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THE INFLUENCE OF ISOMETRIC HIP ADDUCTION ON QUADRICEPS FEMORIS ACTIVITY

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ABSTRACT. In the treatment of muscle imbalances around the knee, hip adduction and the contraction of adductor magnus have been used to facilitate vastus medialis obliquus (VMO) to a greater extent than vastus lateralis (VL). This study was conducted to investigate the effectiveness of this technique. Hip adduction was superimposed onto the contraction of quadriceps femoris in a weight bearing (WB) and a non-weight bearing (NWB) position at three levels of hip adduction force. The muscle activity of VMO and VL was recorded using electromyography with the ratio of the recordings of VMO to VL used for comparison. The activity of VMO compared with VL was greater in WB than NWB without hip adduction. VMO activity increased relatively more than VL with the addition of each level of hip adduction in WB and only with maximal hip adduction in NWB. The results provide support for the use of this technique.

Key words: exercise therapy, electromyography, muscle contraction, knee, patella.

The major function attributed to vastus medialis obliquus (VMO) is the stabilisation of the patella against the laterally deviating action of the other heads of quadriceps femoris (QF) (16, 27, 33, 34). Therefore the QF group forms one example of a situation in which muscles with one common synergistic function, namely knee extension, also have another separate antagonistic role. This situation is not uncommon in the human musculoskeletal system (39).

Research has indicated that occasionally imbalances occur between synergists with resulting effects on function (23, 24). There is evidence in the literature to suggest that relative weakness may be present in one of the synergistic knee extensors, namely VMO (16, 21, 34). The resulting imbalance would reduce the medial stabilisation of the patella and alter the functional patella position allowing the patella to displace laterally (16, 33, 34) potentially resulting in pain (16, 21, 38).

Therefore a problem exists in rehabilitation to establish mechanisms to isolate or disproportionately increase the activation of this single component of the knee extensor synergy.

It is doubtful that conventional treatment strategies such as straight leg raising, quadriceps setting and short arc knee extension are successful due to the concurrent synergistic activation of the opposing QF heads (8, 21, 26). Various movement patterns have been presented in the literature to selectively enhance the motor unit activity of VMO, but with largely inconclusive results (5). These techniques include various movement patterns of the hip, knee and ankle (2, 9, 17, 37). However, each of these techniques has failed to gain support in more recent studies (1, 2, 5, 19, 38).

The interaction of individual muscles with differing actions in motor function has often been mentioned in the literature (6, 14, 22, 23). One example relevant to the activation of VMO relates to the interaction of this muscle with the hip adductors and more specifically adductor magnus (AM). Several authors have suggested that the addition of hip adduction to an active QF contraction may result in a disproportionate increase in the activation of VMO compared to the other components of QF (31, 36). The basis for this proposal was thought to relate to the origin of a large proportion of the oblique fibres of vastus medialis (VM) from the tendon of AM close to its insertion to the adductor tubercle (10). Beck & Wildermuth (8) suggested that, through the insertion, a mechanism may exist for AM to transfer a physiological stretch to VMO. This stretch would alter the length tension properties of VMO through pretensioning the contractile and non-contractile components of the muscle, therefore contributing to an enhanced force of contraction (4, 25).

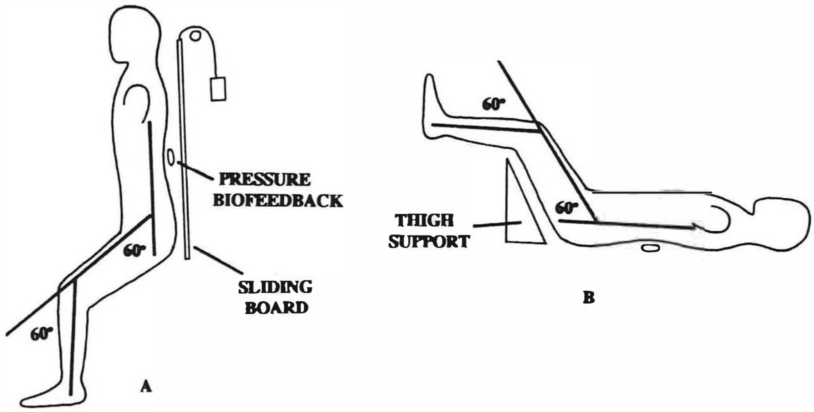

Fig. 1. The standard test positions. (A) Weight bearing position, (B) Non-weight bearing position.

The relationship between VMO and AM and the possibility of VMO enhancement through coactivation with AM has been poorly investigated in the literature. Early evidence for the relationship was suggested by Janda & Véle (22) and MacConnail & Basmajian (30) who reported hip adductor activity in isolated knee motion. However, further indirect studies of the effect have failed to provide support. Hip adduction as a component of a proprioceptive neuromuscular facilitation technique combining low resistance and hip flexion failed to show any interaction between these two muscles (2, 3). A further study using unresisted hip adduction also showed no relationship (1).

Consideration of the function of AM may provide explanation for these negative results. Review of the anatomy and function of AM reveals that this muscle is predominantly a strong hip extensor (35, 39) acting synergistically with gluteus maximus in high load weight bearing activities such as flexed knee lifting (6, 20, 33, 39). The earlier literature has not taken these issues into account when testing the hypothesis. More recently a study was conducted involving maximal hip adduction which provided support for the relationship (19).

The aim of this study was to combine the activity of QF with AM in a more functional weight bearing (WB) role to analyse the relationship between hip adduction and VMO. It was envisaged that comparison of the WB position with a non-weight bearing (NWB) position would provide some insight into the mechanism. Although all four components of the QF group are involved in alignment of the patella it was considered that analysis of the activity of VMO and VL would give an indication of the changing relationship.

METHODS

Subjects

Twenty healthy female volunteers participated in the study. The subjects reported no history of injury to the lower limb or back, no involvement in competitive sport and no recorded tightness of the musculature of the hip. These criteria were set to control for variations in muscle endurance and activation patterns. The mean age, body weight and height were $\bar{x} = 19.5$ years (SD = 0.79), $\bar{x} = 58$ kg (SD = 6.04) and $\bar{x} = 166.7$ cm (SD = 5.24), respectively.

Measurements

Surface electromyography (EMG) was used to monitor the muscular activity of VMO and VL, recorded as root mean square EMG as suggested by Basmajian & Deluca (6). The silver-silver chloride EMG electrodes were positioned centrally over the muscle bellies (assessed by palpation of a static contraction) running longitudinally with the muscle fibres. Skin preparation was conducted in a similar manner to that described by Burbank & Webster (12).

Due to the inadequacies of surface EMG recordings from the deeply placed AM, the isometric hip adduction force was resisted and recorded using a strain gauge and cable arrangement as an indirect measure of the adductor muscle group activity. The apparatus was calibrated with known weights.

Testing procedure

Each subject was randomly assigned to perform either the WB or NWB condition first. Prior to the testing session an orientation session was conducted to familiarise the subjects with the positions and requirements of the procedure.

Weight bearing position

For the WB test the subject adopted a supported semisquat position (Fig. 1A). Several pieces of equipment were required for the maintenance of the appropriate body position and minimisation of extraneous variables. The sacrum was

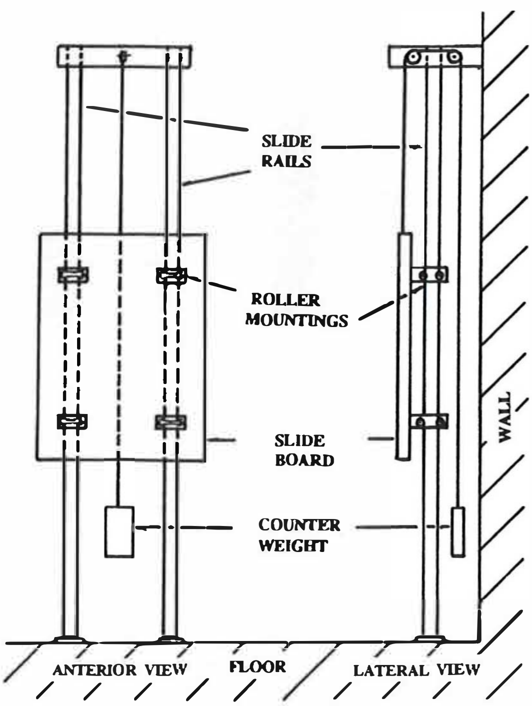

Fig. 2. The sliding board used to minimise the contribution of friction to the weight bearing position.

supported against a freely moving sliding board attached to an equal weight to minimise the contribution of friction to the system (13) (Fig. 2). A pressure biofeedback device (Chattanooga, Australia) consisting of a sphygmomanometer gauge connected to an air filled pressure bag was placed in the lumbar lordosis to ensure that standard body alignment was maintained (Fig. 1A).

The subject placed their feet three paces from the wall, rested the sacrum against the sliding board and moved down the wall until an angle of 60° of knee flexion was reached, measured by a standard goniometer. The knee angle closely corresponds to the angle at which a burst of activity of VMO has been reported (7). The corresponding hip angle of 60° flexion closely approximates the angle at which AM has its greatest contribution to hip extension (35).

Following attachment of the strain gauge to the thigh the subject repeated two submaximal and two maximal hip adduction contractions as a warm up. Two conditions were assessed, referred to as the WB test and the WB test plus hip adduction. The WB test plus hip adduction was further subdivided into a maximal voluntary isometric contraction (MVIC) and two submaximal levels; 50% MVIC and 15% MVIC. The MVIC hip adduction force was assessed by repetition of a maximal contraction until the recordings were repeatable within 5%. The submaximal levels were extrapolated from this recorded maximal value and each required level of hip adduction force was displayed on a cathode ray oscilloscope along with a running trace of the force data. Recordings of the WB test and WB test plus the three levels of hip adduction contractions were taken for five seconds duration in random order.

Non-weight bearing position

The NWB position involved the same joint angles and muscle lengths as the WB position. The subject was positioned supine with a support positioned under the thigh to maintain the 60° flexion angle at the hip (Fig. 1B). The standard body position was monitored using the pressure biofeedback device placed in the lumbar lordosis. In the test position the knee was extended to the desired 60° knee flexion and the position of the toe was marked and noted to the subject. The strain gauge was attached in a similar manner to the weight bearing position and a similar protocol of measurements of force and muscular activity for the NWB test and NWB test plus hip adduction was performed.

Data analysis

The VMO:VL EMG ratio formed the basis of the analysis of the muscular activity. This form of analysis displays a change in the relative activity of the muscles without the necessity for normalisation of the EMG data. The EMG data was compared with the force data and sections of one second duration were edited for analysis that corresponded to the maintenance of the appropriate force. The repeatability was determined by repetition of the test procedure on 8 of the subjects.

RESULTS

The coefficients of variation and root mean square errors of the force and EMG data for the repeatability trial are presented in Tables I and II, respectively. The results display an acceptable degree of variability for each condition.

Analysis of the force data involved application of an ANOVA to the maximal force recordings for both positions. The results demonstrate a highly significant difference between the maximal hip adduction force produced in each position ($F(1,19)=182.19$, $p<0.0001$).

Comparison of the mean VMO:VL EMG ratio data in the WB test and the NWB test (without hip adduction) was conducted using an ANOVA. The results demonstrate that the relative activity of VMO compared to VL was significantly greater in the WB

Table I. *Repeatability of the maximum hip adduction force*

Calculated for two sets of recordings within the same session ($n=8$).

CV=coefficient of variation, *RMSE*=root mean square error.

	Mean force (Newtons)	CV	RMSE
Weight bearing test	191.1	8.12	1.58
Non-weight bearing test	104.37	11.61	1.27

Table II. *Repeatability of the vastus medialis obliquus: vastus lateralis electromyographic ratio scores*

Calculated for two sets of recordings within the same session ($n=8$).

CV=coefficient of variation, *RMSE*=root mean square error, *MVIV*=maximum voluntary isometric contraction.

	Mean ratio	CV	RMSE
Weight bearing test	1.29	17.94	0.23
Weight bearing test plus hip adduction			
MVIC	2.80	9.72	0.22
50% MVIC	2.01	13.94	0.28
15% MVIC	1.66	19.46	0.32
Non-weight bearing test	0.93	14.21	0.13
Non-weight bearing test plus hip adduction			
MVIC	1.33	19.35	0.26
50% MVIC	1.01	10.03	0.10
15% MVIC	0.96	13.85	0.13

Table III. *Analysis of variance summary for the vastus medialis obliquus: vastus lateralis electromyographic ratio scores*

df=degrees of freedom, *WB*=weight bearing position, *NWB*=non-weight bearing position.

Source	df	F value (WB)	F value (NWB)
Subjects	19	10.72*	8.97*
Adduction condition	3	25.29*	4.44**
Error	57		
Total	79		

* $p<0.0001$; ** $p<0.007$.

test when compared to the NWB test ($F(1,19)=10.25$, $p<0.005$).

The interaction between hip adduction and its effect on the VMO: VL EMG ratio was analysed using an ANOVA conducted on the data for the WB position and NWB position comparing the with and without hip adduction tests. The results presented in Table III indicate significant changes in the VMO:VL EMG ratio with manipulation of the hip adduction activity. In view of this result, multiple comparisons were conducted using Duncan's multiple range test (Fig. 3). The comparison of the mean VMO:VL EMG ratio scores revealed a significant change in the ratio between each condition of the WB test plus hip adduction (MVIC, 50% MVIC and 15% MVIC) and

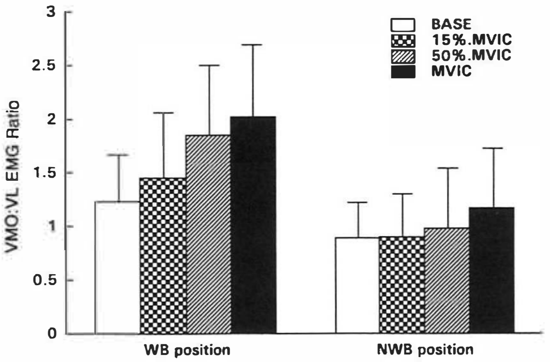

Fig. 3. Changes in the relative activity of vastus medialis obliquus (*VMO*) compared to vastus lateralis (*VL*) with alteration of the level of hip adduction force in each position. *Base*=standard test position without hip adduction, *MVIC*=maximum voluntary isometric contraction, *WB*=weight bearing, *NWB*=non-weight bearing.

the WB test (without hip adduction), with no significant difference between the MVIC and 50% MVIC levels. In the NWB position only the MVIC level of the NWB test plus hip adduction varied significantly from the NWB test (without hip adduction). The mean EMG ratio data presented in Table IV indicate that the activity of both VMO and VL was increased by the addition of hip adduction. However, VMO was increased to a greater extent.

DISCUSSION AND CONCLUSIONS

The results of the study provide support for the selective enhancement of the motor unit activity of VMO compared with another knee extensor synergist, namely VL, with the addition of isometric hip adduction. The VMO: VL EMG ratio for the hip adduction conditions compared with the test conditions without hip adduction were only significantly different under

Table IV. *The* $EMG_{hip\ adduction}/EMG_{without\ hip\ adduction}$ *ratio data for vastus medialis obliquus and vastus lateralis*

MVIC=maximum voluntary isometric contraction, *NWB*=non-weight bearing position, *VL*=vastus lateralis, *VMO*=vastus medialis obliquus, *WB*=weight bearing position.

	VMO WB	VMO NWB	VL WB	VL NWB
MVIC	3.20*	3.85*	1.96*	2.79*
50% MVIC	1.93*	1.42*	1.26	1.27
15% MVIC	1.18	1.00	0.99	1.00

* $p<0.05$ (Duncan's multiple range test).

conditions of high load or WB or both. This is consistent with the suggested functional role of AM, which would be most likely to be active under these circumstances.

WB also appears to have a significant effect on enhancement of the activity of VMO compared to VL. WB tasks such as the semisquat position involve both high load and antigravity postural responses. The basis for the reported disproportionate increase in the activity of VMO with WB may relate to these two functional components. Duarte Cinatre and Furlani (15) reported greater activity of VM compared to VL in high load knee extension. The same study also reported an enhanced activation of VM activity when compared to VL in WB tasks such as squatting. Other studies have also shown an enhanced activation of VM with weight bearing tasks (11), to the extent of recording a burst in the relative activity of VMO at certain ranges of knee extension (7). It is impossible to identify the important feature of WB from the available literature.

An interesting aspect of the results relates to the disproportionate enhancement of VMO activity with even submaximal levels of hip adduction force in the WB position. This tends to indicate a greater magnitude of the interaction between the two muscles when hip adduction and WB are combined. VMO is considered to form an important component of the antigravity postural responses as a component of the knee extensor synergy in high load tasks (6). Support for this functional role of VMO has come from a study of atrophy and muscle fibre distribution in the QF of dogs. The authors suggest that VM contains a much larger proportion of slow fibres than VL, indicating that VM performs a primary antigravity role (28). In contrast, AM has not been considered to be important for this function. However, as presented previously, evidence exists for AM acting in this role (6, 20, 32).

Postural reactions are the patterns of muscle activation involved in the postural basis for movement (4). This definition implies that specific patterns of muscle activation are involved in an antigravity role. Several authors believe that the relationship between movements of the knee and hip adductor activity relate to postural responses (Janda & Stara, cited in 6, 22). Although the basis for this assumption is not present in the neurophysiological literature it may be hypothesised that the specific increase in the activation of a particular muscle with an antigravity function may enhance the level of activity of another muscle component of the antigravity pattern.

It must be acknowledged that the present study cannot rule out the biomechanical stretch as a possible mechanism for the effect. In addition, EMG records the electrical activity of the muscle and does not necessarily reflect the force produced by the muscle. Clearly further investigation is required to analyse the specific nature of the relationship and to investigate the proposed hypothetical mechanism for the effect.

Consideration must also be placed on the influence of cross talk between VMO and AM which are linked anatomically. Pilot trials were conducted using branched electrodes which have been suggested to minimise the recording of distant myoelectric activity (cross talk) (18, 29). These studies indicated that the influence of cross talk from hip adductor activity on the VMO EMG recordings was minimal.

This study of the interaction between the hip adductors and the specific enhancement of VMO independent of the other components of the knee extensor synergy has provided support for the postulated relationship between these two muscles. It has been shown that the addition of hip adduction to a QF contraction enhances the activity of VMO to a greater extent than VL under certain conditions. This finding provides the basis for a mechanism to selectively enhance the activity of VMO with the potential to assist with the resolution of specific QF muscle imbalances.

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REFERENCES

1. Antich, T. J. & Brewster, C. E.: Modification of quadriceps femoris muscle exercises during knee rehabilitation. Phys Ther *66:* 1246, 1986.
2. Arsenault, A. B. & Chapman, A. E.: An electromyographic investigation of the individual recruitment of the quadriceps muscle during isometric contraction of the knee extensors in different patterns of movement. Physiother Can *26:* 253, 1974.
3. Arsenault, A. B., Falconer, K. A. & Winter, D. A.: Diagonal-spiral versus cardinal patterns in the EMG activity of the knee extensors. Physiother Can *30:* 58, 1978.

4. Åstrand, P. & Rodahl, K.: Textbook of work physiology; physiological bases of exercise. McGraw-Hill, Singapore, 1986.
5. Basmajian, J. V., Brown, W. E. K. & Harland, R.: cited in Basmajian, J. V. & Deluca, C. J.: Muscles Alive; their function revealed by electromyography. Williams and Wilkins, Baltimore, 1985.
6. Basmajian, J. V. & Deluca, C. J.: Muscles alive; their function revealed by electromyography. Williams and Wilkins, Baltimore, 1985.
7. Basmajian, J. V., Harden, T. P. & Regenos, E. M.: Integrated actions of the four heads of quadriceps femoris; an electromyographic study. Anat Rec *172:* 15, 1971.
8. Beck, J. L. & Wildermuth, B. P.: The female athlete's knee. Clin Sports Med *4:* 345, 1985.
9. Bos, R. R. & Blosser, T. G.: An electromyographic study of vastus medialis and vastus lateralis during selected isometric exercises. Med Sci Sports Exerc 2: 218, 1970.
10. Bose, K., Kanagasuntheram, R. & Osman, M. B. H.: Vastus medialis oblique; an anatomic and physiologic study. Orthopedics *3:* 880, 1980.
11. Brewerton, D. A.: The function of the vastus medialis muscle. Ann Phys Med *2:* 146, 1955.
12. Burbank, D. P. & Webster, J. G.: Reducing skin potential motion artefact by skin abrasion. Med Biol Eng Comput *16:* 31, 1978.
13. Comerford, M.: Personal Communication, 1991.
14. Denny-Brown, D. E.: The histological features of striped muscle in relation to its functional activity. Proc R Soc Lond [Biol] *104:* 371, 1929.
15. Duarte Cinatra, A. I. & Furlani, J.: Electromyographic study of quadriceps femoris in man. Electromyogr Clin Neurophysiol *21:* 539, 1981.
16. Fox, T. A.: Dysplasia of the quadriceps mechanism; hypoplasia of the vastus medialis muscle as related to the hypermobile patella syndrome. Surg Clin North Am *55:* 199, 1975.
17. Gough, J. V. & Ladley, G.: An investigation into the effectiveness of various forms of quadriceps exercises. Physiotherapy *57:* 356, 1971.
18. Gydikov, A., Kostov, K., Kossev, A. & Kosarov, D.: Estimation of the spreading velocity and the parameters of the muscle potentials by averaging of the summated electromyogram. Electromyogr Clin Neurophysiol *24,* 191, 1984.
19. Hanten, W. P. & Sculthies, S. S.: Exercise effect on electromyographic activity of the vastus medialis oblique and vastus lateralis muscles. Phys Ther *70:* 561, 1990.
20. Hollinshead, W. H. & Rosse, H. C.: Textbook of anatomy. Harper and Row, Philadelphia, 1985.
21. Insall, J.: Current concepts review, patellar pain. J Bone Joint Surg [A] *64:* 147, 1982.
22. Janda, V. & Véle, F.: A polyelectromyographic study of muscle testing with special reference to fatigue. *In* Disability Prevention—Rehabilitation. Proceedings of the Ninth World Congress of the International Society for Rehabilitation of the Disabled, Copenhagen, Denmark, 1963.
23. Janda, V.: Muscles, central nervous motor regulation and back problems. *In* The neurobiologic mechanisms in manipulative therapy (ed. Korr, I. M.) pp. 27-41. Plenum Press, New York, 1978.
24. Jull, G. A. & Janda, V.: Muscles and motor control in low back pain; assessment and management. *In* Clinics in Physical Therapy, Vol 13, Physical Therapy of the low back (ed. Twomey, L. T. & Taylor, J. R.). Churchill Livingstone, New York, 1987.
25. Komi, P. V.: Physiological and biomechanical correlates of muscle function; effects of muscle structure and stretch shortening cycle of force and speed. Exerc Sport Sci Rev *12:* 81, 1984.
26. LeVeau, B. F. & Rogers, C.: Selective training of the vastus medialis muscle using EMG biofeedback. Phys Ther *11:* 1410, 1980.
27. Lieb, F. J. & Perry, J.: Quadriceps function; an anatomical and mechanical study using amputated limbs. J Bone Joint Surg [A] *50:* 1535, 1968.
28. Lieber, R. L., Friden, J. O., Hargens, A. R., Danzig, L. A. & Gershuni, D. H.: Differential response of the dog quadriceps muscle to external skeletal fixation of the knee. Muscle Nerve *11:* 193, 1988.
29. Loeb, G. E. & Gans, C.: Electromyography for Experimentalists. University of Chicago Press, Chicago, 1986.
30. MacConaill, M. A. & Basmajian, J. V.: Muscles and Movement; a basis for human kinesiology. Williams and Wilkins, Baltimore, 1969.
31. McConnell, J.: The management of chondromalacia patellae; a long term solution. The Australian Journal of Physiotherapy *32:* 215, 1986.
32. Nemeth, G., Ekholm, J., Arborelius, U. P., Shuldt, K. & Harms-Ringdahl, K.: Hip load and muscular activation during rising exercises. Scand J Rehabil Med *16:* 93, 1984.
33. Paulos, L., Rusche, K., Johnson, C. & Noyes, F. R.: Patella malalignment; a treatment rationale. Phys Ther *60:* 1624, 1980.
34. Pevsner, D. N., Johnson, D. R. G. & Blazina, M. E.: The patellofemoral joint and its implications in the rehabilitation of the knee. Phys Ther *59:* 869, 1979.
35. Pohtilla, J. F.: Kinesiology of hip extension at selected angles of pelvifemoral extension. Arch Phys Med Rehabil *50:* 241, 1969.
36. Reynolds, L., Levin, T. A., Medeiros, J. M., Adler, N. S. & Hallum, A.: EMG activity of the vastus medialis oblique and the vastus lateralis in their role in patella alignment. Am J Phys Med *62:* 61, 1983.
37. Wheatley, M. D. & Jahnke, W. D.: Electromyographic study of the superficial thigh and hip muscles in normal individuals. Arch Phys Med Rehabil *32:* 508, 1951.
38. Wild, J. J., Franklin, T. D. & Woods, G. W.: Patellar pain and quadriceps rehabilitation; an EMG study. Am J Sports Med *10:* 12, 1982.
39. Williams, P. L., Warwick, R., Dyson, M. & Bannister, L. H. (eds): Gray's Anatomy 37th Edition. Churchill Livingstone, London, 1989.

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