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Characteristics of Foot Dimensions of Children with Cerebral Palsy and Standardizing Orthosis Size - Through an Anthropometric Pilot Study

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ABSTRACT Children with Cerebral Palsy have foot debilitation resulting in change in foot dimension and impaired gait. To overcome this problem customised orthoses are often prescribed. This increases the lead time of manufacturing of the orthosis as well as the cost. The objectve is to study the characteristics of foot dimensions and parameterize the orthoses design to enable CP patients to obtain off the shelf orthoses. Foot dimensions of 86 CP children were captured using a 3D Foot Scanner and cluster analysis statistics and Multivariate regression analysis using SPSS software was performed. CP children foot growth has a pattern as of normal children but varies in magnitude and the boys and girls foot growth rate are similar. Based on the statistical analysis the off the self orthosis can be manufactured in 5 different sizes to fit the targeted population, and furthermore this study may be validate with increased sample size.

INTRODUCTION

Cerebral palsy (CP) manifests itself as a corollary of a brain injury or an abnormality in the development of the brain that occurs either congenitally or after birth (Self 2012). It is a persistent disorder of movement and posture caused by non-progressive defects or lesions of the immature brain (Rosenbaum 2007). As per the statistical data available, the prevalence of cerebral palsy in children is quite significant and alarming (Vincer 2014; Himmelmann 2005). This clearly reflects a huge demand in the development of rehabilitation methodology and the need to increase the research activity towards this area.

The feet of the child with cerebral palsy are severely affected with spasticity and this foot debilitation results in impaired gait and ambulatory instability in them (Hoiness 2014).Cerebral palsy treatment requires a multi-disciplinary medical team and a coordinated, comprehensive treatment plan (Bax 2005). To overcome effects of the spasticity, there are many methods used, prominent amongst them being physiotherapy, drug therapy and surgical method (Paz 2015). In all the above methods, the follow-up or supportive treatment is to make the patient wear orthotic devices. The orthotic device is used to enhance the stability of the limb joints, prevent the propagation of the severity of the deformity and to prevent any new deformity development due to spasticity. The orthosis also helps to improve the gait parameters (step length, stride length, support base, step time, swing time etc.) of children affected by Cerebral Palsy (Ries 2015).

These Special Foot orthoses help in correcting muscle dysfunctionality due to spasticity and also helps in avoiding joint distortion. Orthoses prescribed for them to overcome this problem are generally customised. Customisation of the orthoses makes it costlier, depends on the orthotist's skill to measure the subject and thus the accuracy varies. Moreover, the customisation process increases the lead time of manufacturing (Zifchocka 2008).

To overcome the above difficulties, an attempt has been made in this paper to design an orthotic intervention which can be procured off-the-shelf based on the foot anthropometric data of children with cerebral palsy which would not only help in achieving a near normal gait but would also address other foot problems. The effort to eliminate alteration in the feet and ankles

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is both understandable and important, but to design the correct orthosis, it is imperative that the "Foot Dimensional characteristics" of the children with cerebral palsy be determined and understood so that the correct orthosis is designed, manufactured and fitted.

For development of a standard sizing system for orthoses, the first and foremost thing is to understand the growth pattern of the CP children foot. There are many studies on normal children foot growth rate which shows a pattern in their foot measurements (Gould 1990; Wenger 1983). Using this, groupings are made to manufacture shoes so that the general population can use it as an "off the shelf" item. So, like the grouping of normal shoes, the size groupings for the orthoses for CP children can also be done if the foot growth has a pattern to it. Even the same grouping can be used if CP children growth pattern matches the normal children growth pattern.

Objectives

The study is to carry out an anthropometric foot survey in children afflicted with Cerebral Palsy and to critically analyse the variation of CP children's various foot parameters from that of normal children and also to examine whether any grouping of the foot measurement data could be done in order to parameterize the design of the orthoses.

METHODS

Participants

To understand the dimensional characteristics of children afflicted with cerebral palsy, an anthropometric study of their feet was carried out. For this study a school which has around 425 children in their two branches in the same region were selected for the foot survey. The recruitment was made on the basis of inclusive criteria of 4 to 13 years of age with any type of spastic cerebral palsy and children who have difficulty in standing even with support were excluded. By applying the inclusion and exclusion criteria, 86 children were selected and included in the foot survey after obtaining prior consent from the Institute director. After the foot survey the data was analysed for its integrity and it was found that data on 58 children was possible for analysis. A total of 58 children from special school for CP children were recruited for the study, 35 male subjects and 23 female subjects were included in this study. To establish the significance of the study, a comparative analysis was also carried out with control group comprising the same region and same set of foot parameters measured and comparable sample size in healthy and normal children in the same age bracket.

Measuring Procedure

The foot dimensions of the children were captured using a sophisticated '3D Foot Scanner' which incorporated state of the art laser and camera technology. The 3D Foot Scanner allowed us for capture of accurate 3D foot shape data in a matter of seconds and thus did not disturb the patients for long. The scanner could be used as a standalone unit for foot measurement analysis and size estimation or alternatively used in conjunction with other specialised orthopaedic systems for custom or orthopaedic footwear applications.

Using this scanner ensured a fast capture of the complete foot in a single pass with a high level of accuracy of about ± 1mm. The scanner guaranteed reliable, consistent scanning operation and had the advantage of being portable and easy to move between locations with ease of use and ease of installing and dismantling.

The children were assisted with placement of their feet in the foot scanning device and their feet data – both right and left were captured using the system. This system was also provided with a 'Measuring Software' which helped in analysing the dimensions and shapes of the 3D foot data. The major advantage of using this system was that the foot data got converted to '3D cloud' data which meant that the exact shape of foot could be viewed and also gave room to edit if required.

Statistical Analysis

Statistical analysis is performed using SPSS software. To classify the foot size depending on various dimensions of foot, a cluster analysis is carried out. Student's t-test is made to find whether there is any significant difference in various foot measurements of CP children compared to that of normal children. Subsequently, correlation between the measured foot parameters was

calculated and fitted an appropriate regression model for the parameters. The standard normal curve is used as a reference chart to classify into different sizes.

RESULTS

The statistical analysis was carried out with 95 percent confidence level. The results shows that the foot parameters of a cerebral palsy children also follows a similar foot dimension pattern as that of the normal children, but it is lower than the normal children with respect to the magnitude (Figs. 1 and 2). To know the significance between the CP and normal children foot dimension, the t-test was performed (Table 1). The results conforms statistical significant difference between the control subjects and those of the CP subjects and it is obvious that foot growth of the cerebral palsy children lags the growth seen in the normal children in terms of magnitude.

The grouping of girls and boys data is done by combining both the values and a summary statistics is given in Table 2. To check the varia-

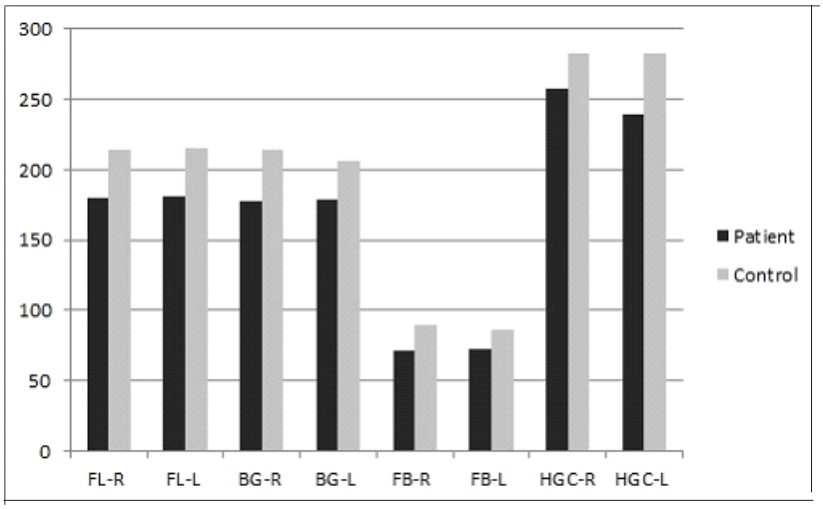

Fig. 1. Group statistics for boys with cerebral palsy

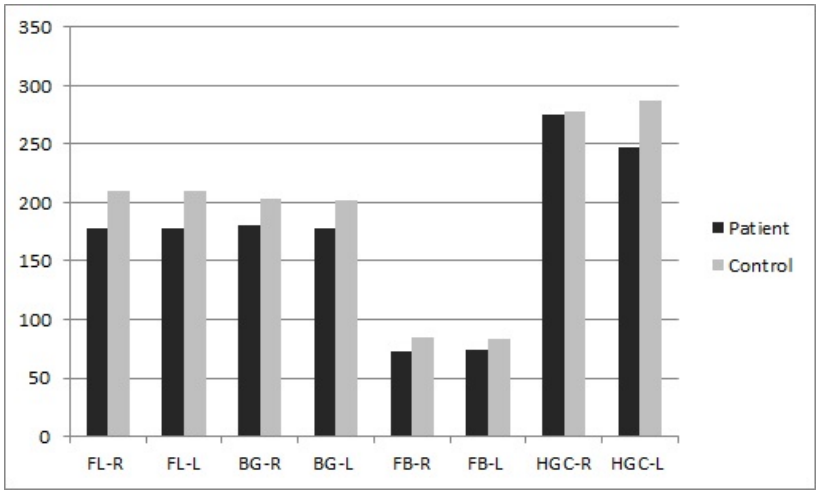

Fig. 2. Group statistics for girls with cerebral palsy

tion on the growth pattern change and to test significance (Table 1) among the grouped variable because of the merging of data, it was compared with the combined normal children data and the results were the same as of the previous girls and boys separate analyses.

Table 2: Descriptive statistics for boys and girls (combined) with cerebral palsy

Parameter	*Type*	*Mean*	*Std. deviation*
Foot length - right	Control	212.00	16.96
	Patient	178.70	20.93
Foot length - left	Control	212.17	17.052
	Patient	179.59	21.76
Ball girth - right	Control	208.80	17.293
	Patient	178.78	17.252
Ball girth - left	Control	204.48	25.45
	Patient	178.56	18.16
Foot breadth - right	Control	86.83	8.43
	Patient	71.83	8.80
Foot breadth - left	Control	84.91	11.24
	Patient	72.79	10.56
Heel girth circumference - right	Control	280.05	38.40
	Patient	263.97	44.92
Heel girth circumference - left	Control	284.68	44.85
	Patient	242.58	33.87

The general regression equation -for 'Foot Length (FL)' as the response variable and the other parameters namely Ball Girth Circumference (BGC), Foot Breadth (FB) and Heel Girth Circumference (HGC) being the independent variables is as follows,

$$FL = a_1 + a_2 \times BGC + a_3 \times FB + a_4 \times HGC \quad (1)$$

Where, a_1, a_2, a_3 and a_4 are the regression coefficients.

The R^2 value for the foot length compared with other foot dimensions for left and right foot is 0.74 and 0.72 respectively, which is sufficient to fit a regression equation. The regression model for the left foot length of boys is given by (equation 2),

$$FL\ (left) = 20.85\text{-}0.34\times BGC+2.282\times FB+0.232\times HGC \quad (2)$$

Similarly for right foot length of boys is given by

$$FL\ (right) = -15.54+0.938\times BGC+0.033\times FB+0.101\times HGC \quad (3)$$

The correlation coefficients were computed for all possible combinations of the various foot parameters and representative values of the boys left feet and the girls right feet are presented as examples in Tables 3 and 4. From Table 3, it is observed that the correlation between foot length, ball girth circumference, foot breadth and heel girth correlation of left feet of boys is having sufficient degree of correlation. In case of girls right foot measurement, that is from Table 4, only foot breadth with respect to ball girth circumference is showing significant correlation and rest of the variables are having weaker correlation. So in case of girls, the foot dimensions don't have significant correlation between the variables. Thus the Foot Length computed from the above equation based on the values of the other parameters namely Ball Girth Circumference, Foot Breadth and Heel Girth Circumference.

From the statistical analysis, the variances (σ^2) for defining parameters of the orthoses namely: The Foot Length, the Ball Girth, the Foot Breadth and the Heel Girth Circumference were arrived at, the variances of $\sigma = 17$ for Foot Length, $\sigma = 17.3$ for Ball Girth, $\sigma = 8.4$ for Foot Breadth, $\sigma = 44.6$ for Heel Girth Circumference. Based on the normal distribution, the spread and coverage of the patients foot dimensions for prescription of 'off the shelf orthoses' would be about 68

Table 1: t-test for boys and girls with cerebral palsy – Independent Samples Test

Parameter	*t-test equality of means (boys) significance (2-tailed)*	*t-test equality of means (girls) significance (2-tailed)*	*t-test equality of means (girls and boys combined) significance (2-tailed)*
Foot length - right	0 (<0.5)	0 (<0.5)	0 (<0.5)
Foot length - left	0 (<0.5)	0 (<0.5)	0 (<0.5)
Ball girth - right	0 (<0.5)	0 (<0.5)	0 (<0.5)
Ball girth - left	0 (<0.5)	0 (<0.5)	0 (<0.5)
Foot breadth - right	0 (<0.5)	0 (<0.5)	0 (<0.5)
Foot breadth - left	0 (<0.5)	0 (<0.5)	0 (<0.5)
Heel girth circumference - right	0.013 (<0.5)	0.768 (>0.5)	0.021 (<0.5)
Heel girth circumference - left	0 (<0.5)	0 (<0.5)	0 (<0.5)

Table 3: Correlation between the various foot parameters for boys left foot

		Foot length (Left foot)	*Ball girth circum- (Left foot)*	*Foot breadth (Left foot)*	*Heel girth circum- ference (Left foot)*
Pearson Correlation	Foot length (Left foot)	1.000	0.783	0.814	0.669
	Ball girth circumference (Left foot)	0.783	1.000	0.974	0.534
	Foot breadth (Left foot)	0.814	0.974	1.000	0.536
	Heel girth circumference (Left foot)	0.669	0.534	0.536	1.000

Table 4: Correlation between the various foot parameters for girls' right foot

		Foot length (Right foot)	*Ball girth circum- (Rightfoot)*	*Foot breadth (Right foot)*	*Heel girth circum- ference (Right foot)*
Pearson Correlation	Foot length (Right foot)	1.000	0.555	0.533	0.420
	Ball girth circumference (Right foot)	0.555	1.000	0.894	0.336
	Foot breadth (Right foot)	0.533	0.894	1.000	0.299
	Heel girth circumference (Right foot)	0.420	0.336	0.299	1.000

percent if the values were within 1 standard deviation of the Mean, that is, Mean ± 1σ (Fig. 3) and would be 95 percent if the values were within 2 standard deviations of the mean, that is, Mean ± 2σ (Fig. 4).

The various parameters for the design of the off-the-shelf orthoses in five different groups: that is, Size 1: Mean Values; Size 2: Mean Values - 1σ; Size 3: Mean Values + 1σ; Size 4: Mean Values - 2σ and Size 5: Mean Values + 2σ were derived. For each of the above 5 groups the Foot Length, Ball Girth, Foot Breadth and the Heel Girth Circumference values for the Control Data as well as for the Patients were computed as shown in Table 5.

DISCUSSION

The analysis done to get the pattern of cerebral palsy children foot growth shows two important aspects. One is that the growth of the cerebral palsy children foot follows a pattern and secondly that the pattern shows similarities between cerebral palsy children and control group. However the magnitude of growth for cerebral palsy children is lower than that of their counterpart, which is with respect to control group children. Even though there is a visible reduction in the growth rate, the t-test is performed between the CP and normal children foot dimension (Table 1) to evaluate whether the difference is sta-

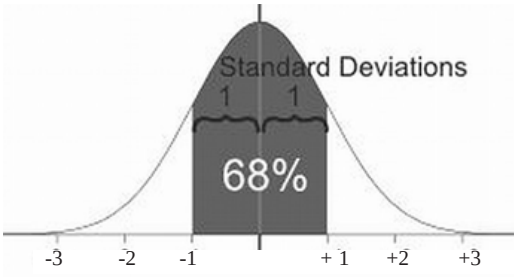

Fig. 3. Coverage of patients for values within 1 standard deviation of the mean

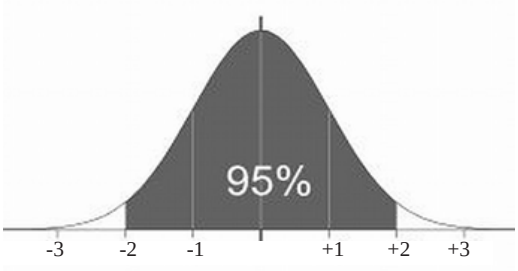

Fig. 4. Coverage of patients for values within 2 standard deviations of the mean

Table 5: Orthosis parameters for Size 1, Size 2, Size 3, Size 4, Size 5

Parameters (mm)	*Size 1 Mean - 2ó values*		*Size 2 Mean - 1ó values*		*Size 3 Mean values*		*Size 4 Mean + 1ó values*		*Size 5 Mean + 2ó values*	
	Control	*Patients*	*Control*	*Patients*	*Control*	*Patients*	*Control*	*Patients*	*Control*	*Patients*
Foot length	178.2	145.6	195.2	162.6	212.2	179.6	229.2	196.6	246.2	213.6
Ball girth	174.2	144.2	191.5	161.5	208.8	178.8	243.4	196.1	243.4	213.4
Foot breadth	70	56	78.4	64.4	86.8	72.8	95.2	81.2	103.6	89.6
Heel girth circum-ference	195.5	153.8	240.1	198.4	284.7	243	329.3	332.2	373.9	332.2

tistically significant or not. The result suggests that there is a significant difference between the control subjects and those of the CP subjects and thus it is obvious that foot growth of the cerebral palsy children lags the growth seen in the normal children. This low foot growth than the normal children may be because of lower nutritional level intake by cerebral palsy children (Bruno da Silva 2014). However, the result shows similarity between the normal children foot growth pattern to cerebral palsy children foot growth pattern may be interpreted as the cerebral palsy itself doesn't directly contribute to deficiency in growth, rather the deficiency in foot growth may be because of most of the children with cerebral palsy may have problem with food intake (Andrew 2015).

Even though growth pattern exist, the growth variation between the control and cerebral palsy children is found and this suggests that the available grouping cannot be used and thus arises need to develop new sizing system. The sizing system will be less cumbersome if the girls' and boys' growth rate are same, so that the girls and boys growth data can be combined and statistically analyzed (Table 2). From the result it is found that there was no difference between the foot growth rates of girls and boys. This matches with the previous studies on the normal children's foot growth pattern (Wenger 1983; Volpen 1994). However the correlation between various foot dimensional parameters in terms of boys and girls changes. From Table 3, it is observed that the correlation between foot length, ball girth circumference, foot breadth and heel girth correlation of left feet of boys is having sufficient degree of correlation. This states that the foot length changes with respect to other foot parameters. This may be taken as base for calculating other dependent variables. However in case of girls right foot measurements, only foot breadth with respect to ball girth circumference is showing significant correlation, and rest of the variables are having weaker correlation. This may be because of lower sample size which is less than that of boys sample size. There is sufficient degree of correlation for boys and can fit regression models to estimate the foot length. Furthermore, the combined group statistics of boys and girls suggest same pattern as of separate statistics of boys' data and girls' data, in case of girls, the foot dimensions don't have significant correlation between the variables; hence the estimate obtained from the regression model fitted in such situation will have less efficiency.

Furthermore the correlation on the boys' data may be used for development of standard orthosis dimensional parameters. Thus the Foot Length could be computed from the equation based on the values of the other parameters namely Ball Girth Circumference, Foot Breadth and Heel Girth Circumference. This led to suggest that the set of measurements tabled (Table 5) could optimise on the sizes to be manufactured, which would result in better productivity and easy availability of the orthoses. However that the existing foot data are collected in a particular region, which limits this calculated data be region specific. The study may be further expanded to develop a universal sizing system and also to increase its effectiveness of the orthosis.

CONCLUSION

The overriding objective was to establish that Anthropometric research could be used in studying characteristic of foot dimensions and product design in improving the ability to create specialized products. The development of a reli-

able sizing system based on anthropometric principles of the study of children with Cerebral Palsy, contributed to the establishment of parametrization of orthoses to meet the needs of specific user groups, to optimise the number of items of a certain size to be manufactured and to improve the fit, comfort and reliability of the Orthoses.

The orthoses manufactured using the above dimensions would comfortably fit 95 percent of the children afflicted with cerebral palsy and they would now have access to 'off the shelf' orthoses which would result in quicker delivery, thus considerably reducing the time taken to obtain the 'Customised Orthosis' and would also ensure that the foot movement is restored immediately without having to undergo trauma till the customised foot orthosis arrived. Moreover, the cost of 'off the shelf' orthoses would be significantly lesser as compared to the 'customised' orthoses, thus making it affordable and accessible to a large number of children with cerebral palsy.

RECOMMENDATIONS

Thus the results shows positive note towards the objective and shows foot growth of cerebral palsy children follows the unique pattern. Also the correlation between the dimensional parameters exist, hence standardized parameters of orthosis dimensions may be used to develop off the self orthosis for children affected with cerebral palsy.

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Abbreviations

Foot Length - Right	FL-R
Foot Length - Left	FL-L
Ball Girth - Right	BG-R
Ball Girth - Left	BG-L
Foot Breadth - Right	FB-R
Foot Breadth - Left	FB-L
Heel Girth Circumference - Right	HGC-R
Heel Girth Circumference - Left	HGC-L