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Using Muscle Architecture to Predict Maximum Strength and Its Relation to Activity Levels in Cerebral Palsy Patients

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ABSTRACT

Background: *To provide insight into the relationship between muscle architecture, muscle strength and activity level in CP.*

Subjects and Methods: *This study was conducted on forty subjects divided into two groups of equal number, group A (normally development) and group B (cerebral palsy patients). All participated subjects examined for their rectus femoris and vastus lateralis muscle thickness by sonography, quadriceps muscle isometric peak torque measured by isokinetic dynamometer, activity level for group B only evaluated by pediatric outcome data collection instrument (parent report and self-report). Group A evaluated for one time and group B evaluated two times at starting and after six months of physical therapy program.*

Results: *showed direct relationship between muscle thickness measured by sonography and both muscle strength and activity level.*

Conclusion: *muscle thickness measured by sonography can be used to evaluate muscle strength and activity level in cerebral palsy patient.*

Key words: *Muscle architecture, muscle strength, activity level, cerebral palsy.*

Cerebral palsy (CP) is a group of motor disorders of movement and posture, often characterized by impairments such as muscle weakness, spasticity, stiffness, and excessive co-contraction **(Bax et al., 2005).**

Cerebral palsy (CP) describes a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non-progressive disturbances that occurred in the developing fetal or infant brain. The motor disorders of cerebral palsy are often accompanied by disturbances of sensation, perception, cognition, communication, and behaviour, by epilepsy, and by secondary musculoskeletal problems **(Rosenbaum et al.,2007).**

Singhi (2004) and Edwin et al (2006) reported that cerebral palsy occurs in approximately 3 per 1000 of live births 75% of cerebral palsy children have spastic cerebral palsy.

The goal of management of cerebral palsy is not to cure or to achieve normality but to increase functionality, improve capabilities, and sustain health in terms of locomotion, cognitive development, social interaction, and independence. The best clinical outcomes result from early, intensive management **(Taylor, 2005).**

In patientswith CP, the strength (force-generating capacity) of the knee extensor muscles alone is significantly correlated with the standing, walking, running, and jumping components of the Gross Motor Function Measure and with the total Gross Motor Function Measure score **(Goh 2006).**

In children and adolescents with CP, exercise and resistance training are important components of rehabilitation programs for counteracting these impairments at the muscle level, thus improving muscle force output and efficiency **(Verschuren et al., 2007).**

Muscle architecture is defined as the internal arrangement of muscle fibers within a muscle and has been described as the primary determinant of muscle function **(Lieber et al., 2000).**

Because the architecture of a muscle determines the force-velocity properties of the muscle, including outcome measures of muscle architecture is of clinical importance. Such measures include physiological and anatomical cross-sectional areas, muscle thickness, and length and angle of fascicles (bundles of muscle fibers). However, researchers are only beginning to understand the differences in muscle architecture in children and adolescents with CP and those with typical development (TD). Furthermore, information in the literature about how muscle architecture predicts muscle function in CP is scarce. Even more scarce are studies reporting on how muscle architecture predicts other impairments or activity levels in CP, which are important for informing clinical practice. Children and adolescents with CP have lower activity levels than their peers with TD **(Moreau, 2010).**

Children and adolescents with CP have lower activity levels than their peers with TD. Whether primary weakness is the cause of decreased activity levels or whether decreased activity levels result in secondary weakness is unknown. Over time, the interaction of these 2 properties, in conjunction with abnormal movement patterns, may perpetuate a continuous cycle of inactivity and weakness, accompanied by disuse atrophy and alterations in muscle architecture **(Damiano., 2006).**

The possible role of muscle dysgenesis, or abnormal development of muscle architecture, in weakness, spasticity, and disuse is unknown. It has been shown that weight-bearing muscles, particularly the quadriceps and gastrocnemius muscles, are most affected by disuse and inactivity in humans because of their antigravity function **(De Boer, 2007).**

The quadriceps muscles are particularly important for transitioning from sitting to standing, ascending and descending stairs, and antigravity control during the stance phase of gait, among other functional activities **(Mizner, 2005).**

Ohata et al (2006) examined Muscle Thickness (MTH) measured by ultrasonography as Quantitative Muscle Evaluation for Adults with Severe Cerebral Palsy. The results suggested that the muscle thickness of the quadriceps muscle and longissimus differed significantly depending on the subjects' motor function during daily activity. The measurement of MTH may be an alternative method of quantitative muscle evaluation for people with severe CP for whom direct measurement of muscle strength is difficult.

SUBJECTS, INSTRUMENTATION AND PROCEDURES

Forty subjects aged eight to twelve years include two groups:

Group A: included twenty child with normal development

And group B: included twenty spastic diplegic cerebral palsy children.

Inclusion criteria for group B with cerebral palsy all, of them were:

1. Ambulant
2. Having mild spasticity
3. Were at Gross Motor Function Classification System (GMFCS) levels I through IV

Exclusion criteria for group B:

1. Have no orthopedic or neurological surgery within 6 months before testing
2. Have no botulium toxin injections to the quadriceps muscle within 3 months before testing.
3. Have no cognitive or other behavioral impairments that interfered with the ability to understand and follow directions.

NB: parental written informed consent was obtained for each participant.

Both groups A and B were evaluated at starting the study. While group B(cerebral palsy) only was evaluated after 6 months of physical therapy treatment for architectures of the quadriceps, their maximum strength and for group B only the activity level.

A. Ultrasound images of the rectus femoris (RF) and vastsus lateralis (VL) muscles was recorded in real time with a 6- to 12-MHz linear-array transducer in 2D B-mode. Imaging was performed prior to strength assessment, and the right lower extremity was chosen for measurement.

Participants must rest comfortably in the supine position with the knee joint near the natural resting position of 10 degrees flexion; a towel roll was placed under the knee as needed for positioning or to aid comfort and muscle relaxation. Participants were supine for approximately10 to 15 minutes prior to imaging. The resting angle of the knee was measured and recorded with a goniometer.

Participants were instructed to relax their muscles during scanning. Images was recorded only when the muscle is fully relaxed, as evidenced in real time.

Images of the rectus femoris RF muscle was taken at 50% of the distance between the anterior superior iliac spine and the superior border of the patella.

Images of the vastsus lateralis (VL) muscle was taken at the midpoint between the most prominent portion of the greater trochanter and the lateral femoral epicondyle.

To ensure proper placement of the probe, each midpoint was clearly marked on the skin with a surgical pen.

To eliminate compression of the muscle, a generous amount of gel was applied to the skin, and the examiner will hold the probe suspended on top of the gel with the forearm supported.

Images were taken with the probe oriented in the sagittal plane and perpendicular to the skin, and the muscle thickness was calculated as the distance between the superficial and the deep aponeurosis in the middle of the ultrasound image at a 90-degree angle from the deep aponeurosis with the ultrasound system software.

Three images was taken three times per muscle, and the average value from the 3 images for each measurement was used in the analyses.

B. Maximum voluntary knee extensor torque tested isometrically at a knee angle of 60 degrees of flexion with an isokinetic dynamometer (System 3 Pro). The 60-degree position was chosen because it approximates the optimal point on the length-tension curve for generating force. The peak isometric torque of the highest of 3 repetitions was used as the measure of strength, or maximum force-generating capacity.

C. The pediatric Outcomes Data Collection Instrument parent report and self-report administered as measures of activity and participation. The pediatric Outcomes Data Collection Instrument was designed to assess self-reported and parent reported physical function and psychosocial aspects of health status in children with mild to moderate musculoskeletal disability. The following scales, with scores ranging from 0 (worst) to 100 (best), will be used for analysis: Transfers and Basic Mobility Scale, Sports and Physical Functioning Scale, and Global Functioning Scale, which includes the preceding 2 scales in addition to an Upper- Extremity Scale and a Pain and Comfort Scale. The pediatric Outcomes Data Collection Instrument has been widely administered in children with CP; it has high internal consistency, moderate to good test-retest reliability, moderate to excellent concurrent validity with the Gross Motor Function Measure, and the ability to discriminate across motor groups for certain domains and is responsive to change after orthopedic surgery.

Data analysis was performed using:

Correlation test to detect relationship between variables

RESULTS

The results gained from group A (normally developed children) revealed direct relationship between rectus femoris muscle thickness and maximum isometric strength of quadriceps muscle as shown in figure(1) and it showed direct relationship between vastus lateralis muscle thickness and maximum isometric strength of quadriceps muscle as shown in figure (2).

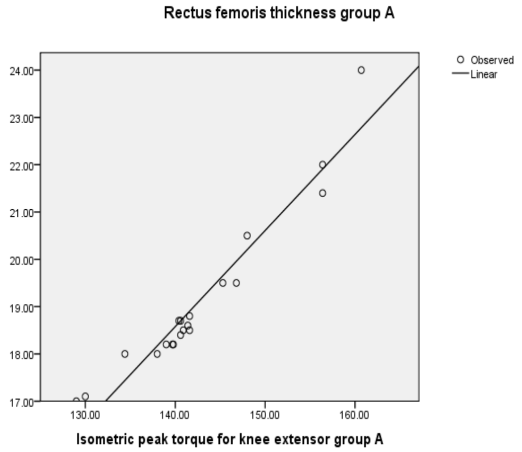


Figure (1): Relationship between rectus femoris muscle thickness and maximum isometric strength of quadriceps muscle

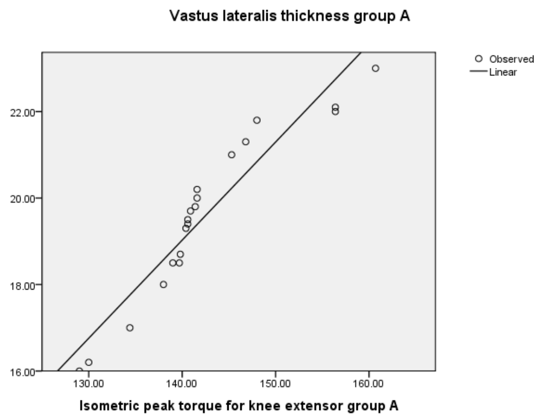


Figure (2): Relationship between vastus lateralis muscle thickness and maximum isometric strength of quadriceps muscle

The results gained from pre-training evaluation of group B (spastic diplegic cerebral palsied children) revealed direct relationship between :

Rectus femoris thickness and isometric peak torque of quadriceps muscle as shown in figure (3).

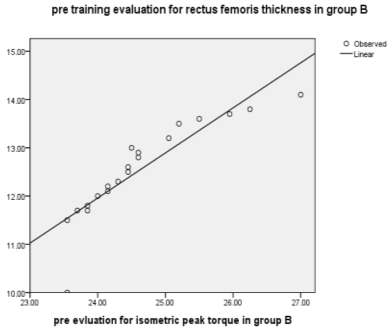


Figure (3): Relation between rectus femoris thickness and maximum isometric strength of quadriceps muscle

Vastuslateralis thickness and isometric peak torque of quadriceps muscle as shown in figure (4).

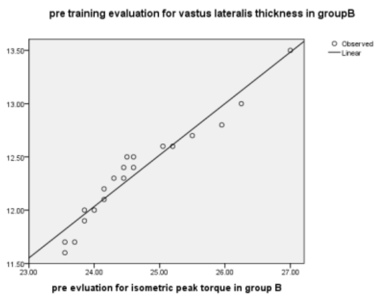


Figure (4): Relation between vastus lateralis thickness and maximum isometric strength of quadriceps muscle

Rectus femoris thickness, vastus lateralis thickness and pediatric outcome data collection instrument (parent report and self-report) as shown in figure (5).

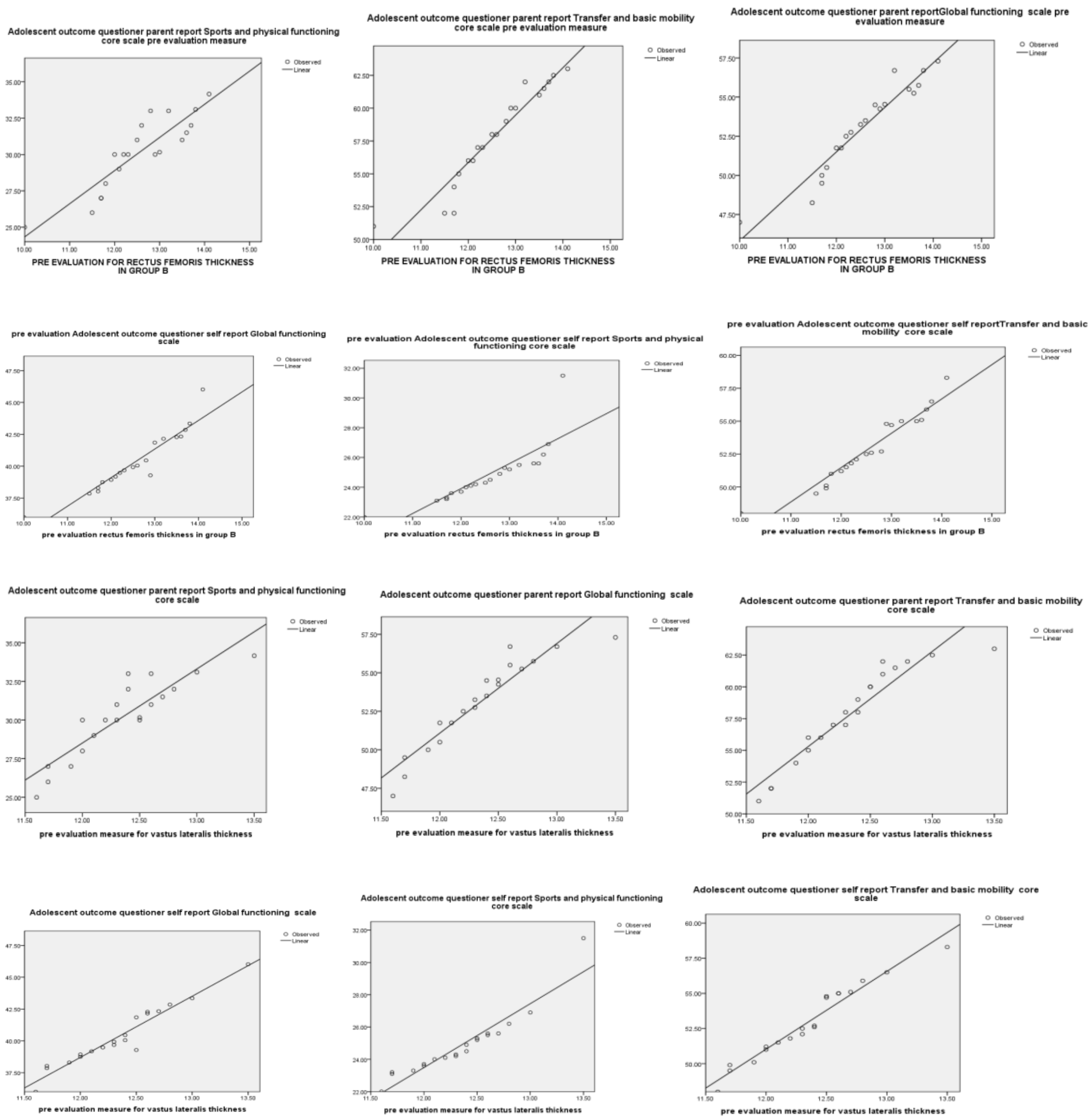


Figure (5): Rectus femoris thickness, vastus lateralis thickness and pediatric outcome data collection instrument (parent report and self-report).

4-Isometric peak torque of the quadriceps muscle pediatric outcome data collection instrument (parent report and self-report) as shown in figure (6)

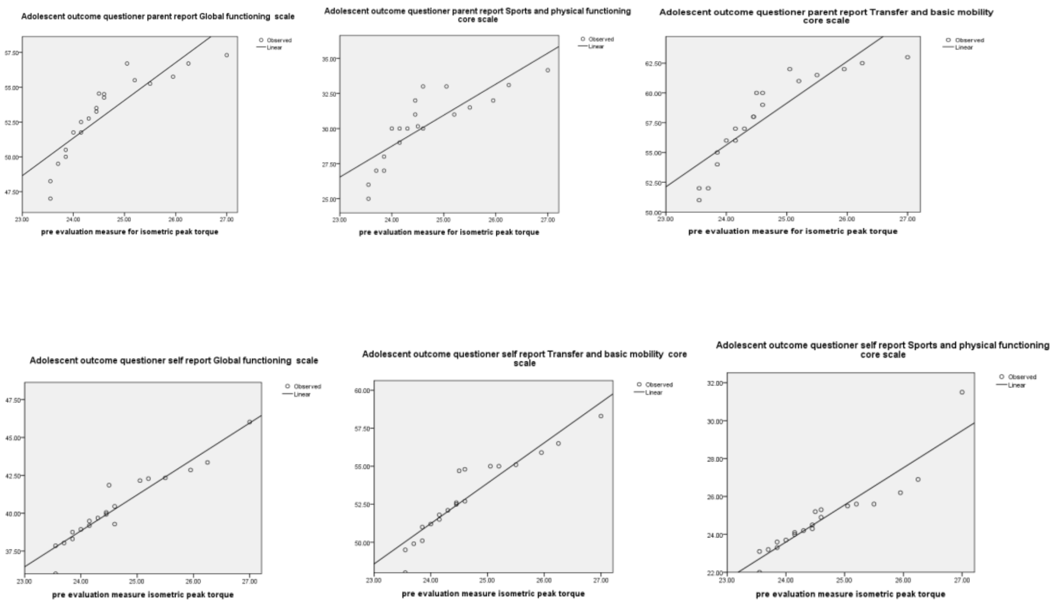


Figure (6): Isometric peak torque of the quadriceps muscle pediatric outcome data collection instrument (parent report and self-report).

The results gained from post-training evaluation of group B (spasticdiplegic cerebral palsied children) revealed direct relationship between :

Rectus femoris thickness and isometric peak torque of quadriceps muscle as shown in figure (7)

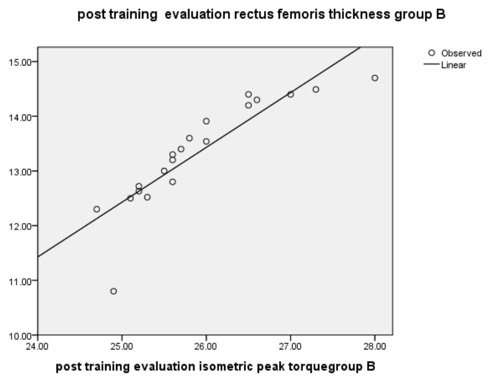


Figure (7): Rectus femoris thickness and isometric peak torque of quadriceps muscle.

Vastuslateralis thickness and isometric peak torque of quadriceps muscle as shown in figure (8)

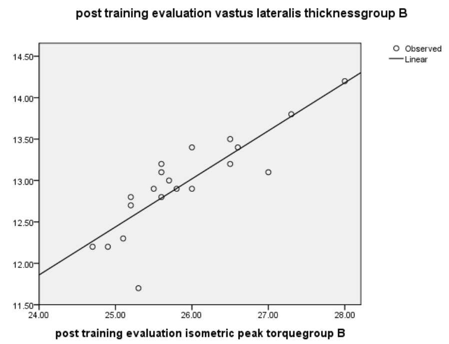


Figure (8): Vastuslateralis thickness and isometric peak torque of quadriceps muscle.

Rectus femoris thickness, vastus lateralis thickness and pediatric outcome data collection instrument (parent report and self-report) as shown in figure (9)

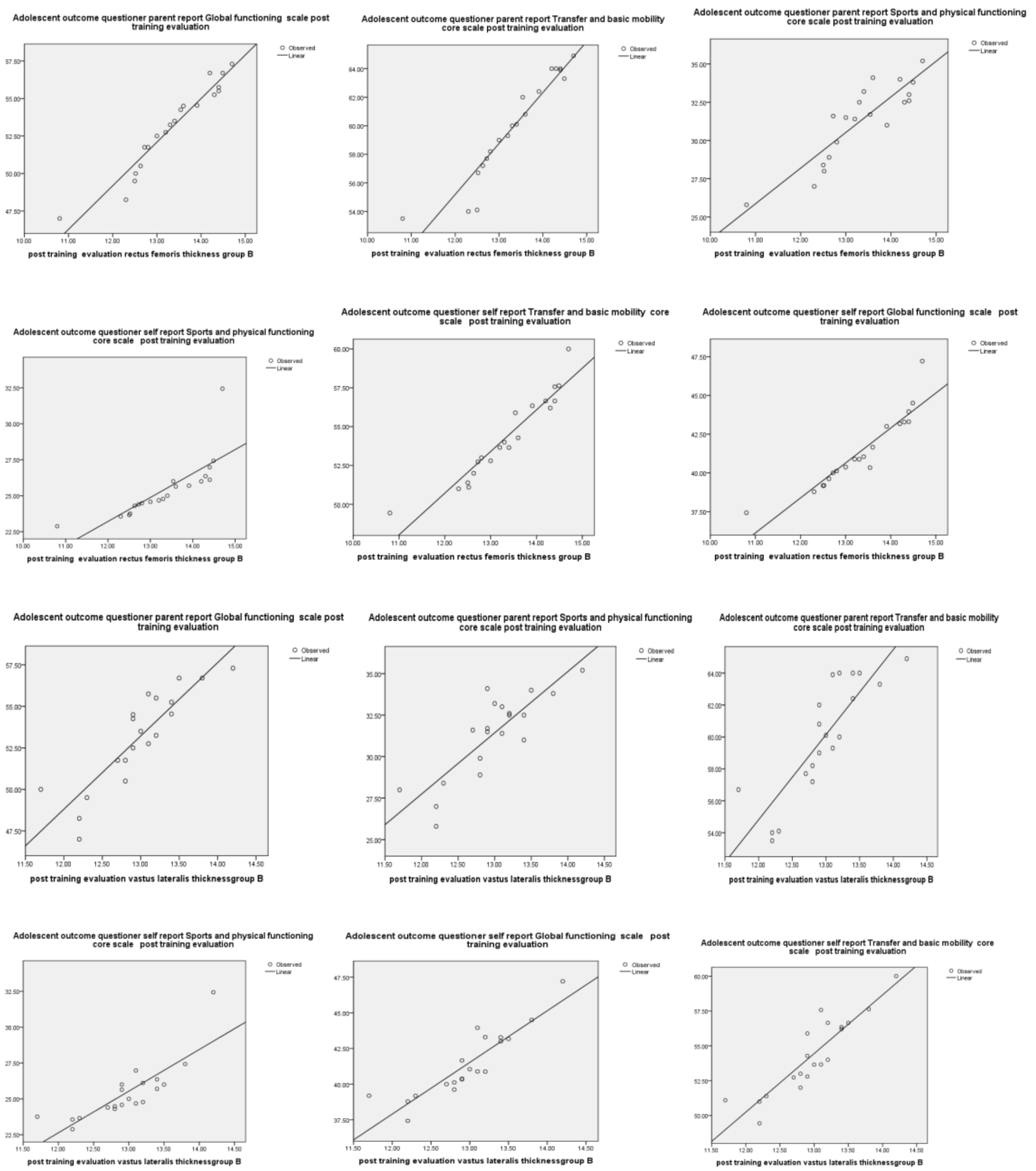
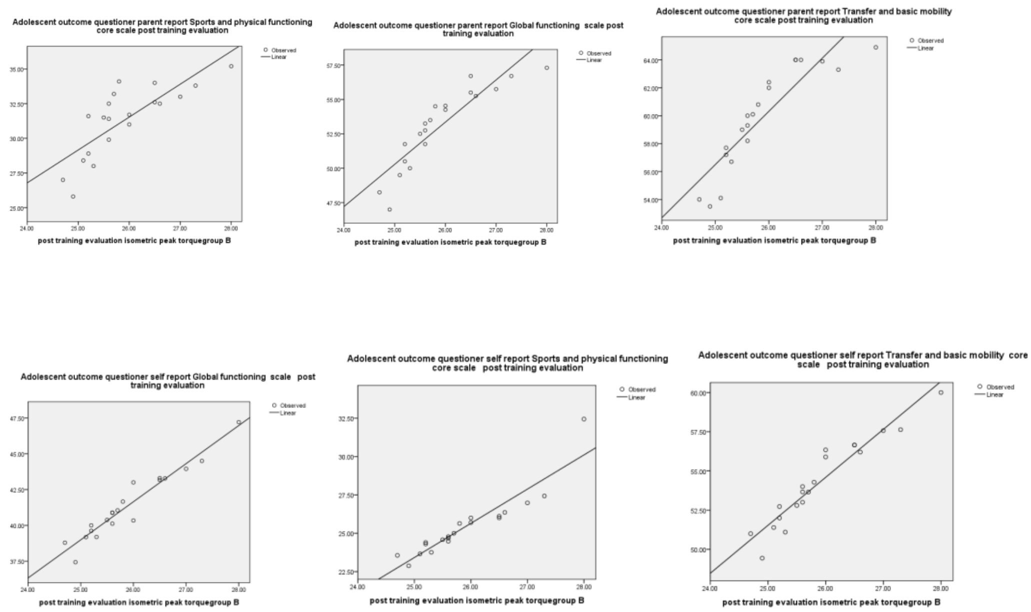


Figure (9): Rectus femoris thickness, vastus lateralis thickness and pediatric outcome data collection instrument (parent report and self-report).

Isometric peak torque of the quadriceps muscle pediatric outcome data collection instrument (parent report and self-report) as shown in figure (10)



DISCUSSION

Cerebral palsy (CP) is a group of disorders of movement and posture, often characterized by impairments such as muscle weakness, spasticity (hyper tonicity), stiffness, and excessive co-contraction. In children and adolescents with CP, exercise and resistance training are important components of rehabilitation programs for counteracting these impairments at the muscle level, thus improving muscle force output and efficiency **(Damiano, 1998).**

Muscle architecture is defined as the internal arrangement of muscle fibers within a muscle and has been described as the primary determinant of muscle function .Because the architecture of a muscle determines the force-velocity properties of the muscle, including outcome measures of muscle architecture is of clinical importance. Such measures include physiological and anatomical cross-sectional areas, muscle thickness, and length and angle of fascicles (bundles of muscle fibers) **(Liber R 2000).**

Researchers are only beginning to understand the differences in muscle architecture in children and adolescents with CP and those with typical development (TD). Furthermore, information in the literature about how muscle architecture predicts muscle function in CP is scarce. Even more scarce are studies reporting on how muscle architecture predicts other impairments or activity levels in CP, which are important for informing clinical practice **(Moreau N 2010).**

The current study conducted to investigate the ability to use the muscle thickness as component of muscle architecture as method to predicts muscle power , functional impairment and activity level in children with cerebral palsy.

Our current study conducted on forty subjects included two groups group A included twenty normal development children and adolescents (age 12.38±0.4 years, body weight 41.135±1.125 kg and body tall

1.44±0.0425 m and consist of 13 male and 7female) and group B included twenty cerebral palsy patients (age12.172±0.484 years, body weight 33.52±0.89kg and body tall1.295±0.04 m). The gross motor classifications for group B was 13 subject level I and 7 subject level II. consist of 14 male and 6female).Both group A and group B evaluated for right rectus femoris muscle thickness and right vastus lateralis muscle thickness by sonography, isometric peak torque of the right quadriceps muscle by isokinetic dynamometer .Group B (cerebral palsy subjects) evaluated for their activity level by Adolescent outcome questioner parent report and Adolescent outcome questioner self-report. GroupA evaluated for one time only and group B evaluated for two times before and after six months of physical therapy program including strengthening of the right quadriceps muscle.

Correlation between group A rectus femoris muscle thickness and isometric peak torque of the quadriceps muscle showed strong direct relationship and correlation between group A vastus lateralis muscle thickness and isometric peak torque of the quadriceps muscle showed strong direct relationship.

Correlation between group B pre training evaluation results rectus femoris muscle thickness and isometric peak torque of the quadriceps muscle showed strong direct relationship and correlation between group B pre evaluation results vastus lateralis muscle thickness and isometric peak torque of the quadriceps showed strong direct relationship.

Correlation between pre training evaluation results rectus femoris muscle thickness and Adolescent outcome questionnaire parent report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between pre training evaluation results of vastus lateralis muscle thickness and Adolescent outcome questionnaire parent report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between pre training evaluation results rectus femoris muscle thickness and Adolescent outcome questionnaire self-report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between pre training evaluation results of vastus lateralis muscle thickness and Adolescent outcome questionnaire self-report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between pre training evaluation results of the isometric peak torque and both adolescent outcome questnaire (parent report and self-report) showed strong direct relationship.

Correlation between group B post training evaluation results rectus femoris muscle thickness and isometric peak torque of the quadriceps muscle showed strong direct relationship and correlation between group B post evaluation results vastus lateralis muscle thickness and isometric peak torque of the quadriceps showed strong direct relationship.

Correlation between post training evaluation results rectus femoris muscle thickness and Adolescent outcome questionnaire parent report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between post training evaluation results of vastus lateralis muscle thickness and Adolescent outcome questionnaire parent report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between post training evaluation results rectus femoris muscle thickness and Adolescent outcome questionnaire self-report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Correlation between post training evaluation results of vastus lateralis muscle thickness and Adolescent outcome questionnaire self-report (Sports and physical functioning core scale, Transfer and basic mobility core scale, Global functioning scale) showed strong direct relationship.

Collection between post training evaluation results of isometric peak torque of the quadriceps muscle and both adolescent outcome questionnaire (parent report and self-report) showed strong direct relationship.

In this current study we suggest that muscle thickness as component of muscle architecture detected by sonography can be used as predictive tool to evaluate muscle power and functional level in children and young adolescent with cerebral palsy patients.

Our results added further support to thoseof **Moreau et al (2010)** who examined whether the architecture of the rectus femoris (RF) and vastus lateralis (VL) muscles was predictive of maximum voluntary knee extensor torque in children and adolescents with and without CP and whether these measures were related to activity and participation levels. Found that Ultrasound measures of VL muscle thickness, adjusted for age and GMFCS level, were highly predictive of maximum torque and have the potential to serve as an alternative measures of voluntary strength (force-generating capacity) in children and adolescents with and without CP.

Additionally, our results are in agreement with that reported by**Abe et al (2000)** who stated that although people with severe CP usually show muscle atrophy caused by palsy and limited activity, it is still possible that muscle thickness (MTH) measured by ultrasound imaging reflects muscle strength, at least to some extent. It has been proposed that quantitative ultrasonography is a potentially useful tool for studying skeletal muscle.

Our results also added further support to those of **Elder et al (2003) and Mohagheghi et al (2007) who** reported decreased anatomical cross-sectional area and thickness of the gastrocnemius muscles, respectively, on the paretic compared to non-paretic sides in children with hemiplegic CP.

Our results disagree with **Shortland et al (2002)** who used ultrasound imaging to evaluate muscle architecture in a small group of children with CP and a control group with TD. They observed no differences in fascicle angles and fascicle lengths between the groups.

CONCLUSION

Ultrasound measures of rectus femoris and vastus lateralis muscles thickness were highly predictive of isometric peak torque of the quadriceps muscle and activity level and have the potential to serve as surrogate measures of voluntary strength and activity level in children and adolescents

REFERENCES

1. Abe T, Kumagai K and Brechue W (2000). Fascicle length of leg muscles is greater in sprinters than distance runners. Med Sci Sports Exerc. 2000 Jun;32(6):1125-9.
2. Akagi R, Kanehisa H, Kawakami Y et al(2008).Establishing a new index of muscle cross-sectional area and its relationship with isometric muscle strength. J Strength Cond Res.;22:82–87.
3. Anderson M, Kaplan P and Dussault R (2001). Adductor insertion avulsion syndrome (thigh splints): spectrum of MR imaging features. AJR Am J Roentgenol 1776:673–675
4. Anderson S, Johnston J, Donnell R et al (2001). MR imaging of sports-related pseudotumor in children: midfemoraldiaphysealperiostitis at insertion site of adductor musculature. AJR Am J Roentgenol 176:1227–1231
5. Annika L , Gun B, Christina G et al (2009).Longitudinal Construct Validity of the GMFM-88 Total Score and Goal Total Score and the GMFM-66 Score in a 5-Year Follow-up Study .PHYS THER April89:342-350
6. Anuschka S, Heleen A, Reinders M et al(2012). Feasibility, Reliability, and Agreement of the WeeFIM Instrument in Dutch Children With Burns. PHYS THER July 92:958-966.
7. Bax M, Goldstein M, and Rosenbaum P (2005).Proposed definition and classification of cerebral palsy, April.Dev Med Child Neurol. 2005;47:571–576.
8. Berg R, Baak M and Barbanson D (1996).Reliability of tests to determine peak aerobic power, anaerobic power and isokinetic muscle strength in children with spastic cerebral palsy.Dev Med Child Neurol.;38:1117–1125.
9. Bianchi S, Martinoli C, Abdelwahab I et al (1998).Sonographic evaluation of tears of the gastrocnemius medial head (tennis leg). J Ultrasound Med 17:157–162
10. Bianchi S, Martinoli C, Waser P et al (2002).Rectus femoris central tear. Skeletal Radiology 31:581–586.
11. Bianchi S, Zwass A, Abdelwahab I et al (1994). Diagnosis of tears of the quadriceps tendon of the knee: value of sonography. AJR Am J Roentgenol 162:1137–1140
12. Bjornson K, Belza B, Kartin D et al (2007). Ambulatory physical activity performance in youth with cerebral palsy and youth who are developing typically.PhysTher.; 87:248–257.
13. Bodner G, SchockeM ,Rachbauer F et al (2002) .Differentiation of malignant and benign musculoskeletal tumors: combined color and power Doppler US and spectral wave analysis. Radiology 223:410–416

14. Bottos M, Feliciangeli A and SciutoL(2001).Functional status of adults with cerebral palsy and implications for treatment of children.Dev Med Child Neurol.;43:516 –528
15. Brandser E, el-Khoury G, Kathol M et al (1995). Hamstring injuries: radiographic, conventional tomographic, CT, and MR imaging characteristics. Radiology 197:257–262
16. Carolyn E (1994).The Determinants of Treatment Duration for Congenital Muscular Torticollis PHYS THER October 74:921-929
17. Chammout M and Skinner H (1986).The clinical anatomy of commonly injured muscle bellies. J Trauma 26:549–552 Chason DP, Schultz SM, Fleckenstein JL (1995) Tensor fasciae suralis: depiction on MR images. AJR Am J Roentgenol165:1220–1221
18. Cheatwood A (1995). Changes in Medial Gastrocnemius Architecture With Spasticity and Contracture [doctoral dissertation]. Los Angeles, CA: University of Southern California;.
19. Cohen J(1988).Statistical Power Analysis for the Behavioral Sciences. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates;.
20. Connell D, Schneider-Kolsky M, Hoving J et al. (2004).Longitudinal study comparing sonographic and MRI assessments of acute and healing hamstring injuries. AJR Am J Roentgenol Oct;183(4):975-84.
21. Daltroy L, Liang M, Fossel A et al (1998). Pediatric Outcomes Instrument Development Group, Pediatric Orthopaedic Society of North America. The POSNA pediatric musculoskeletal functional health questionnaire: report on reliability, validity, and sensitivity to change. J Pediatr Orthop.;18:561–571.
22. Damiano D (2006). Activity, activity, activity: rethinking our physical therapy approach to cerebral palsy. Phys Ther.;86: 1534 –1540.
23. Damiano D and Abel M (1998).Functional outcomes of strength training in spastic cerebral palsy. Arch Phys Med Rehabil.; 79:119–125.
24. Damiano D, Gilgannon M and Abel M (2005). Responsiveness and uniqueness of the Pediatric Outcomes Data Collection Instrument compared to the Gross Motor Function Measure for measuring orthopaedic and neurosurgical outcomes in cerebral palsy. J PediatrOrthop.; 25:641– 645.
25. Damiano D, Quinlivan J, and Owen B (2001). Spasticity versus strength in cerebral palsy: relationships among involuntary resistance, voluntary torque, and motor function. Eur J Neurol.;8(suppl 5): 40 – 49.
26. De Boer M, Maganaris C, Seynnes O et al (2007).Time course of muscular, neural and tendinous adaptations to 23 day unilateral lower-limb suspension in young men. J Physiol.;583:1079–1091.
27. De Boer M, Seynnes O, and Prampero P (2008). Effect of 5 weeks horizontal bed rest on human muscle thickness and architecture of weight bearing and non-weight bearing muscles. Eur J Appl Physiol.; 104:401–407.

28. Dhara H, Stephen M, Kathleen M et al(2003).Measuring Functional Change in Children With Acquired Brain Injury (ABI): Comparison of Generic and ABI-Specific Scales Using the Pediatric Evaluation of Disability Inventory (PEDI). PHYS THER September 83:776-785
29. Dodd K, Taylor N and Graham H (2003).A randomized clinical trial of strength training in young people with cerebral palsy.Dev Med Child Neurol.;45:652–657.
30. Doreen J, Lisa A, Sarah W et al (2010) .The Move & PLAY Study: An Example of Comprehensive Rehabilitation Outcomes Research PHYS THER November 90:1660-1672.
31. Edwins D(2006). an investigation into the effect of electrical stimulation of the calf muscles in children with cerebral palsywww. cerebra. org. 2004; retrieved 10th january.
32. Elder G, Kirk J, and Stewart G(2003).Contributing factors to muscle weakness in children with cerebral palsy.Dev Med Child Neuro l;45:542–550.
33. Feldman A, Haley S and Coryell J(1990). Concurrent and Construct Validity of the Pediatric Evaluation of Disability Inventory PHYS THER October 70:602-610.
34. Futani H, Yamagiwa T, Yasojimat H et al (2003).Distinction between well-differentiated liposarcoma and intramuscular lipoma by power Doppler ultrasonography. Anticancer Res 23:1713–1718
35. Garrett W (1990). Muscle strain injuries: clinical and basic aspects. Med Sci Sports Exerc 22:436–443 Garrett WE Jr (1996) Muscle strain injuries. Am J Sports Med24:S2–S8
36. Goh H, Thompson M, Huang W et al (2006). Relationships among measures of knee musculoskeletal impairments, gross motor function, and walking efficiency in children with cerebral palsy. PediatrPhys Ther.;18:253–261.
37. Graif M, Seton A, Nerubai J et al (1991). Sciatic nerve: sonographic evaluation and anatomic-pathologic considerations. Radiology 181:405–408
38. Greco A, McNamara M, Escher R et al (1991). Spin-echo and STIR MR imaging of sports-related muscle injuries at 1.5 T. J Comput Assist Tomogr 15:994–999
39. Hasselman C, Best T, Hughes C et al (1995). An explanation for various rectus femoris strain injuries using previously undescribed muscle architecture. Am J Sports Med23:493–499
40. Heckmatt J, PierN and Dubowitz V (1988).Measurement of quadriceps muscle thickness and subcutaneous tissue thickness in normal children by real-time ultrasound imaging.Journal of Clinical Ultrasound.Volume 16, Issue 3, pages 171–176.
41. Heckmatt J, PierN and Dubowitz V (1988).Assessment of quadriceps femoris muscle atrophy and hypertrophy in neuromuscular disease in children.Journal of Clinical Ultrasound.Volume 16, Issue 3, pages 177–181.
42. Hughes C, Hasselman C, Best T et al (1995).Incomplete, intrasubstance strain injuries of the rectus femoris muscle.Am J Sports Med 23:500–506

43. Ikeda A, Abel M, Granata K et al (1998).Quantification of co-contraction in spastic cerebral palsy.ElectromyogrClinNeurophysiol.; 38:497–504.
44. International Classification of Functioning (2001).Disability and Health: ICF. Geneva, Switzerland: World Health Organization.
45. Julie D and Rebecca L (2006).Is there evidence to support the use of constraint-induced therapy to improve the quality or quantity of upper extremity function of a 2 1/2-year-old girl with congenital hemiparesis? If so, what are the optimal parameters of this intervention? .PHYS THER May 86:746-752.
46. Kang, Robert J, Margo N et al (2010). Determinants of Social Participation—With Friends and Others Who Are Not Family Members—for Youths With Cerebral Palsy PHYS THER December 90:1743-1757.
47. Kathleen W, Jean C, Owen R et al(2002).The Effects of a Contoured Foam Seat on Postural Alignment and Upper-Extremity Function in Infants With Neuromotor Impairments PHYS THER November 82:1064-1076
48. Kawakami Y, Abe T and Fukunaga T (1993).Musclefiberpennation angles are greater in hypertrophied than in normal muscles. J Appl Physiol.;74:2740–2744.
49. Koulouris G and Connell D (2005) Hamstring muscle complex: an imaging review. RadioGraphics 25:571-586
50. Kues J, Rothstein J and Lamb R (1994). The relationships among knee extensor torques produced during maximal voluntary contractions under various test conditions. PhysTher.; 74:674–683.
51. Lakshmi V, Stephen M, Mary P et al(2003).Establishing Minimal Clinically Important Differences for Scores on the Pediatric Evaluation of Disability Inventory for Inpatient Rehabilitation PHYS THER October 83:888-898.
52. Laura A (2007). Locomotor Training within an Inpatient Rehabilitation Program After Pediatric Incomplete Spinal Cord Injury PHYS THER September 87:1224-1232.
53. Lieber R and Friden J (2000).Functional and clinical significance of skeletal muscle architecture. Muscle Nerve. 23:1647–1666.
54. Maurits N , Beenakker A, Schaik A et al (2004).Muscle ultrasound in children: Normal values and application to neuromuscular disorders. Ultrasound in Medicine and Biology. Volume 30, Issue 8 , pages 1017-1027.
55. McCarthy M, Silberstein C and Atkins E (2002).Comparing reliability and validity of pediatric instruments for measuring health and well-being of children with spastic cerebral palsy.Dev Med Child Neurol.; 44:468–476.
56. Mellado J, Palomar L, Diaz L et al (2004). Long standing Morel-Lavallée lesions of the trochanteric region and proximal thigh: MRI features in five patients. AJR Am J Roentgenol 182:1289–1294.

57. Mizner R and Snyder-Mackler L (2005). Altered loading during walking and sit-to-stand is affected by quadriceps weakness after total knee arthroplasty. J Orthop Res.; 23: 1083–1090.
58. Mohagheghi A, Khan T and Meadows T (2008).In vivo gastrocnemius muscle fascicle length in children with and without diplegic cerebral palsy.Dev Med Child Neurol; 50:44 –50.
59. Mohagheghi A, Khan T, and Meadows T (2007). Differences in gastrocnemius muscle architecture between the paretic and nonparetic legs in children with hemiplegic cerebral palsy. ClinBiomech (Bristol, Avon).; 22:718–724.
60. Montet X, Mauget D, Martinoli C et al (2002). Tensor fasciae suralis US and MRI imaging. Skeletal Radiol 31:536–538 Olsen KI, Stacy S, Montag A (2004) Soft-tissue cavernous haemangioma. Radiographics 24:849–854
61. Moreau N and Simpson K (2010). Muscle Architecture Predicts Maximum Strength and Is Related to Activity Levels in Cerebral Palsy PHYS THER.; 90:1619-1630.
62. Moreau N, Kit N, Sharlene A et al (2010). Muscle Architecture Predicts Maximum Strength and Is Related to Activity Levels in Cerebral Palsy. PHYS THER November 90:1619-1630.
63. Moreau N, Teefey S and Damiano D (2009).In vivo muscle architecture and size of the rectus femoris and vastus lateralis in children and adolescents with cerebral palsy.Dev Med Child Neurol.; 51:800–806.
64. Mutch L, Alberman E, and Hagberg B (1992). Cerebral palsy epidemiology:where are we now and where are we going? Dev Med Child Neurol.; 34:547–551.
65. Nelson A, Emily F, David P et al (2011). Ultrasound-assisted musculoskeletal procedures: A practical overview of current literature.World J Orthop.Volume 2, Issue 7. July 18; 2(7): 57-66-
66. Ohata K, Tsuboyama T, Ichihashi N et al (2006).Measurement of muscle thickness as quantitative muscle evaluation for adults with severe cerebral palsy.Phys Ther.;86:1231–1239.
67. Palisano R, Copeland W and Galuppi B (2007).Performance of physical activities by adolescents with cerebral palsy.PhysTher.; 87:77–87.
68. Pierce R, and Barbe M(2008). Roles of Reflex Activity and Co-contraction During Assessments of Spasticity of the Knee Flexor and Knee Extensor Muscles in Children With Cerebral Palsy and Different Functional Levels. *PHYS THER.*; 88:1124-1134.
69. Rask M and Lattig G (1972).Traumatic fibrosis of the rectus femoris muscle.Report of five cases and treatment. JAMA17:268–269
70. Rouvière H (1974).Anatomiehumaine, descriptive, topographiqueetfonctionnelle. Masson, Paris, p 354 Schneider R, Kaye JJ, Ghelman B (1976) Adductor avulsive injuries near the symphysis pubis. Radiology 120:567–569
71. Sara J, Carolee J, Kornelia K et al (2011). Special Issue on Advances in Disability Research: Secondary Mediation and Regression Analyses of the PTClinResNet Database: Determining Causal Relationships Among the *International Classification of Functioning, Disability and Health* Levels

for Four Physical Therapy Intervention Trials, for the Physical Therapy Clinical Research Network (PTClinResNet) PHYS THER December91:1766-1779.

72. Shortland A, Harris C, Gough M et al (2002).Architecture of the medial gastrocnemius in children with spastic diplegia.Dev Med Child Neurol.; 44: 158 –163.
73. Singhi P (2004). cerebral palsy management Indian J.Paediatrcs;71(7): 635-639.
74. Sipila S and Suominen H (1991).Ultrasound imaging of the quadriceps muscle in elderly athletes and untrained men. Muscle Nerve. 14:527–533.
75. Slavotinek J, Verrall G and Fon G (2002). Hamstrings injury in athletes: using MR imaging measurements to compare extent of muscle injury with amount of time lost from competition. AJR Am J Roentgenol 179:1621–1628
76. Stacey C, Catherine M, and Shaaron E (2012).Instituting Parent Education Practices in the Neonatal Intensive Care Unit: An Administrative Case Report of Practice Evaluation and Statewide Action PHYS THER July 92:967-975
77. Stackhouse S, Binder-Macleod S and Lee S(2005).Voluntary muscle activation, contractile properties, and fatigability in children with and without cerebral palsy. Muscle Nerve. 31:594–601.
78. Stephen M, Helene M and Larry H (2001). Variation by Diagnostic and Practice Pattern Groups in the Mobility Outcomes of Inpatient Rehabilitation Programs for Children and Youth PHYS THER August 81:1425-1436.
79. Stephen M, Maria A, Helene M et al (2009).Evaluation of an Item Bank for a Computerized Adaptive Test of Activity in Children With Cerebral Palsy. PHYS THER June89:589-600
80. Temple H, Kuklo T, Sweet D et al (1998). Rectus femoris muscle tear appearing as a pseudotumor. Am J Sports Med26:544–548
81. Thubi H (2004).Childrearing Practices and Developmental Expectations for Mexican-American Mothers and the Developmental Status of Their Infants.*PHYS THER May 84:439-453*.
82. Thubi H, Michelle B and Louisa S(2004). Predicting Motor Outcome at Preschool Age for Infants Tested at 7, 30, 60, and 90 Days After Term Age Using the Test of Infant Motor Performance.PHYS THER December 84:1144-1156.
83. Uremović M, Pasić M, Serić V et al. (2004).Ultrasound Measurement of the Volume of Musculus Quadriceps after Knee Joint Injury.Volume of Musculus Quadriceps, Coll. Antropol.28 Suppl. 2:227–233.
84. Verschuren O, Ketelaar M, and Gorter J (2007). Exercise training program in children and adolescents with cerebral palsy: a randomized controlled trial. Arch PediatrAdolesc Med.;161:1075–1081.
85. Weaver J, Jacobson J, Jamadar D et al (2003).Sonographic findings of adductor insertion avulsion syndrome with magnetic resonance imaging correlation. J Ultrasound Med22:403–407

86. Wickiewicz T, Roy R, Powell P et al (1983). Muscle architecture of the human lower limb. ClinOrthopRelat Res.; Oct:275–283.
87. Yoshioka H, Anno I, Niitsu M et al (1994) MRI of muscle strain injuries. J Comput Assist Tomogr 18:454–460
88. Young N ,Williams J, Yoshida K et al (2000).Measurement properties of the Activities Scale for Kids. J Clin Epidemiol.;53:125–137.
89. Young N, Yoshida K and Williams J (1995).The role of children in reporting their physical disability. Arch Phys Med Rehabil.;76:913–918.