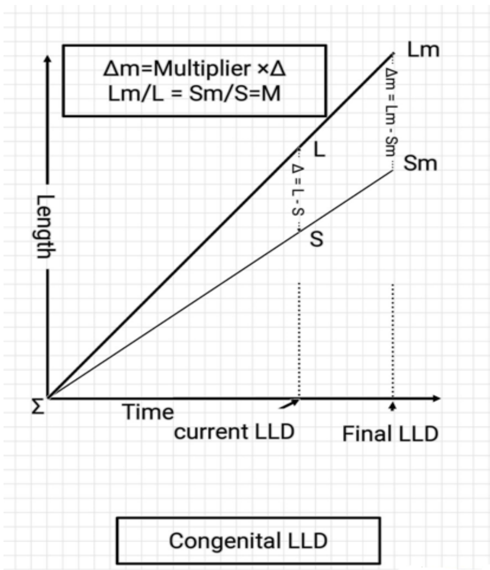

Figure 2. Calculation of LLD in congenital type

Trigonometric proof for calculating Sm in developmental type

The starting point of discrepancy (Σ point) lies somewhere on the normal limb growth curve [Figure 3]. Therefore, we cannot accurately measure the length of a short limb after skeletal maturity (Sm) by merely using the multiplier factor (M). It means that Sm≠M*S is in developmental LLD. Trigonometric proof for the estimation of Sm is demonstrated in Figure 3. The calculation process of Sm actually does not need the complex formula of GI. We can predict the length of the short limb in skeletal maturity (Sm) by applying a simple mathematical proportionality [Figure 4].
(Lm-L)/ (L- L') = (Sm-S)/(S- S') OR ΔLm/ΔL = ΔSm/ΔS

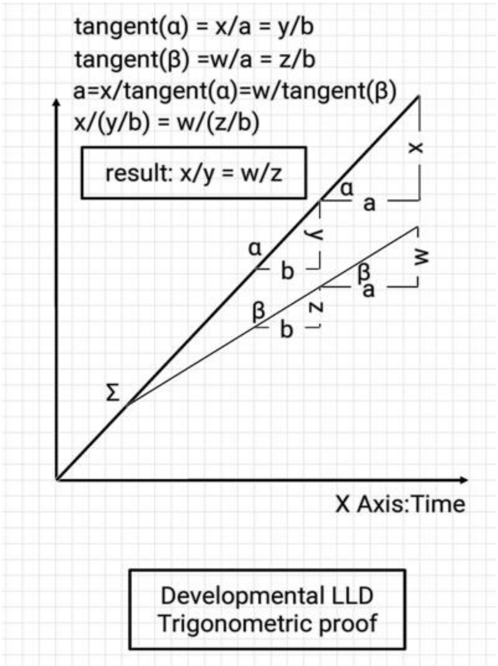

Figure 3. Trigonometric proof in developmental LLD

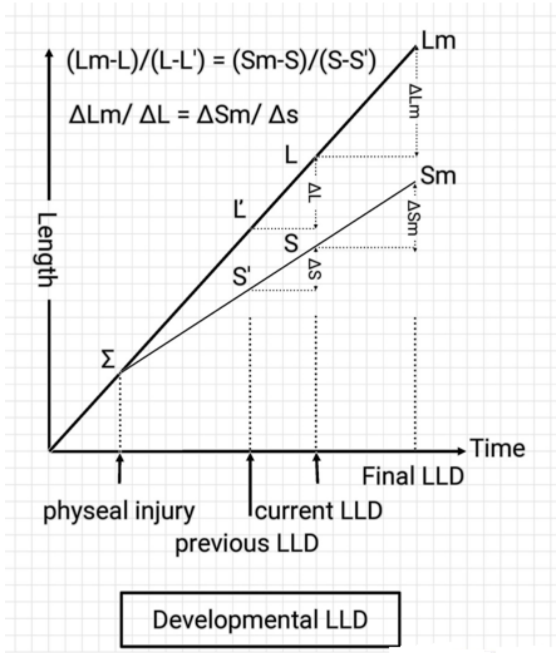

Figure 4. Calculation of LLD in developmental type

This is an example extracted from the original article on the multiplier method

"An eight-year-old girl has a limb-length discrepancy of 2.7 centimeters due to distal femoral growth arrest following trauma three years earlier. The current length of the normal femur (L) is 28 centimeters, and the length of the normal femur one year ago (L') was 26 centimeters. The current length of the short femur (S) is 25.3 centimeters, and the length of the short femur one year ago (S') was 24.4 centimeters. The multiplier for eight-year-old girls is 1.33. The amount of growth remaining in the normal femur is G=L (M–1) =28(1.33–1) =9.2 centimeters. The amount of growth in the normal femur during the previous year was (L–L') =28–26=2 centimeters, and the amount of growth in the short femur during the previous year was (S– S') = 25.3 – 24.4 = 0.9 centimeter. Therefore, the growth inhibition (GI) can be calculated as I=1–(S–S')/ (L–L') =1–(0.9/2) =0.55. The discrepancy in the amount of growth remaining is Δg = I×G = 0.55×9.2 = 5.1 centimeters. Therefore, the total predicted limb-length discrepancy is Δm = Δ + Δg = 2.7+ 5.1 = 7.8 centimeters." [4] It is believed that the above calculation is really complex. We can solve the example by following proportionality [Table 1].

(ΔLm/ΔL = ΔSm/ΔS)

(37.24-28)/ (28-26) = (Sm-25.3)/ (25.3-24.4)

So Sm=29.45

Δm=Lm-Sm=37.24-29.45=7.79≃7.8 (original number)

Finally, the following calculation process of time prediction of epiphysiodesis is derived from Paley's original article. After calculating Lm and Sm, the right time for the epiphysiodesis of the normal limb can be similarly estimated in both congenital and developmental types.

Table 1. Calculation of the long and short limb lengths by proportionality (Paley's original article example)

Previous length	Current length	Maturation length
L'=26	L=28	Lm=M*L=1.33*28=37.24
S'=24.4	S=25.3	Sm=? Sm can be extracted by **ΔLm/ΔL = ΔSm/ΔS** Sm=S+ ΔSm

Results

In our approach, the following steps should be considered:

The desired length of the normal limb after skeletal maturity is equal to Sm.

1. All variables (Lm, Sm, L, S, L', S,' ΔLm, ΔSm) are related to the length of specific bone, such as femur or tibia in isolated femoral or tibial epiphysiodesis; however, in total epiphysiodesis around the knee, they are related to the total length of the femur plus tibia.

2. Le = length of the normal limb in the age of epiphysiodesis
3. 71% of the total femoral growth occurs at the distal femoral physis, and 57% of the total tibial growth occurs at the proximal tibial physis.
4. Disappeared amount of limb length after epiphysiodesis of normal limb is illustrated by Gf (femur epiphysiodesis), Gt (tibia epiphysiodesis), and Gft (total knee epiphysiodesis).
5. If epiphysiodesis of normal distal femoral physis is accomplished in the time point of Le, %71 of the remaining normal femoral growth will disappear. (Gf=%71*[Lm-Le])
6. If epiphysiodesis of normal proximal tibial physis is accomplished in the time point of Le, %57 of the remaining normal tibial growth will be disappeared. (Gt=%57*[Lm-Le])
7. If epiphysiodesis of distal femoral physis and proximal tibial physis is accomplished in the time point of Le simultaneously, %67 of the remaining normal total growth will disappear. (Gft=%67*[Lm-Le])

Although Paley et al. did not explain %67 of the total growth of the lower limb provided by physis around the knee, it is used by multiplier mobile application.[4-7]

8. The desired length of both limbs after epiphysiodesis of normal limb is equal to Sm. [Table 2]
9. After calculating Le by the middle column, the multiplier specific to the age of epiphysiodesis (Mε) will be achieved by the third column.
10. Finally, we can check the multiplier table to obtain the value of (Mε) and determine the age corresponding to this multiplier value retrogradely.

Table 2. Calculation of multiplier in the age of epiphysiodesis (Mε)

Location of epiphysiodesis	The aim of this column is extraction of the final length of the normal limb is equal to Sm that it can be extracted by ΔLm/ΔL = ΔSm/ΔS Sm=S+ ΔSm	Multiplier Coefficient in the age of Epiphysiodesis (Mε)
Distal Femoral	Sm= Lm-%71*[Lm-Le]	Mε =Lm/Le
Proximal Tibial	Sm= Lm-%57*[Lm-Le]	Mε =Lm/Le
Both bone	Sm= Lm-%67*[Lm-Le]	Mε =Lm/Le

Discussion

There are different methods for calculating the time of epiphysiodesis and LLD in skeletal maturity, including the Green and Anderson chart method(1963), Menelaus Method (1966), Moseley Straight-Line Graph (1977), and Paley Multiplier Method (2000).[2,4,8-11] Although the most popular tool for predicting LLD is the Moseley straight-line graph, the multiplier method can predict LLD in skeletal maturity precisely.3,4 The multiplier method can estimate LLD by using one multiplier table and chronological age precisely. However, Eltayeby et al. believe that it has a tendency to underestimate LLD.[12,13] Moseley defined the GI concept for the first time in 1977 and proposed the growth ratio of short limb (growth-slop of short limb) as constant compared to normal limb before skeletal maturity, when both charts are linear.[8,9] He defined GI by the following formula:

GI = (Growth of long leg – Growth of short leg) / Growth of long leg *100

Moseley stated that the formula is provable mathematically; however, he did not prove it. [9] In addition, he did not use the numerical value of GI since his method was based on drawing charts and lines. Thereafter, Paley used the numerical value of the growth inhibition variable in the multiplier method by means of the following formula:

Growth inhibition (GI) = 1–(S–S')/ (L–L')

L, L', S, and S' stand for the length of normal and short limbs in two consequent measurements, respectively.[4] The formula was a simple form of Moseley's formula, whereas by using Paley's multiplier method, we need to calculate the numerical value of GI for the estimation of the LLD in maturity in developmental LLD. It is complicated to explain how the GI variable affects the final length of the short limb. Probably, the complexity of the GI variable leads to the innovation of mobile applications. Furthermore, other researchers present more complex formulas.[14,15] Therefore, based on Paley's multiplier method and Moseley's GI concept, we redefined the calculation process of the length of the short limb in skeletal maturity (Sm) without GI calculation in developmental LLD.

Conclusion

The most critical step in the calculation process of LLD after skeletal maturity is estimating the length of the short limb (Sm). Although the GI concept presented by Moseley and the numerical calculation of GI by Paley's method is important, the numerical calculation of the growth inhibition is unnecessary in the multiplier method. Therefore, estimating the length of the short limb in skeletal maturity can be performed using the following simple proportionality. (ΔLm/ΔL = ΔSm/ΔS)

Acknowledgement

Not applicable

Conflict of interest: None
Funding: None

Reza Abdi MD [1]
Omid Shahpari MD [1]
Farshid Bagheri MD [1]
Ramin Zargarbashi MD [2]

1 Orthopedic Research Center, Ghaem Hospital, Mashhad University of Medical Sciences, Mashhad, Iran

2 Tehran University of Medical Sciences, Tehran, Iran

References

1. Monier BC, Aronsson DD, Sun M. Percutaneous epiphysiodesis using transphyseal screws for limb-length discrepancies: high variability among growth predictor models. J Child Orthop. 2015; 9(5):403-410. doi: 10.1007/s11832-015-0687-3.
2. Ruzbarsky JJ, Goodbody C, Dodwell E. Closing the growth plate: a review of indications and surgical options. Curr Opin Pediatr. 2017; 29(1):80-86. doi: 10.1097/MOP.0000000000000438.
3. Aguilar JA, Paley D, Paley J, et al. Clinical validation of the multiplier method for predicting limb length discrepancy and outcome of epiphysiodesis, part II. J Pediatr Orthop. 2005; 25(2):192-196. doi: 10.1097/01.bpo.0000150808.90052.7c.
4. Paley D, Bhave A, Herzenberg JE, Bowen JR. Multiplier method for predicting limb-length discrepancy. J Bone Joint Surg Am.2000; 82(10):1432-1446. doi: 10.2106/00004623-200010000-00010.
5. Lamm BM, Paley D, Kurland DB, Matz AL, Herzenberg JE. Multiplier method for predicting adult foot length. J Pediatr Orthop. 2006; 26(4):444-448. doi: 10.1097/01.bpo.0000226274.63083.38.
6. Hubbard EW, Liu RW, Iobst CA. Understanding Skeletal Growth and Predicting Limb-Length Inequality in Pediatric Patients. J Am Acad Orthop Surg. 2019; 27(9):312-319. doi: 10.5435/JAAOS-D-18-00143.
7. Makarov MR, Jackson TJ, Smith CM, Jo CH, Birch JG. Timing of Epiphysiodesis to Correct Leg-Length Discrepancy: A Comparison of Prediction Methods. J Bone Joint Surg Am. 2018; 100(14):1217-1222. doi: 10.2106/JBJS.17.01380.
8. Moseley CF. A straight-line graph for leg-length discrepancies. J Bone Joint Surg Am. 1977; 59(2):174-179.
9. Moseley CF. Leg-Length Discrepancy. Pediatric Clinics of North America. 1986; 33(6):1385-1394. doi: 10.1016/s0031-3955(16)36149-1.
10. Menelaus MB. Correction of leg length discrepancy by eplphysial arrest. J Bone Joint Surg Br. 1966; 48 (2):336-339. doi.org/10.1302/0301-620X.48B2.336.
11. Anderson M, Messner MB, Green WT. Distribution of lengths of the normal femur and tibia in children from one to eighteen years of age. J Bone Joint Surg Am. 1964; 46:1197-1202.
12. Eltayeby HH, Gwam CU, Frederick MM, Herzenberg JE. How Accurate is the Multiplier Method in Predicting the Timing of Angular Correction after Hemiepiphysiodesis? J Pediatr Orthop. 2019; 39(2):e91-e94. doi.org/10.1097/BPO.0000000000001278.
13. Amstutz HC. Natural history and treatment of congenital absence of the fibula. J Bone Joint Surg Am. 1972; 54:1349.
14. Mills G, Nelson S. An improved spreadsheet for calculating limb length discrepancy and epiphysiodesis timing using the multiplier method. J Child Orthop.2016; 10(4):313-9. doi: 10.1007/s11832-016-0754-4.
15. Mudgal CS. Many Drops Make a Lake. Arch Bone Jt Surg. 2014; 2(1):1.