Scand J Rehab Med 29: 43–48, 1997

A COMPARISON OF THE ACTIVATION OF MUSCLES MOVING THE PATELLA IN NORMAL SUBJECTS AND IN PATIENTS WITH CHRONIC PATELLOFEMORAL PROBLEMS

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ABSTRACT. The activation of the oblique fibres of vastus medialis, the postero-lateral fibres of vastus lateralis, and rectus femoris was studied by surface electromyography, during the force development of a maximal isometric contraction, performed near full extension (20° of flexion), by 49 patients with chronic patellofemoral problems and 20 normal subjects. In the normal subjects activation of oblique portions of the vasti was in advance of force rise, during the time for 80% tension development. In the patient group, however, the activation of these lagged behind force rise. Force rise was slower in the patients even though the contraction was generally pain free. In all groups the activation of these two sections of the muscle remained approximately synchronous, suggesting that they have a reciprocal action in controlling patellar position, disruption of which might contribute to patellofemoral problems.

Key words: activation, electromyography, force, muscle, patella.

INTRODUCTION

The quadriceps muscle has as one of its main functions the extension of the knee, via its action on the patella and the patellar ligament. The muscle is very large and is conventionally regarded as having these four sections which are anatomically distinct: vastus lateralis (VL), vastus intermedius, vastus medialis (VM) and rectus femoris (RF). Different sections of the muscle pull on the patella from somewhat different angles, and therefore the possibility should be considered that an additional function of the quadriceps is to control the position of the patella with respect to the trochlear surface of the femur (e.g. 1, 12). The most oblique parts of VM (VMO) and of VL (VLO) as well as RF would be the sections most suited anatomically to exert this control. VMO has been seen, in many cases to be separated from the long fibres by a fascial plane, and most of the fibres of VMO arise from the tendon of adductor magnus (1). The innervation appears to be variable, and in some cases a separate motor nerve to the belly of VMO has been observed (12, 17). VL has also been shown to be divided into two parts; the proximal fibres are straighter, originate from the femur and are inserted into the middle layer of the quadriceps tendon, whereas the distal, or postero-lateral fibres originate from the iliotibial band, are more oblique in their direction and are inserted into the base and lateral border of the patella (10). It has therefore been suggested that they have a controlling effect on the patella, acting in opposition to that of VMO. Rectus femoris in contrast exerts a relatively straight pull on the patella.

An example of the need for control of patella position is that when the knee is nearly straight all the quadriceps, except VMO, have a lateral pull on the patella, which can only be dynamically counterbalanced by the action of VMO (7). Stability is also provided by the retinacula, but the transverse fibres can scarcely be dynamized by muscular action (6). As the knee is bent, the patella moves downwards and medially (11), entering the trochlea by about 20° of flexion. The trochlea is deeper distally, so that the congruity of the bony parts gives the joint more stability at increased angles of flexion. We have therefore investigated the timing of activation of VMO, of VLO and of RF during isometric contractions with the knee flexed at 20°. If these parts of the muscle are actively to control the position of the patella we should expect them to be rapidly activated, at the same time as, or even in advance of, the larger parts of the muscle which generate the majority of the isometric force. We have therefore compared the timing of their activation with that of the onset of extensor torque. The method of motor control of the patella is not known, but there may be an initial ballistic movement. This learnt control of movement has been described by Rothwell (16). "This pattern of EMG activity ... represents a package of nervous commands which can be 'preprogrammed' in advance by the central nervous system ... this does not mean that commands cannot be modulated under normal conditions by peripheral feedback mechanisms." Because this type of motor control is stereotyped, we monitored the first 80% of the force rise, in the expectation that this might exhibit a relatively simple behaviour.

MATERIALS AND METHOD

Forty-nine patients with chronic patellofemoral pain were studied. This pain was exacerbated by climbing or descending stairs, or undertaking sports and other activities involving running and/or deep flexion of the knee. In some cases the retropatellar pain was exacerbated by prolonged sitting. Each had been diagnosed by an orthopaedic surgeon, and each was also re-examined for suitability for inclusion. Criteria for their choice were, not only the presence of the above symptoms but also retropatellar tenderness, and that the onset of their symptoms was insidious rather than a response to trauma, and had occurred between the ages of 12 and 30. In 34 patients the symptoms were bilateral, but usually the symptoms were more severe in one knee than the other. The duration of their symptoms was 6 months to 10 years. Exclusion criteria were: bipartite patella, femoral trochlea fracture, osteochondritis dissecans, muscle tear, meniscal or ligamental pathology, reflex sympathetic dystrophy, Osgood-Schlatters disease, Sinding–Larson–Johannson disease, patellar tendinitis, prepatellar bursitis, scarred or inflamed plicae, gross effusion, or recent knee operation, not including arthroscopy.

The age range of the patients was 20–37 with a median age of 26, and 67% were female.

A group of 20 normal subjects were recruited, of age range 20–33 with a median age of 25 and 65% were female. Although they were mostly university staff and students, care was taken that not only athletic subjects were chosen, so that the range of accustomed physical activities was similar in patient and control groups. The controls were carefully questioned to ensure that they did not suffer, and had not previously suffered, from any knee symptoms.

Both legs of the patients were studied and only the right leg of the controls. In this report only the most affected leg (or the only affected leg) of the patients is presented. The subject was positioned on a couch with legs stretched out and was instructed to brace his/her quadriceps so that the individual muscles of the group could be delineated and electrode placings selected. Each pair of electrodes was mounted in a fixed unit (Motion Lab Systems Inc.) (supplied by Oxford Metrics). The electrodes, which were AC coupled, were raised stainless steel discs 3.5 cm apart, with a diameter of 1.2 cm with the indifferent electrode situated between the active electrodes. They were used without gel but provided a very good contact, which was accentuated by being fixed, first with micropore, and then firm, fitted tubigrip. This ensured that the good contact was maintained during any movement which might occur. The electrodes over VMO were placed at an angle of 55° to the line of the femur, that is along the line of the fibres; so that the distal edge was 1.5 cm from the medial edge of the base of the patella. The location for the electrodes over VLO was found by taking a line from the iliotibial band to the lateral edge of the base of the patella, as far down the muscle belly as possible. The position for the electrode on the muscle belly of RF was located over the motor point which had been previously found, in a small sample of subjects, to be slightly medial and about midway along the length of the thigh. Since RF is a bipennate muscle, the electrodes were angled at 15°. The skin was rubbed with alcohol, before the application of the electrodes.

The subjects were then seated in a Cybex II Plus Isokinetic Dynamometer, with the thigh carefully aligned so that the hip was in neutral rotation and neither abducted or adducted. The force arm of the Cybex was replaced, for greater accuracy, by a custom-built force arm which contained strain gauges. This arm could be very firmly tightened and had a better frequency response. It was frequently calibrated and was found not to vary over the experimental period. The fulcrum of this force arm was placed over the jointline of the knee. Ninety-degree flexion was found and verified with a goniometer (Akron), to take account of the slope of the thigh when the subject was seated. The goniometer was aligned along lines taken from the greater trochanter, through the jointline and terminating with the external malleolus of the fibula. The knee was extended in the Cybex to 20° of flexion and fixed. The knee angle was again verified by the use of the goniometer. The subjects were instructed to apply maximum force as fast as possible and hold it for 2 seconds. The amount of extension caused by a maximal extensor effort was about 4°. The exhortations to produce the force quickly were repeated over a few trials when patients, or subjects, appeared to produce the force rather slowly.

The electrodes contained preamplifiers with a gain of about 400. The leads from these preamplifiers were well screened. Each time it was used care was taken that a noise-free preamplifier output was obtained. These signals were further amplified with a gain trim so that there was no inter-electrode variability. Also the signals were rectified and smoothed with a leaky integrator (100-millisecond time constant). After digitization they were displayed and stored on a computer, together with the record of force exerted. This apparatus was regularly calibrated.

Statistical methods

Parametric statistical methods were used throughout. Variation in the measured parameters are expressed as ± the standard error of the mean (s.e.m.). Groups were compared using Student's t-test (unmatched samples) and the values of the probability of the null hypothesis (p) were obtained from Tables of the "two-tailed" t-test. Correlation coefficients r were calculated using the Pearson product–moment formula. All the statistical formulae used in these calculations are those of Snedecor Cochran (17).

RESULTS

A typical result from a normal subject is shown in

Fig. 1A. Each record has been expressed as a proportion of the maximum during this contraction. The force rises to 80% of its maximum within less than 200 milliseconds. Within this time all the electromyographic (EMG) signals rise rapidly to a peak. In Fig. 2 the EMG record from VMO is plotted against the force record for the first 80% of the tension rise, to see whether the activation of this muscle keeps pace with the development of force, which indicates the timing of the activation of the other parts of quadriceps. The resultant line falls above, or close to, the line of identity ($y = x$) indicating that all parts of the muscle are activated more or less together, with some tendency for VMO and VLO to be activated more quickly than the bulk of the muscle.

A result from a patient is shown in Fig. 1B. In this example, which is typical, the force develops rather more slowly than in the normal subject and the EMG records show a delay in activation of those parts from which we recorded, relative to the force development, i.e. relative to the activation of the bulk of the muscle. This is seen most clearly by the plot in Fig. 2, in which the line falls well *below* the line of identity, instead of along the line of identity as it did in the normal subject, when oblique fibres kept pace with the activation of the long fibres producing the force. This has been quantified by measuring the area between the line of identity and the EMG data. This area, which we refer to as the lag factor will be zero when the EMG data falls about the line of identity, positive when it falls below the line and negative when it falls above the line. The scale of the lag factor is such that a value of +1 would indicate no activation at all, and −1 would indicate instantaneous full activation. For the patient shown the value is +0.321, whereas for the normal subject shown in these figures the value is −0.046.

A comparison of these factors for the 20 normal subjects and the 49 patients is shown in Table I. The force exerted by the patients is slightly, but significantly, less than for the control subjects and its onset is on average more than twice as slow. There is also, for each of the regions from which recordings were made, a large and significant difference between the patient group and the normal subjects in the timing of activation relative to the activation of the main bulk of the muscle. The difference seen for the oblique fibres (VMO and VLO) is greater than for RF.

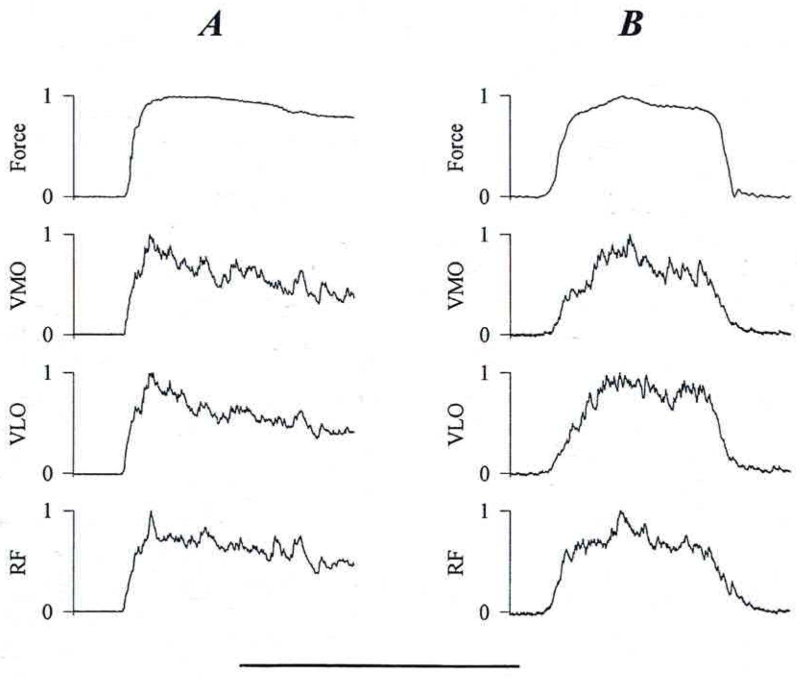

Fig. 1. Recording of force and rectified, smoothed EMG from two subjects during maximum isometric contraction of quadriceps; (A) normal subject; (B) patient with patellofemoral problems. All the recordings are expressed relative to the maximum value observed during the period shown.

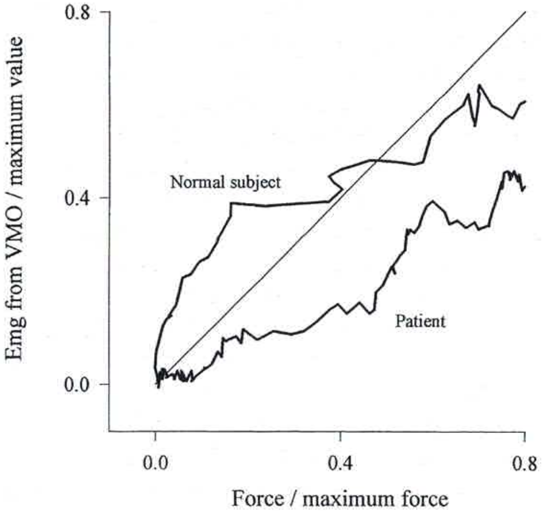

Fig. 2. Plots of recorded EMG from VMO against force developed during the first 80% of force rise for the contractions shown in Fig. 1. The thin line shows the line of identity which the data would follow if VMO was activated with the same time-course as the bulk of quadriceps.

Although these differences are large there is still some overlap between the control and patient groups for each of these measurements. This is illustrated by the histogram of the lag factors for VMO shown in Fig. 3.

Considering all the observations (patients and control subjects) as a group, there are correlations between the three different lag factors. This correlation is strongest between VMO and VLO ($r = 0.743$) and least between VLO and RF ($r = 0.432$). There is also (an inverse) correlation between the time for 80% tension development and the VMO lag factor. This might suggest that the increased lag factor was somehow due to the slower rise of tension. This was tested by selecting those of the patients ($n = 21$) whose rise times were within the normal range. Eleven of these patients had a positive lag factor. Comparing the mean VMO lag factor for this group (-0.002) with that for the controls (-0.158), shows the former to be significantly ($p < 0.05$) greater. Thus this cannot be the only reason for the change in the lag factor.

DISCUSSION

As we expected from the hypothetical function of VMO and VLO each of these sections of the quadriceps in the normal subject is activated somewhat ahead of the main bulk of the quadriceps, as is shown by the significant negative lag factors in Table I. RF by contrast, in our normal subjects is activated along with the bulk of the muscle. Grabiner et al. (3) have previously reported that activation of VMO leads that of vastus lateralis in normal subjects; he studied isokinetic extension of the knee, but did not find any statistically significant effect during isometric contraction. For VLO, which we are the first to investigate physiologically, we find a similar mean negative lag factor as for VMO and a strong correlation between the lag factors for these two parts of quadriceps. Thus they seem to share a common activation pattern, as suggested by the anatomical finding of Javadpour et al. (10). We feel that the need for this common activation will be particularly great with the knee at the angle we have used because otherwise an unapposed pull of VMO would not only produce the necessary slight medial patellar shift, but also an unwanted medial tilt because of the insertion of VMO on the medial border of the patella.

The patient group showed large and significant differences from the control group in the lag factors of the muscles tested. These oblique portions were activated more slowly in the patients relative to the main bulk of quadriceps. Quadriceps activation in patellofemoral dysfunction has also been studied by Moller et al. (13) and by Grabiner et al. (4). The former study is of the comparative amplitude of VMO and VL EMG records and found no significant differences between the groups; however they used as a control group the contralateral leg of the patients. We have not used such data as controls because we noticed at an early stage of our study that the contralateral leg was often not entirely asymptomatic. Also abnormalities of muscle function have been found on the asymptomatic leg of other knee conditions (14). Grabiner studied isometric contractions with fast and slow activation and reported that the patients showed decreased excitation of both VMO and VL in the fast but not the slow contractions. He, however, did not record from the oblique section of VL.

The abnormality in activation of these oblique portions is unlikely to be simply a response to pain because the majority of patients did not experience pain on being asked to undertake the isometric contraction that we studied. Frequently patients did find an isometric contraction at 30° of flexion uncomfortable. There was also a small group who did not experience any difficulty in performing an isometric contraction at either of these angles, but did so at 60

Table I. *A comparison of the results for the 20 normal subjects and for the 49 patients*

	Normal subjects $n = 20$ male/female: 7/13 age: 20–30 years Mean ± SE	Patients $n = 49$ male/female: 16/33 age: 20–37 Mean ± SE	Significance of difference
Time for 80% tension development (msec)	185.8 ± 13.3	385.8 ± 31.4	$p < 0.001$
Force developed (N)	224.5 ± 12.3	174.0 ± 8.3	$p < 0.001$
Lag factors			
VMO	−0.158 ± 0.047	0.161 ± 0.032	$p < 0.001$
VLO	−0.204 ± 0.040	0.083 ± 0.032	$p < 0.001$
RF	−0.019 ± 0.057	0.180 ± 0.028	$p < 0.002$

or 90°. Our findings resemble those of other workers and short arc exercises are very frequently given for rehabilitation because that arc of movement is considered the most comfortable (5).

In a study on cadavers, loads were applied to the muscles to produce a knee extension movement from 0° to 90° (12). When the muscles were loaded singly, vastus intermedius was seen to be the most effective extensor. All the other long heads needed a mean 12% increase in force to produce the same movement. VMO could not, by itself, effect a knee extension movement, no matter how great the loading, but VL, by itself, subluxated the patella laterally without a countering force from VMO. It is likely that VMO has a similar function in vivo, and that its action is necessary as the patella moves medially to enter the trochlea at about 20° of flexion (10). If the activation of VMO is sluggish and inadequate to the purpose, then the patella would not go down at the correct angle. This would mean that by 30°, in which position the patella is somewhat deeper in the groove, it would not articulate correctly with the femur, as is necessary for the area of articulation to be a large enough band as shown by Goodfellow et al. (2), for the patellar contact force to be applied in the usual manner. There would then be areas of hyperpressure, which is thought to cause pathological changes (8, 15) and also hypopressure, which is thought to cause disturbances of nutrition (9).

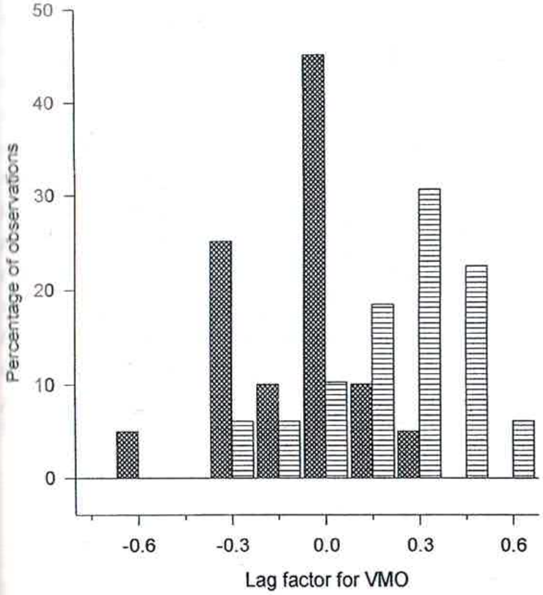

Fig. 3. A histogram showing the distribution of the VMO lag factors (see text) for normal subjects (cross-hatched bars) and patients (striped bars).

This cross-sectional study cannot answer the question as to whether these abnormalities of muscle action are a cause or effect of chronic patellofemoral pain, but we have demonstrated large and significant differences in the activation of VMO and VLO in the patient group, compared with that in the normal subjects.

ACKNOWLEDGMENTS

This study was supported by a grant from the Sir Jules Thorn Charitable Trust. We also thank Professor David Jones of the University of Birmingham for his help in the initiation of the project. Permission was granted by the ethics committee of the University College London Hospitals.

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Accepted February 2, 1996

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