The Applicability of Muscle Ultrasonography in Physiotherapy Researches

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Abstract. Within the last century, many medical approaches have been invented and widely upgraded in the field of medical sciences. Ultrasonography is a non-invasive method in medical diagnosis which has several applications in musculoskeletal evaluation. Each ultrasonography picture is a very thin tomographic slice of the anatomy being examined. With ultrasonography an examiner is able to measure the cross-sectional area, and linear dimensions such as the anterioposterior dimension (APD) and lateral dimension (LD) of the muscle. It is also possible to calculate the multiplied linear dimension by the equation APD times LD and the shape ratio by the equation LD/APD. In biophysiological measurement ultrasonography is a digital measurement device with a high accuracy for identifying small structures. In the field of muscle research, compared to muscle strength test and surface electromyography, ultrasonography can easily screen and evaluate the individual muscle contraction even in the deep layers. During ultrasonography the muscle image is continuously updated. Therefore, the method may be useful in physiotherapy of weak muscles by means of visual feedback.

Key words: Muscle, Ultrasonography, Physiotherapy

INTRODUCTION

Muscle ultrasonography has been reported to be a valuable technique in muscle size evaluation. Statistical outcomes have shown muscle ultrasonography is highly reproducible for the tibialis anterior muscle, back multifidus muscle, quadriceps femoris muscle, splenius capitis muscle and semispinalis capitis muscle measurements1-5). The growing number of muscle ultrasonographic studies entering the literature may reflect an increased acceptance of the technique in musculoskeletal evaluation6-11). Heckmatt et al.12) studied muscle atrophy and related pathological changes with ultrasonography and proposed that muscle ultrasonography was a good indicator for muscle wasting.

Gunreben and Bogdahn13) demonstrated that ultrasonic scanning had some specificity and was more sensitive than biopsy in the early stages of myopathy in spinal muscle atrophy. Walker et al.14) reported that muscle ultrasonography was capable of identifying fasciculation in neuromuscular diseases, especially in an area where thin muscles overlap. By using real-time ultrasonography Young et al.15) and Hides et al.16) revealed a remarkable loss of quadriceps muscle bulk and back multifidus muscle size in a group of patients suffering from knee pain and acute low back pain.

In the field of musculoskeletal research, ultrasonography has been successfully used to studying the function of individual muscles1, 6, 17). Kelly and Stokes18) compared the right and left tibialis anterior muscles and stated that muscle size
was independent of hand dominancy. In further studies, Hides et al. described the level of the difference between the sizes of the right and left spinal multifidus muscles in a group of healthy subjects. In the patients with acute low back pain and scoliosis Kennelly and Stokes and Hides et al. presented ultrasonography as a new approach for identifying patterns of asymmetry in lumbar multifidus muscle sizes.

Muscle ultrasonography has also been used to compare the size of an individual muscle in different groups of elite athletes with different training and competition programmes. Another application of muscle ultrasonography is describing the association between muscle size and concerned muscle force in biomechanical studies. Muscle size measurements have been suggested as good indicators for muscle force measurement. In a comparison between the thickness of the triceps brachii muscle and force output during elbow extension, the antero-posterior dimension of the muscle was revealed to be proportionate to the level of the muscle performance.

Evaluation of muscle components is another application of ultrasonography. In an earlier study, Sipila and Suominen evaluated the composition of the quadriceps muscle after a follow-up training programme in elderly females. They found that the training programme had led to a marked decrease in the inter-muscular fat component of the quadriceps muscle. Ultrasound myography is a different application of ultrasonography in musculoskeletal research. It has been suggested as a practical, easy and non-invasive technique for the assessment of the peripheral nerve conduction velocity.

MUSCLE SIZE MEASUREMENTS BY ULTRASONOGRAPHY

Each ultrasound image is a very thin tomographic slice of the anatomy being examined. In each slice, muscle bundles have a hyperechoic appearance which is seen as a bright hyperechoic line in an ultrasonographic picture. Fat planes appearing between muscles make it easier to separate muscles from each other. Inside the muscles there are several fascicles and there may also be some aponeurotic intersections. Like the muscle bundles, the fascicles and the aponeurotic intersections appear as brightly echogenic lines. Resolution is the ability of ultrasound to display the distance between two separate echogenic interfaces, for example muscle tissues and bundles. A high resolution for muscle examination can be achieved by using a 7.5 MHz linear array transducer.

In real-time linear array ultrasonography, if the area of the muscle is less than the width of the probe, then the entire muscle bundle will be shown in a single image. In this case the area and distance values (width and thickness) of the muscle can be

GENERATING ULTRASOUND

Ultrasound is defined as any sound with a frequency greater than 20 KHz. It was after 1945 that ultrasound gradually began to play an important role in medical diagnosis. Ultrasonic waves are artificially produced when an alternating high-voltage electric current of 300–700 volts stimulates the sides of a quartz crystal which is located in a transducer. The frequency produced by the transducer will depend on the number of voltage cycles. That is, a transducer with a 7.5 MHz frequency requires an alternating voltage of 7.5 million times per second.

Ultrasonic energy traverses a medium such as human tissues by means of wave motion. Ultrasonic waves become weaker as they travel further through the tissues and weaken also as they return toward the skin’s surface. The interaction of ultrasound and tissues appears as attenuation, the diminution of wave amplitude under several processes such as absorption, reflection and scattering.

A useful measure of the energy associated with ultrasonic waves is intensity. This is defined as the amount of energy crossing a unit area during a unit of time. The intensity of ultrasound varies smoothly as the ultrasonic wave passes through the medium. When echoes are reflected back to the crystal they vibrate the crystal surface and produce a very short-voltage electrical current (from .01 to 1,000 mV). These short voltages pass through a pre-amplifier, becoming stronger, and then proceed to a scanner. The scanner identifies and measures the amplitude of the different echoes and produces an image of the different soft tissues. The brightness of the tissues depends on the amplitude of the echoes. The higher the amplitude, the brighter is the picture. An ultrasonography method capable of producing a bright and two-dimensional picture is b-mode ultrasound.
measured by means of caliper marks.

The cross-sectional area (CSA) of the muscle can be measured in two ways, either by enclosing the outline of the muscle using an elliptical measurement tool, or by tracing the outline of the muscle manually. Such muscle linear dimensions as width or the lateral dimension (LD) and thickness or the anteroposterior dimension (APD) are measured as the greatest distance between muscles borders perpendicular to each other. The multiplied linear dimension (MLD) is calculated as $\text{LD} \times \text{APD}$.

**Agreement between muscle cross-sectional area and the multiplied linear dimension**

The results of investigations into the association between CSA and the MLD have demonstrated a high degree of correlation between the two variables for the back multifidus muscle and neck splenius capitis muscle$^{2, 5, 19}$.

The association between CSA and MLD is important because some portable ultrasonography units are incapable of measuring CSA. Therefore, measuring linear dimensions may be the only way to evaluate muscle size. In addition, linear dimension measurement is quick and enables a rapid comparison of muscle size changes between states of relaxation and contraction$^{28}$.

Measuring the linear dimensions makes it possible to compute the shape ratio through the calculation of width/thickness (LD/APD). Possible practical uses for muscle shape estimation include comparisons of different groups of subjects and clinical diagnoses of injured muscles. Hides et al.$^{2}$ and Hides et al.$^{16}$ calculated the shape ratio of the back multifidus muscle and found a marked difference in muscle shape between normal healthy male and female subjects, and a significant difference between the symptomatic and the asymptomatic side in acute low back pain patients. The authors reported that the lumbar multifidus muscle was rounder in male than in female subjects and on the symptomatic side than on the asymptomatic side.

A pitfall of muscle area and linear dimension measurements is that overestimation of muscle thickness may result if the probe is not perpendicular to the skin surface. When the beams are oblique to the muscle, the thickness and area of the muscle will increase in direct proportion to the increase in the angle of incidence. Therefore, care should be taken while performing ultrasonography to ensure the probe is perpendicular to the skin surface.

**DISCUSSION**

Despite the extensive use of muscle ultrasonography in clinical diagnosis, it has been not widely used in musculoskeletal researches. There are some reports in the literature which used ultrasonography to explain the adaptation of an individual muscle in response to a disability or to the types of physical activities$^{16–20}$. The adaptational changes of an individual muscle have been detected in comparisons between the right and left muscle size and/or in a muscle size comparisons between different groups of subjects$^{16, 17}$. Hides et al.$^{2}$ and Kelly and Stokes$^{18}$ computed the percentage difference between the right and left muscle size measurements in healthy subjects and suggested that muscle size comparisons can provide basic data for clinical diagnosis. Further, Hides et al.$^{16}$ measured the CSA of the lumbar multifidus muscles by real-time ultrasonography, and revealed a significantly greater percentage difference between the sides in patients with acute low back pain. Using real-time ultrasonography apparatus, Kennelly and Stokes$^{19}$ found a marked pattern of asymmetry in the lumbar multifidus muscle in idiopathic scoliosis.

Another kind of muscle adaptation can be estimated in muscle size comparisons between different groups of subjects having different physical activity backgrounds. Maughan et al.$^{20}$ and Hakkinen and Keskinen$^{21}$ measured the size of the quadriceps muscle in different groups of athletes representing different type of sports, the authors revealed a remarkable difference in the size of the quadriceps muscle between groups of elite athletes. In another study, a significant difference in semispinalis capitis muscle size was found between elite wrestlers and elite weightlifters. In this study, the wrestlers were found to have rounder and larger muscle CSAs than the weightlifters$^{17}$. The rounder muscle shape and larger muscle size was suggested as a result of specific adaptation due to cervical muscle strength being more demanded in wrestling than in weightlifting.

In biomechanical studies, muscle ultrasonography has been used to investigate the relationship between muscle force and the image character of an individual muscle$^{7, 21–23, 29–33}$. The
relationship between the size of the quadriceps muscle and knee extension force has been examined by Young et al.34). The results of their study which were obtained by b-mode ultrasonography apparatus and an isometric muscle strength test instrument revealed a linear correlation between quadriceps muscle size and knee extension force. Moreover, in a simultaneous measurement of muscle size and muscle force measurements Henriksen-Larsen et al.35) and Rutherford and Jones36) scanned the vastus lateralis muscle at rest and during the maximum voluntary contraction force of knee extension. The authors revealed a significant increase in the angle of the muscle fascias and a significant positive correlation between the fiber angle and the CSA of the muscle during maximum voluntary contraction as compared to a state of rest.

In our earlier study, we indicated that neck semispinalis capitis muscle outline increased significantly when subjects supported the weight of their heads in a prone position28). In another study, we found a statistically significant correlation between the MLD and cervical extension force during voluntary contraction 37). The results of our study on the enlargement of the semispinalis capitis muscle during isometric extension revealed that an increase of the load to 60 per cent of the maximum voluntary contraction force of cervical extension resulted in an approximately 55 mm² increase in the MLD of the muscle.

Monitoring muscle contraction by ultrasonography can provide a clear view of the function of the muscles in a complex structure like the cervical spine38). Estimating muscle contraction by ultrasonography was revealed to be an exciting method for re-educating or strengthening of the muscles by means of visual feedback in physiotherapy39).

Today the field of muscle evaluation needs a reliable and feasible method which is also replicable in follow-up studies such as rehabilitation assessments. Within the last decade, a few imaging techniques, particularly computerised tomography and magnetic resonance imaging, have been used to evaluate the function of the muscles. Ultrasonography has previously been applied to this purpose.

It has been proven to be a valuable method in follow up training programs. As compared to MRI and CT scanning, ultrasonography is readily available, easier to perform, and cheaper. It is a non-invasive method which allows the examination of the muscle structure during dynamic palpation.

The method may prove highly efficacious in clinical diagnosis and in rehabilitation-oriented investigations. Ultrasonography can play an important role in the training and re-education of weak muscles in physiotherapeutic and rehabilitation programmes. The data provided by muscle ultrasonography can be of considerable value in estimating the results of follow-up training programmes.

REFERENCES


