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TITLE PAGE

ARTICLE INFORMATION	Fill in information in each box below
Article Title	PARASPINAL MUSCLES TONE ASSESSMENT IN SUBJECTS WITH A MILD SINGLE SCOLIOSIS CURVE: A MYOTONOMETER PILOT STUDY
Key Words – ***only use*** **MeSH** terms that are found at http://www.nlm.nih.gov/mesh/meshhome.html	Adolescent; Muscle Tonus; Physical Examination; Scoliosis; Spine
Running head - no more than 40 letters/ spaces	MYOTONOMETRY AND IDIOPATHIC SCOLIOSIS
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Practical Applications Three to 5 short sentences that highlight *findings* of the study. These statements should relate directly to the study findings.	• No differences in muscle hardness have been found using a myotonometer in paravertebral sites related to the concave and convex sides of the scoliosis curve in subjects with a mild IS. • The scoliosis curve severity (Cobb angle) showed a negative correlation with muscle hardness at two points on the convex side. • No correlation was found between hardness of the spinal muscles and the body mass index. • Future studies with a control group are necessary to determine the validity of these results
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Abstract

Objective: To evaluate the paraspinal muscles hardness in the convexity and concavity of the scoliosis curvature and in the upper trapezius (UT) muscle in subjects with mild idiopathic scoliosis (IS), and to observe the correlation between the myotonometer (MYO) measurements and the value of the body mass index (BMI) and the Cobb angle.

Methods: The sample included 13 patients with a single-curve mild IS (Risser sign ≤ 4) at thoracic, lumbar or thoracolumbar level (mean Cobb angle of 11.53º). Seven females and 6 males were recruited, mean age 12.84 ± 3.06 (9-18 years). A MYO was used to examine the differences in muscle hardness on both sides of the scoliosis curvature at several points: (i) apex of the curve; (ii) upper and lower limits of the curve; (iii) the midpoint between the apex and the upper limit and between the apex and the lower limit. The UT was also explored.

Results: Although the MYO recorded lower values in all points on the concave side of the scoliosis, there were no significant differences in the comparison between sides ($p > 0.05$). No association was observed between BMI and MYO values, whereas the Cobb angle negatively correlated with muscle hardness only at two points on the convex side.

Conclusion: The preliminary findings show that in subjects with a single-curve mild IS, muscular hardness in the UT and paraspinal muscles, as assessed using a MYO, was not found to differ between the concave and the convex sides at different reference levels.

Key Indexing Terms: Adolescent; Muscle Tonus; Physical Examination; Scoliosis; Spine

INTRODUCTION

Scoliosis is a common health problem, defined as a three-dimensional spine deformity. [1] Its origin is only verifiable in 15%-20% of cases. [2] Therefore, idiopathic scoliosis (IS), which cannot be aetiologically linked to any particular factor, is the most common diagnosis of spine curvature dysfunction in young subjects. [3] Prevalence rates vary from 0.35% to 13%, and it is most commonly seen in females. [4] The presence of a neuromuscular disorder has been suggested as a plausible cause for scoliosis, [5, 6] along with hormonal and chemical dysfunctions. [7] A brain asymmetry has even been related to a head tilt and a consequent blocking of the atlanto-occipital joint, which may influence the curve progression. [8]

A change in the spinal muscles fibre composition in the thoracic region has been observed in female scoliosis patients. [9] A significant decrease in the proportion of type I fibers and an increase in the percentage of types IIB and IIC fibers, in comparison with a control group, has been found on the concave side, whereas changes on the muscles of the convex side were of similar nature, but not so severe. [9] Whether these changes are a consequence or a causal factor of IS remains unknown. [10] Other studies also point to a difference in the spinal muscles volume between both sides of the curve, [2] and to an increased electromyographic activity of the paravertebral muscles at the convex side, [11] especially at the apex vertebra. [2, 12]

All of this translates as a possible spinal muscles tone imbalance and the presence of compensatory patterns as aetiological factors for adolescent IS. [7] On the one hand, instability of the spine in IS has been correlated with muscle atrophy, [13] and overstretching of the tissue on the convex side. [14] In regards to the metabolic processes involved in the pathogenesis of IS, there appears to be a disruption in the balance between muscle tone regulators (melatonin and calmodulin). [7] Higher levels of calmodulin have been found in paraspinal muscles at the convex side, which seems to increase muscle contractility at that side and to cause a neuromuscular imbalance. [15] On the other hand, several studies indicate an absence of changes in the erector spinae muscle functionality when comparing IS individuals with a control group. [16, 17] Therefore, it is difficult to reach a definite conclusion about the possible differences between the sides of the scoliosis curve. [17]

Previous research in this area has primarily used surface electromyography (EMG) or magnetic resonance imaging (MRI) as evaluative tools of muscle activity. [2, 12, 18] Muscle hardness (MH) is also a defining characteristic of muscle activity and can be measured using a myotonometer (MYO). MH has been suggested to correlate with muscle pain sensitivity and exercise. [19] An increased MH seems to be associated with chronic musculoskeletal dysfunctions, [19] and may be an indication of tissue oedema, hypoxia and local acidosis, [20] or even altered mechanosensitivity in soft tissues. [21]

Truncal asymmetry has been linked with body mass index (BMI) in adolescent IS. [22] A lower BMI was found in IS and related to back shape asymmetry. [22] As suggested by Cheung et al, [23] increased paraspinal activity at different levels of the scoliotic curve may disturb the spinal balance and be related to the curve progression, and consequently, to the value of the Cobb angle. Therefore, an asymmetric paraspinal activity is associated with increased axial rotation, which in its turn is linked with progressiveness of the scoliosis, [24] especially at the lower end vertebra of the curve. [6] However, no previous attempts have made been to correlate BMI or Cobb angle values with spinal MH.

The present research hypothesized that MH differs in the convex and concave sides of the scoliosis curve. The purpose of this study was to assess the paraspinal MH in both sides of the scoliosis curvature and in the upper trapezius muscle in subjects with mild IS, and to observe the correlation between the MYO measurements and the value of the BMI and the Cobb angle.

METHODS

Study Design

An observational and controlled pilot study was carried out.

Setting

Participants were recruited from the clinical practice where one of the researchers was working. Data was collected for 5 consecutive months (from January to May 2012). Based on a non-probability convenience sample, 22 eligible adolescents were sequentially selected for the study. Seven of them did not meet the inclusion criteria and 2 refused to participate. The final sample included 13 subjects (7 females and 6 males) who were diagnosed with mild IS. No losses to follow-up were recorded during data collection and analysis phases. Inclusion criteria were established as follows: (a) not older than 18 years; (b) Cobb angle ≥ 10°, because scoliosis is defined as a lateral spinal curvature of at least 10° Cobb angle; [25] (c) Risser sign ≤ 4; (d) scoliosis single curve (C-curve). Excluded from the study were subjects with: (a) any known and diagnosed cause for scoliosis; (b) a history of central nervous system and/or peripheral degenerative diseases; (c) neuromuscular or rheumatic diseases and/or tumours; (d) fractures at any vertebral level; (e) having experienced back pain in the 6-months before data collection; (f) having undergone bracing treatment or surgery for the IS; (g) presence of lower limb dysmetria. The study complied with the ethical precepts of research involving human subjects and was approved by the Institutional Research Ethics Committee.

Evaluator

A registered physical therapist with 4 years of clinical experience performed the assessments. The evaluator was previously trained by an instructor in managing the assessment tool (MYO) and practised the evaluation protocol for a week before data collection.

Muscle hardness (MH) assessment

MH is defined as the degree of deformity of the muscle to a given pressure. [21] The MYO is one of the non-invasive examination tools to assess MH, along with the "hardness-meter", [26] and the muscle compartment pressure tool. [27] MH is measured taking into account the tissue displacement (mm) under the measurement area or area under the curve (AUC), in relation to a perpendicularly applied compressive force (kg). Hence, the AUC score (unit-less) is related to the work done while the probe compresses the tissue, [28] and the amount of energy stored in the tested tissue. [29] The AUC value can be a measure of muscle spasm, [27] and it also correlates with tissue stiffness. With a constant force, the amount of work decreases when the tissue distance travelled while compressing is less. [28]

The device used in this study (Neurogenic Technologies ® Inc., Missoula, USA) consists of a metal probe, 1 cm in diameter, surrounded by a 3.5 cm diameter metal and plastic shaft. The surfaces between the probe and the shaft are die-casted to reduce friction between them (fig 1). By applying pressure, the housing remains stationary on the surface of the skin while the probe exerts the muscular level deformation. All the data is registered and stored by software attached to the device that creates a real-time force displacement curve based on these data with a sampling rate of 200 samples per second. The program usually defaults the *x*-axis to show the force used in each position while the *y*-axis shows the distance travelled by the probe (fig 2). The MYO is programmed to take 8 length-tension measurements per recording. The measurements were performed at 0.25 kg intervals (0.25 to 2.0 kg). In the case of children and/or young people, the subject may require the application of the maximum force to be reduced to 1 kg. Data recorded at force levels between 0.75 and 1.50 kg are recommended as the most reliable. [30] The rate of force application was approximately 1kg/s.

During the measurement protocol, the evaluated muscles were relaxed. With the patient lying prone, 10 reference points were marked on the vertebral spine on both sides of the curve. Five consecutive measurements were taken, with a 15 to 30 seconds interval between them. [30] This pause between measurements has been standardised for soft tissues to return to baseline in the MYO assessments in children. [30] It is also higher than the 10 seconds resting period that has been established in adults when measuring MH during isometric contraction. [31] The mean of the different evaluations was taken as the reference value.

MH was assessed in the medial and lateral points at: (I) apex of the curve; (ii) upper and lower limits of the curve; (iii) midpoints between the apex vertebra and the upper limit and between the apex of the curve and the lower limit of the same (fig. 3). The medial location was considered as on the spine whereas the lateral point was immediately external to the anterior. Apex, upper and lower limits were identified with radiographs, and then localised in the subject with manual palpation along with the rest of the points. The MH was also explored in the upper trapezius (UT) muscle in both hemibodies. The reference point was located in the angle between the side of the neck and the cranial edge of the UT, coinciding with the area described for the location of the tense band of this muscle. [32]

The intra and inter-observer reliability of this assessment procedure in adults has proven to be high to very high, [31] and the test-retest reliability has seen to be good to excellent (ICC 0.80 to 0.93). [33] Myotonometry has been also described as reliable when assessing muscle tone in children under contracted and relaxed conditions, with high to very high intrarater ICC with the muscle relaxed (0.80 to 0.94). [30] The statistical treatment and subsequent analysis of the results used the AUC value. [34] The MYO has shown a low standard error of measurement (below 10%) and minimally detectable change values (below 25%), at least for the biceps and triceps brachii muscles. [35]

Measurement Protocol

After confirming that the subject fulfilled the inclusion/exclusion criteria and desired to participate, the first step was to sign, both by the subject and the legal guardian, the informed consent form that was prepared in accordance with the Declaration of Helsinki. The participant's clinical data (age, height, weight, body mass index, location of the scoliosis curve) were collected prior to the MYO evaluation.

Data Analysis

The statistical data processing was performed using the PASW Advanced Statistics 18.0 tool (SPSS Inc., Chicago, USA). The values are expressed as mean, with the corresponding standard deviations and/or 95% confidence intervals (95% CI), as well as percentage frequencies for the qualitative variables. The normality of the variables was verified with the Kolmogorov-Smirnov test. Only the MH in the lateral location midway between the apex and the lower limit of the curve followed a non-normal distribution ($p = .004$).

The comparison of the MYO scores between the concave and convex sides was analyzed using the Student t-test for independent samples and the U Mann-Whitney test. The Pearson correlation test or, if applicable, the Spearman test, were used to analyze the clinical association between the AUC value at the different points and the value of both, the BMI as well as the Cobb angle. All the hypothesis tests considered statistically significant a p value $< .05$.

RESULTS

Thirteen subjects with IS, 7 females and 6 males, aged between 9 and 18 years (12.84 ± 3.06) constituted the study sample. The baseline clinical characteristics of the participants are shown in table 1.

Table 2 lists the results of the MYO examination in the concavity and convexity of the scoliosis curve, and the between-sides comparison of the MH scores. The highest values were found for the lower limit of the curve and the lateral location to the midpoint between the apex and the superior limit of the curve on both sides. In addition, the AUC scores were higher on the convex side of the scoliosis at all the reference points. The UT followed the behaviour described for paravertebral muscles. However, the score differences between sides were not significant in any of the evaluated points ($p > .05$ in all cases).

In the correlation study, there was no statistical significance between BMI and MYO values at any point ($p > .05$). On the contrary, the Cobb angle significantly correlated with MH at two points, but only on the convex side of the curve. There was a negative correlation between the Cobb angle and the UT hardness ($p = .024$, $r = -0.598$, $r^2 = 0.35$) and between the Cobb angle and the MH in the location lateral to the midpoint between the apex and the lower limit of the curve ($p = .030$, $r = -0.579$, $r^2 = 0.33$). In all other locations there was no significant correlation ($p > .05$).

DISCUSSION

The study results seem to point to preliminary findings related to no differences in spinal MH between areas located in the concavity and convexity of the scoliotic curve. The same MH pattern was found in the UT muscle. These results do not support the initial hypothesis. In addition, here was a negative correlation between the severity of the curvature and the AUC score in the UT muscle and the site lateral to the midpoint between the apex and the lower limit on the convex side of the curve. The finding suggests that the higher the Cobb angle is the lower the MH is in some specific sites, but only on the convexity of the scoliosis.

This is the first study to use a MYO as an assessment tool in IS. The MYO has been described as accurate to measure muscle stiffness, [33] and to detect differences in muscle tension. [36] It can also be helpful to diagnose muscle pathology. [37] Myotonometry is a valid and reliable assessment tool, both in adults [31, 33] and children (mean age 10.85 years). [30] However, some of the error values reported in the present study surpassed the standard error of the MYO. [35] This could be attributable to the fact that a week was probably an insufficient period of training for the evaluator, even though high intrarater and interrater reliability has been previously observed for novice users (ranging from 0.74 to 0.99). [38] The speed of force application was controlled, in opposition to previous studies, [31] and was below the 2kg/s force that has been usually applied in healthy adults, [39, 40] which could have influenced the findings.

Along with EMG, myotonometry has also been found to be a reliable method to predict intramuscular pressure, at least in subjects with compartment syndrome. [37] In addition, MH has been associated with morphological changes of muscles. [39] Even though myotonometry is correlated with surface EMG and with the modified Ashworth scale, [40] the use of a MYO has several advantages compared to EMG. While EMG is time-consuming and data interpretation may be difficult, the MYO is simple to use and the data is easy to obtain and interpret.[41] It has been recommended to describe the MYO results with regard to the AUC, instead of reporting the amount of tissue displacement.[28] In addition, risk of measurement error decreases if the reference value is the mean of several consecutive measurements,[31, 33] as in the present research.

Although no statistical significance was found in the comparison between sides, differences between the concavity and convexity of the curve need to be discussed. The higher the degree of muscle stiffness, the smaller the tissue displacement per unit force.[34] A higher value of the AUC was found in the convex side, which means that the soft tissue at that side showed less resistance to the pressure of the MYO device.

These observations disagree with previous studies that concluded differences between both sides of the curve. A higher activity (EMG) in the muscles of the convex side has been previously reported.[6, 42] Regarding muscular composition, the concave side has been described as the most affected, especially at the apex vertebra, because a lower percentage of type I tonic fibres has been found in this side in individuals with IS.[9] These findings suggest an inability of the spinal muscles to maintain tonic contractions due to prolonged muscle inactivity.[9] One of the possible reasons for the difference in results between studies may be that the present research has assessed subjects with a mild curve (mean Cobb angle 11.53º). An EMG difference in the active trunk extension was found in adolescent IS only when the Cobb angle was above 30º.[42] Also, Reuber et al[43] concluded that a greater myoelectric activity in the convex side is only evident in individuals with a Cobb angle higher than 25º. In female subjects with a mild IS, EMG recordings differed only during asymmetrical stretching of the paravertebral muscles on the concave side during trunk extension, but not at rest or during symmetrical contractions. [44] In any case, the methodological differences hinder the comparison between studies as none of the previous works used myotonometry.

On the contrary, in line with the present results, no EMG changes have been found between sides, at least at the thoracic level, in subjects with IS. [16] However, only 6 subjects with right thoracic curve were evaluated in that study. In addition, EMG assessments were made in several spinal level sites not strictly related to the curve endpoints or apex. [16] De Oliveira et al [17] also concluded a lack of EMG differences in the apex vertebra in thoracic and lumbar scoliosis curves. The present findings seem to confirm these observations for MH and in new sites of the scoliosis curve. The differences among studies using EMG have been explained based on the use of unclear methodology or because some of them were conducted before the appearance of international guidelines about the development of surface EMG, which may lead to their results being called into question. [17]

The lack of differences in MH was also seen in the UT muscle. Some works have found morphological alterations in peripheral muscles of subjects with IS, [3] while others have reported changes in the EMG values only in the body area where the scoliosis is located. [6] A moderate correlation between the degree of curvature and UT hardness was observed. Even though only mild curves were evaluated, the severity of the Cobb angle accounted for about 35% of the MH value in the UT, and approximately 33% in the midpoint between the apex and the lower limit on the convex side. This observation must be interpreted with caution. In addition, a relatively lower BMI has been associated with truncal asymmetry in healthy adolescents. [22] Nevertheless, the musculo-skeletal mechanisms involved in truncal asymmetry remain unknown. [22] In the present study, the BMI was within the average and no differences in MH of the paravertebral muscles were observed. This may explain the lack of correlation that was found between BMI and MH.

The absence of MH differences between the sides of the curve appears to be confirmed not only in the apex vertebra, but also in the upper and lower limits of the curve and at its midpoint. Paravertebral muscles seem to present an important functional deficiency on both sides of the curve. [45] It has been previously suggested that the concave and convex sides of the scoliosis may be equally responsible for the static imbalance that accompanies IS. [45] On the contrary, an asymmetric approach has been found to improve muscular activity on the concave side, at least in the apex site at the thoracic and lumbar levels. [46] It remains unknown if the MYO results are related or not to muscle strength. This aspect needs to be evaluated in future studies, because paravertebral muscles strength is a key factor for the physical therapy treatment protocol in IS. Likewise, myotonometry could be used to observe the efficacy of different therapeutic interventions that aim to reduce muscle stiffness in IS. [36]

Study Limitations

The MYO is not appropriate for thin muscles, deep soft tissues, muscles with small mass or those that are palpable in small volume. [35] The selected sample was small because the research was designed as a pilot study, in line with former works assessing paravertebral muscles in IS. [16] Data obtained from this study will be used to determine the number of subjects needed in future studies to evaluate new findings in a larger sample. Manual palpation was used to locate the spinal sites. Although very common in daily practice, spinal manual palpation is subject to certain discrepancy among examiners and has a generally low reliability. [47] Measurements were made with the subject resting in the prone position. [5] However, bipedality appears to be crucial in the aetiology, incidence and development of IS. [7] Therefore, future evaluations with the subjects in standing position would be of interest.

The study has not evaluated a matched healthy control group of volunteers without IS. In addition, the research has focused only on individuals with a single scoliosis curve, whether thoracic, lumbar or thoracolumbar. Therefore, even though MYO measurements were made in the paravertebral muscles, the heterogeneity of apical sites between subjects may have an influence concerning the muscle layers that were tested. The possible variability in regard to the tested muscles may have obscured the convex-concave differences in the analyses. In addition, the study was only focused on mild IS. Mild forms of adolescent IS are not always treated. For instance, physiotherapy is highly recommended when curve magnitude is > 15º Cobb angle. [48] However, patients with mild-scoliosis are very common in the clinical practice, [49] and both, treatment and a proper assessment are needed in an early stage to prevent progression. It would be possible that the lack of significant findings simply reflects a lack of difference because the scoliotic curves were too small. Hence, the study sample may not be considered as a representative group of adolescents with IS, although the present findings may help to get a better understanding of the spinal MH in IS.

CONCLUSIONS

This study provides preliminary evidence that in subjects with a single-curve mild IS, there are no differences in MH, as assessed using a MYO, between the concave and convex sides of the curvature in the UT and paravertebral muscles at the apex vertebra, midpoint of the curve, and upper and lower limits of the scoliosis curvature. A negative correlation was found between the Cobb angle and MH only at two points on the convex side, whereas there was no association between BMI and MYO values.

Practical Applications

No differences in muscle hardness have been found using a myotonometer in paravertebral sites related to the concave and convex sides of the scoliosis curve in subjects with a mild IS.

The scoliosis curve severity (Cobb angle) showed a negative correlation with muscle hardness at two points on the convex side.

No correlation was found between hardness of the spinal muscles and the body mass index.

Future studies with a control group are necessary to determine the validity of these results

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LIST OF FIGURES AND TABLES

Table 1 Clinical characteristics of the study subjects*

Item	Study Group. Sample total (N=13)
Age (years)	12.84 ± 3.06 (9 - 18)
Gender Male (n / %) Female (n / %)	 6 / 57.1 7 / 42.9
Height (cm)	158.46 ± 8.85 (145 - 175)
Weight (kg)	50.34 ± 9.26 (33 - 63)
BMI (kg/m²)	19.98 ± 2.97 (14.90 - 26.14)
Cobb Angle (°)	11.53 ± 1.42 (10 - 14)
Scoliosis curve location Dorsal (n / %) Lumbar (n / %) Dorso-lumbar (n / %)	 1 / 7.69 1 / 7.69 11 / 84.61

* Data are expressed as mean ± standard deviation (lower to upper limits) or frequency mode (%)

Table 2 Muscle hardness value (unit less) and mean differences between concave and convex sides of the curve, in the myotonometry examination†

Reference Point AUC Value	Mean Value ± standard deviation	Mean difference between sides (95% CI)	P value
Medial Apex of the Curve Concave Side Convex Side	 14830.38 ± 3667.34 17180.92 ± 3101.74	 -2350.53 (-5099.97 / 398.89)	 0.090
Lateral Apex of the Curve Concave Side Convex Side	 16221.84 ± 2428.66 17766.76 ± 2440.87	 -1544.92 (-3515.94 / 426.06)	 0.119
Medial Upper Limit Curve Concave Side Convex Side	 16542.07 ± 2520.71 17072.92 ± 2709.18	 -530.84 (-2649.09 / 1587.40)	 0.610
Lateral Upper Limit Curve Concave Side Convex Side	 17581.38 ± 3415.15 20493.38 ± 4805.77	 -2912.00 (-6286.80 / 462.80)	 0.088
Medial Lower Limit Curve Concave Side Convex Side	 21516.23 ± 5241.64 22092.07 ± 5439.42	 -575.84 (-4899.89 / 3748.20)	 0.786
Lateral Lower Limit Curve Concave Side Convex Side	 19821.23 ± 4279.30 21773.76 ± 4790.95	 -1952.53 (-5629.60 / 1724.56)	 0.284

Medial Superior Midpoint Concave Side Convex Side	 15871.15 ± 3318.96 16137.76 ± 3517.12	 -266.61 (-3034.78/ 2501.54)	 0.844
Lateral Superior Midpoint Concave Side Convex Side	 22792.07 ± 4077.01 23649.00 ± 3860.40	 -856.92 (-4070.89 / 2357.04)	 0.587
Inferior Medial Midpoint Concave Side Convex Side	 16673.76 ± 3388.08 17783.76 ± 4235.31	 -1110.00 (-4214.67 / 1994.67)	 0.468
Lateral Inferior Midpoint Concave Side Convex Side	 19546.61 ± 3842.80 19836.53 ± 4205.65	 -289.93 (-3550.96 / 2971.11)	 0.856 *
Upper Trapezius Concave Side Convex Side	 14651.07 ± 3549.18 16524.92 ± 3260.11	 -1873.84 (-4632.49 / 884.79)	 0.174

†The results are expressed as mean ± SD, standard deviation and 95% Confidence Interval (95% CI)

AUC = area under the curve, p – value = statistical significance of the comparison between sides (Student's t test), * as compared with the U-Mann Whitney test

Figure 1 Myotonometer

Figure 2 Force-displacement curve displayed by the myotonometer in the lateral midpoint between the apex and the upper limit of the curve.

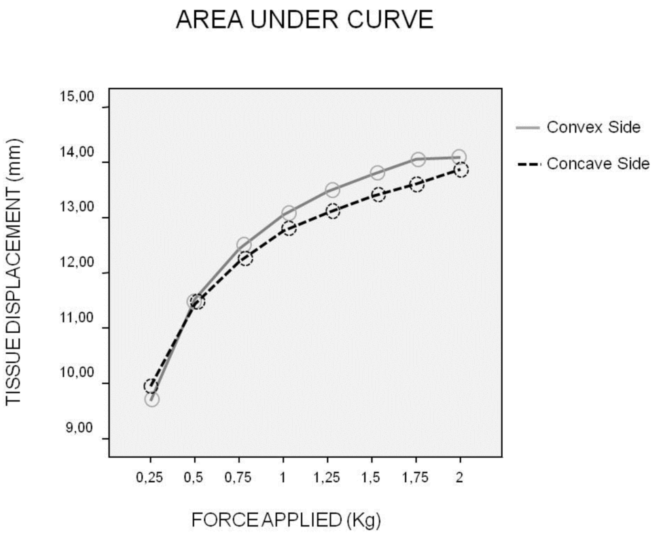

Figure 3 Reference points for the examination of muscle tone by myotonometry

AV = Apex Vertebra of the Curve, UL = Upper limit of the curve, LL = Lower limit of the curve, AVUL = Midpoint between apex and upper limit, AVLL = midpoint between apex and lower, UT = Upper trapezius

Black circles represent the medial points in each location and white circles represent the lateral point.

Note: Measurements were made in both sides.