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ULTRASOUND SECTOR SCANNING USED TO DEFINE CHANGES IN MUSCLE CONFIGURATION

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ABSTRACT. Dynamic configurational changes in the rectus femoris muscle were examined using a real time ultrasound sector scanner in ten normal subjects. The angle of passive knee flexion was varied as transverse ultrasound scanning was performed at the mid-transverse thigh. Configurational changes in the rectus femoris were computed from a traced outline of the muscle and the geometric center of the mass was calculated at all degrees of knee flexion. The geometric center of the mass varied with knee position. The anterioposterior dimensions and cross sectional areas of the rectus femoris and vastus intermedius remained constant, however, despite changes in knee position. The pattern of change observed was reproducible and reflects consistent changes in muscle configuration. The technique and instrumentation should have value for non-invasive dynamic and static observation of individual muscles.

Key words: ultrasonics; muscular atrophy; muscle degeneration; extremity, lower; thigh.

To our knowledge, dynamic relationships in a group of muscles have never been directly observed. Therapeutic approaches to the quadriceps muscles have been based on static observation and biomechanics modelling. Cadaver manipulations have led to definition of muscle group function, and inferences about dynamic force vectors in individual quadriceps' components (4). Computed tomography has also been employed in the study of muscle anatomy (3) but once again this technique is one of static observation. More recently, ultrasound has proved to be a technique useful in describing the quadriceps mass (cross-sectional area) in normal thighs and in the presence of knee pathology (2, 6, 7). The effects of training have also been measured using ultrasound techniques (2). All these investigations have studied muscle with no observation of the configurational changes that accompany limb positioning or dynamic muscle activity.

Our study was designed to observe changes in the quadriceps muscles as the knee progressively flexes. The rectus femoris (RF) was chosen because of accessibility and the ease with which measurements can be made. The hypothesis on initiation of the study was that configurational changes in the RF occur depending on the angle of knee flexion.

METHODS

The thighs of ten subjects were examined using a real-time ultrasound sector scanner employing a 5 MHz transducer (Diasonics, Inc. Milpitas, California). The thighs were scanned in a transverse plane in the middle of a line between the lateral femoral condyle and the anterior superior iliac spine (Fig. 1). All examinations were recorded on $^3/_4$ inch videotape for review and analysis.

Ten male subjects with no history or evidence of back, hip, knee, or neuromuscular pathology were studied. Data from eight subjects are reported (Table I) as two were excluded because the muscle echogenicity prevented delineation of fascial and bony landmarks. (One of the excluded subjects subsequently acknowledge a history of inflammatory bowel disease, inactive for ten years.)

The subjects were positioned seated with the hips flexed 40 degrees (Fig. 1). The thighs were examined individually and studied first at 90 degrees of knee flexion (for a comparative baseline), then at 15, 30, and 60 degrees of knee flexion (Fig. 1). Three individual observations were made and recorded for each knee position. The relaxed position was manually supported by the examiner at the given angle of flexion, avoiding any change that might result from muscle contraction. All ultrasound observations were made with the transducer submerged in a water-filled plastic sac, over the thigh. The skin was coated with ultrasound gel (Fig. 2). The limb was passively positioned while the ultrasound study was conducted and video-recorded ($^3/_4$" U-Matic format).

DATA ANALYSIS

Ultrasound scans were reviewed by selecting single frames of video image and tracing the borders of the muscles on the screen with a graphics cursor (Microsonics, Inc. Indianapolis, IN). When the muscle anatomy was satisfactorily outlined, this outline was committed to memory with the midanterior femur marked and recorded to serve as an anatomic land-

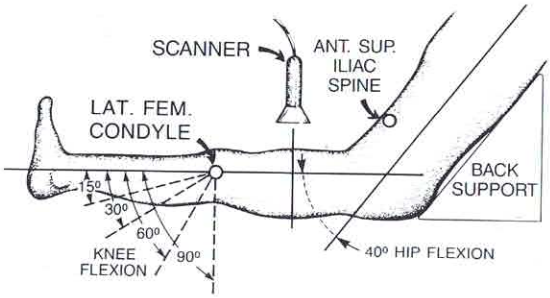

Fig. 1. Five leg positions and transducer placement used in the investigation of muscle configuration. Hip flexion was maintained at 40 degrees and knee flexion was passively varied between 15 and 90 degrees. Initial readings at 90 degrees were used for reference in comparative studies.

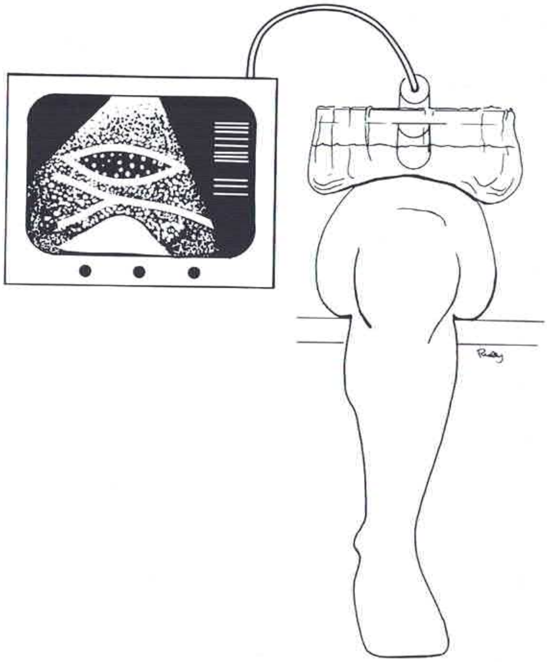

Fig. 2. Use of the ultrasound sector scanner submerged within a water filled plastic sac with the underlying thigh coated with ultrasound gel. Readings were made in a transverse plane in the middle of a line between the lateral femoral condyle and the anterior superior iliac spine. Hips were maintained at 40 degrees of flexion.

mark. (Studies were compared using individual outlines and the common femur reference point.) The tracings at various positions of knee flexion were compared with the baseline initial 90° flexion observation.

Measurements were also made on the screen by delineating the appropriate points or areas and measuring dimensions with graphic software (Microsonics, Inc., Indianapolis, IN). Three variables were evaluated. The first was the Rectus Femoris Anterioposterior Dimension (RF-AP). This represents the thickness in centimeters of the Rectus Femoris as measured from anterior fascia to the Vastus Intermedius (VI) anterior fascia. The second variable was the change in the Cross-Sectional Area of the Rectus Femoris (RF-CSA), and the third variable was the Center of Mass Deviation (CMD) in centimeters. CMD is a measurement of the change in position of the geometric center calculated by the graphic software from the outlined muscle, and is a measurement of the change in position of the muscle. Both the RF-CSA and the CMD were calculated for each degree of flexion, three determinations were made, and the average was compared with the averaged 90 degree baseline measurement.

Each of the three dependent variables (RF-AP, RF-CSA, and CMD) was analyzed with a 2×4 repeated Analysis of Variance (ANOVA). The first independent variable was side (right, left), and the second independent variable was angle (15, 30, 60, 90 degrees of knee flexion). Significant effects were further probed with a Student–Newman–Keuls post hoc test.

Table I. *Eight subjects observed with ultrasound sector scanning in trials of this technique*

Subject	Handedness	Height (cm)	Weight (kg)	Age
1	Left	175	65.9	33
2	Right	181	79.0	34
3	Right	177	76.0	36
4	Right	174	79.5	38
5	Left	175		31
6	Right	188	100	40
7	Right	186	53.2	34
8	Right	180	72.7	31

RESULTS

The average values for the three dependent variables, RF-AP, RF-CSA, and CMD, are presented in Table II. Results from the Analysis of Variance procedures achieved significance only for the dependent variable CMD, under the effect of angle ($p<0.02$). The ANOVA summary for CMD is shown in Table III. A Student–Newman–Keuls post hoc test indicated that CMD at a knee angle of 15 degrees was significantly larger ($p<0.5$) than CMD at 30 or 60 degree knee angles (Table II and Fig. 3). All other ANOVA variables and effects were non-significant though a trend is noted.

Although the thickness of the rectus femoris (RF-AP) appeared to increase slightly as the knee was moved from 15 to 90 degrees this difference was not significant. The cross-sectional area of the rectus fe-

Table II. *Average values of three variables at four different knee angles*

Muscle configuration of the rectus femoris observed with ultrasound sector scanning in eight normal subjects. The Center of Mass Deviation (CMD) was noted significantly different at knee flexion angles of 15 and 60 degrees. Rectus femoris cross sectional area (CSA) and Anterioposterior dimensions (AP) did not vary significantly and cannot explain observed changes in CSA

Knee angle (degrees)[a]	AP (cm)	CSA (cm^2)	CMD (cm)
15	2.64	.092	.981*b**
30	2.77	.109	.840
60	2.85	.096	.718*c**
90	3.02	.093	

[a] Fully extended (straight) knee = 0 degrees.
* $b > c$ at $p = 0.05$ (Table III) (both CSA and CMD are changes in comparison with an initial observation of the limb positioned at 90° of knee flexion).

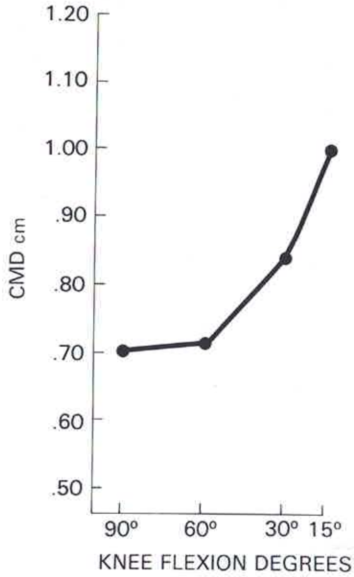

Fig. 3. Graphic representation of the relationship between knee flexion and resulting center of mass deviation (CMD). Observations resulted from ultrasound observation of the rectus femoris muscle as the leg was passively positioned by examiner. CMD is the geometric center of mass.

moris (RF-CSA) remained essentially unchanged. No changes in VI AP dimension or CSA were observed with changes in knee position. The CMD, an appropriate measurement of the rectus femoris position, derived from its baseline position at 90 degrees flexion as the leg was subsequently extended.

The rectus femoris muscle center of mass was observed to tend to move anterior and medial to its baseline position with progressive extension of the leg.

DISCUSSION

The technique described allowed reproducible observations of muscle configuration as knee position was varied. The position of the rectus femoris muscle (CMD) was noted to be dependent on knee position, with greater change in position within the thigh at extended positions. This CMD was not related to the AP dimension of the underlying vastus intermedius, nor was there a change in the overall RF-CSA accompanying this change in CMD. The precise explanation for this consistently noted change in geometry (CMD) is unclear at present but possibly results from a shift in muscle position perpendicular to the scan plane (mediolateral). We were consistently able to note CMD configurational changes with unchanging RF-AP. One limitation, however, well known in cardiac ultrasound techniques, is the difficulty in observing tangential margins. Not all fascial planes are easily defined, so that there is some small, not quantifiable error in outlining the medial and lateral margins of the muscle. More precise definition of these lateral fascial planes may explain more fully the changes in relative muscle position. A different transducer configuration such as a linear transducer may assist these observations. One additional difficulty encountered with the technique described relates to problems experienced with consistent relaxed positioning of the limb being studied. Muscle contraction was noted to alter the configuration observed and these altered

Table III. *Analysis of variance calculated for Center of Mass Deviation (CMD) observed in eight normal subjects*

Significance was noted for angles of knee flexion observed at 15 and 60 degrees of knee flexion. (Table II.) df = degree of freedom—probability, SS = sum of squares, MS = mean squares, $F = F$ ratio, p = probability value

Source	df	SS	MS	*F*	*p*
Angle	3	2.326	0.775	4.0	.0199
Angle × subj.	21	3.999	0.190		
Side	1	2.121	2.121	3.23	.1153
Side × subj.	7	4.594	0.656		

observations required exclusion. An alternative approach to passive positioning might require additional equipment that could decrease the variability and improve the reliability of observations.

CONCLUSION

The study describes a technique that can be used to observe reproducibility in real time, changes in muscle position achieved by varying the amount of knee flexion. Position change in the knee results in a change in CMD not explained by changes in RF-AP and CSA.

Ultrasound sector scanning and computer assisted analysis may be useful in understanding the effects of a variety of pathologic processes on static and dynamic muscle configuration. Such problems as the motor unit compromise seen in late effects of polio and other peripheral motor neuropathies will warrant further investigation using this technique. With further experience, dynamic muscle configuration can be begun.

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