MAXIMAL ISOMETRIC PATELLOFEMORAL CONTACT FORCE IN PATIENTS WITH ANTERIOR KNEE PAIN
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We assessed patellofemoral joint function by combining the measurement of maximal isometric extensor torque at the knee with clinical and radiological measurements in order to calculate the patellofemoral contact force.

Eighteen volunteers established the normal ranges of results and the reliability of the system. Of the 39 patients with a variety of knee problems, 29 had anterior knee pain, and all had a subsequent arthroscopy.

Patients with anterior knee pain and lesions in the patellar cartilage had significantly reduced isometric contact forces, but those with normal patellofemoral cartilage had normal contact forces. Our method may be useful in providing an objective assessment of anterior knee pain and a quantitative means of monitoring its treatment.

Anterior knee pain is common: Fairbank et al. (1984) found symptoms in 69 girls and 67 boys out of 446 randomly selected adolescents. Abnormal patellofemoral loading has been implicated as a cause by many authors (Wiberg 1941; Insall, Falvo and Wise 1976; Hungerford and Barry 1979) but none have confirmed this by measurement.

The role of degeneration of articular cartilage in anterior knee pain is disputed. Outerbridge (1961) found chondromalacia patellae (CMP) in 50% of his meniscectomy patients, but Leslie and Bentley (1978), using arthroscopy, found evidence of chondromalacia in only 50% of patients with anterior knee pain. Goodfellow, Hungerford and Woods (1976) accounted for this paradox by describing two different lesions of the patellar cartilage. The first, superficial degeneration of the odd facet, is common, age dependent and asymptomatic; the second, basal degeneration, is rarer, confined to adolescents, symptomatic, and occurs on the true medial facet. Radiological and clinical assessments, although widely used, have been shown to be unreliable (Fairbank et al. 1984; Dowd and Bentley 1986). Thus evaluation of this condition is subjective and assessment of its treatment remains empirical.

No attempt to correlate arthroscopic findings with biomechanical measurements of loading has been reported. We have calculated patellofemoral contact force (PFCF) using measurements of extensor torque in patients with painful knees and then correlating them with arthroscopic findings. We aimed to find an objective non-invasive method of assessment of anterior knee pain.

METHODS

The patellofemoral joint can be represented by a free body diagram (Fig. 1). Extensor torque (R) was measured using a specially designed chair (Figs 2a and 2b) in which a strain gauge at the centre of rotation of the test arm was connected to a chart recorder via an amplifier. Each subject was tested at five angles of knee flexion (θ) - 30, 45, 60, 75 and 90°. The subject made a maximum extensor effort at each angle for two seconds, repeated three times. The mean value at each angle was recorded.

Testing did not produce pain, but at the end of tests on each limb, the 60° test was repeated. The subject was then asked to make a prolonged effort so as to provide a fatigue curve. Sincerity of effort was assessed from the repeatability of the results for this angle and from the shape of the fatigue curve (Haley 1983). The shank mass (W) and the centre of mass for each subject was calculated from their body weight and shank length (Contini 1972).

Patellar tendon force (P_T) does not equal quadriceps (Q_T) force. Ellis et al. (1980) and Nisell (1985) have shown that P_T = k Q_T, where the constant K differs at varying angles of knee flexion (Table I). The patellar tendon moment arm (d) was calculated from lateral radiographs taken at 45° of knee flexion and assumed to
be constant within the range tested (Nisell 1985). The angle that the patellar tendon subtends to the long axis of the tibia (\(\alpha\)) was estimated for varying angles of knee flexion (Table II).

The angle of the line of action of the quadriceps through the range tested was then assumed to be constant at 5° (Perry, Antonelli and Ford 1975).

Taking moments about the knee:

\[
P_T \cdot d = R + W \cdot C \cdot \cos \theta
\]

\[
P_T = \frac{R + W \cdot C \cdot \cos \theta}{d}
\] .................................(1)

\[
Q_T = \frac{P}{k}
\] .................................(2) (Table I)

\[
\text{PFCF} = \text{Resultant of } Q_T \text{ and } P_T
\]

Horizontal Vector = \(Q_T \cos \theta - P_T \cos \alpha + \theta\) .... (3)

Vertical Vector = \(Q_T \sin \theta + P_T \sin (\alpha + \theta)\) .... (4)

\[
\text{(PFCF)}^2 = (\text{Horizontal Vector})^2 + (\text{Vertical Vector})^2
\]

By substituting (1) and (2) into (3) and (4) and then into (5)

\[
\text{PFCF} = \frac{R + W \cdot C \cdot \cos \theta}{d} \left[ 1 + \frac{1}{k^2} \left( -2\cos \theta \cos \alpha \right) + \frac{2 \sin \theta \sin \alpha}{k} \left] \right. \right.^2
\]

With a few simplifying assumptions, this analysis provides a method of assessing patellofemoral loading. It gives comparable values to those observed using pressure sensitive film in cadavers (Huberti and Hayes 1984).

SUBJECTS AND PATIENTS

Eighteen volunteers were studied to establish the normal range of results. There were 10 males whose mean age was 27 years (range 20 to 36) and eight females whose mean age was 29 (range 19 to 34). One volunteer was tested on seven consecutive days to establish repeatability of results.

Thirty-seven patients (40 knees) were tested before they had arthroscopy for a variety of knee complaints. There were 22 men in whom 24 knees were studied. Their mean age was 33 years (range 17 to 55); 15 knees were being investigated for anterior knee pain and nine for other complaints. In 15 women with a mean age of 23 years (range 16 to 29) 16 knees were assessed for anterior knee pain, and two knees also showed recurrent patellar dislocation.

At arthroscopy the patellar cartilage was inspected and probed for softness. The cartilage was described either as normal, or as showing evidence of chondromalacia. Fronding or fibrillation of the "odd" facet was considered to be normal (Goodfellow, Hungerford and Hindell et al. 1976).
Patellofemoral contact force in eight female patients (3a) and nine male patients (3b) with anterior knee pain and abnormal patellar cartilage, compared with normal subjects.

Patellofemoral contact in six female patients (4a) and six male patients (4b) with anterior knee pain but normal patellar cartilage on arthroscopy, compared with normal subjects.
Statistical analysis was by Student's unpaired t-test with 95% confidence limits.

RESULTS

Males and females were analysed separately because of known sex differences in patellofemoral loading (Morrison 1967; Nisell 1985); this difference was confirmed in our own normal subjects. No significant differences were found between dominant and non-dominant limbs. Two females failed the “sincerity” test and were excluded. One of these was arthroscopically normal; the other was not arthroscopically because of the test result.

Patients with anterior knee pain and chondromalacia had significantly lower patellofemoral contact forces at all angles of knee flexion, except at 30° in the male patients (Figs 3a and 3b). Patients with anterior knee pain but a normal patellofemoral joint showed no difference in contact forces from the normal group (Figs 4a and 4b).

Our observations did not correlate with clinically measured quadriceps wasting, and we felt that the reduced contact forces in patients with chondromalacia was not merely a reflection of joint abnormality, since patients with other knee lesions had normal contact forces.

DISCUSSION

Although our patient numbers are small and the mechanics of the patellofemoral joint has been simplified to make the method clinically applicable, our results show that patients with chondromalacia patellae have lower patellofemoral contact forces, a finding not previously reported. Patients with macroscopically normal articular cartilage had normal contact forces.

This difference in contact forces may be due to quadriceps inhibition caused by abnormal subchondral pressure which may result from increased force transmission through the deformed cartilage matrix (Goodfellow et al. 1976) or because a decreased patellofemoral contact area leads to increased pressure (Wiberg 1941; Sikorski, Peters and Watt 1979).

Our test for contact force can differentiate between patients with and without significant patellofemoral abnormalities and may be of value in the assessment of patients with anterior knee pain and of their treatment. It appears to provide a reproducible quantitative assessment which has previously been lacking from clinical practice. We now plan to study the relationship between contact forces and the severity of chondromalacia and to investigate the dynamic force characteristics of the patellofemoral joint.

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REFERENCES


Morrison JB. The forces transmitted by the human knee joint during activity. Thesis presented for PhD Philosophy in Engineering, University of Strathclyde, 1967.


