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Patellofemoral contact forces and pressures during intramedullary tibial nailing

A. T. Devitt[1], **K. A. Coughlan**[2], **T. Ward**[3], **D. McCormack**[1], **D. Mulcahy**[1], **P. Felle**[2], **J. P. McElwain**[1]

[1] Department of Orthopaedic Surgery, Meath Hospital, Dublin, Ireland
[2] Department of Anatomy University College, Dublin, Ireland
[3] Department of Electronic Engineering, University College Dublin, Ireland

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Summary. *Patellofemoral joint forces and pressures were measured in a cadaver model during intramedullary nailing of the tibia. A significant increase in contact pressures was found at the lateral facet of the patellofemoral articulation using the medial paratendinous approach (P = 0.01) and at the medial facet when using the trans-patellar tendon approach (P = 0.001) to the proximal tibia. Increased contact pressures at the patellofemoral joint may result in chondral injury, which in turn may cause anterior knee pain, a common complication of tibial nailing.*

Résumé. *Les auteurs ont mesuré les forces et les pressions de l'articulation fémoro-patellaire sur un modèle cadavérique au cours de l'enclouage intramédullaire du tibia. Une augmentation notable de la pression au niveau de la facette latérale de la fémoro-patellaire a été mesurée lors de l'utilisation d'un abord paratendineux interne tandis qu'une augmentation de la pression au niveau de la facette médiane était notée lors de l'abord trans-tendineux de l'extrêmité supérieure du tibia (P = 0.01). Ces augmentations de pression au sein de l'articulation fémoro-patellaire peuvent aboutir à une lésion cartilagineuse pouvant provoquer des douleurs antérieures du genou, complication fréquente de l'enclouage tibial.*

Reprint requests to: A. Devitt, Professorial Unit, Cappagh Orthopaedic Hospital, Finglas, Dublin 11, Ireland

Introduction

Anterior knee pain is the commonest complication following intramedullary nailing of the tibia. The aetiology of this complication is unknown. Pain usually begins several months after the procedure and removal of the nail does not necessarily effect a cure. Court Brown et al. [1] reported anterior knee pain in 41% of patients following intramedullary nailing, with 26% requesting nail removal. More recently, the same authors reported an incidence of anterior knee pain at the site of nail entry of 56.2%, with 65.2% of these patients requesting nail removal [2]. In this series, after removal there was complete resolution of symptoms in 27.4% of patients, with marked improvement in 69.3%. The authors found a significant association between pain and younger age but none between pain and the surgical approach to the proximal tibia.

Orfaly et al. [3] reported troublesome anterior knee pain in 56% of patients and concluded that a paratendinous approach was less likely to cause this complication than one which split the patellar tendon. In this series only 45% of symptomatic patients had relief of symptoms following removal of the nail. Keating et al. [4] also found an association between the site of insertion and subsequent anterior knee pain and therefore recommended the paratendinous approach.

None of the above studies have demonstrated an association between knee pain and the nail position in relation to the anterior cortex or tibial plateau. This suggests that the aetiology of pain following intramedullary nailing of the tibia is not necessarily related to the continued presence or the position of the implant in the bone.

We have found arthroscopic evidence of chondromalacia patellae in a small number of patients with anterior knee pain following tibial nailing. While this may be an incidental finding, the possibility that tibial nailing might result in chondral injury by increasing joint contact pressure was explored using a cadaver model.

Materials and methods

Eight cadaveric knees which had been preserved in formalin were tested. The quadriceps muscle was sectioned at the musculotendinous junction and the incision carried distally to the medial and lateral femoral condyles. Access to the patellofemoral joint was achieved by excising the suprapatellar portion of the fat pad and the synovial membrane. A transverse Kirschner wire was inserted superior to the patella and connected to a wire which ran proximally over the centre of the anterior superior iliac spine, and to which a weight of 125 Newtons (N) was attached. This experimental design permitted flexion of the knee from 0 to 100 degrees.

Both the medial parapatellar and the patellar tendon splitting approach were evaluated in each specimen. The entry point for the nail was fashioned in the midline using a curved awl. The medullary cavity was reamed to 12 mm and an 11 mm Russell Taylor tibial nail (Smith and Nephew, Memphis, USA) of appropriate length was inserted in the usual fashion over a guide wire.

The forces across the patellofemoral joint were measured using a force-sensitive resistor. This device incorporates a transducer which measures alteration in force as a change in resistance. In the circuit a constant current was passed through the transducer and the voltage, which is proportional to the resistance, was measured on a voltmeter and oscilloscope. The voltmeter provided an accurate voltage reading at specified points during the experiment, while the oscilloscope provided a real time visual display of the change in voltage when the nail was inserted. The corresponding forces were read directly from a calibration graph.

The transducer was sealed between two discs of card, both as a protective measure and to increase its reliability [5]. It was then placed posterior to the medial and then to the lateral facets of the patella, centred on the area of maximum contact. Repeated patellofemoral joint forces were measured at 0, 30, 60 and 90 degrees of flexion, both as a baseline measurement and to check the reproducibility of the observations. The change in force was observed when the nail was inserted and a final measurement was obtained with the nail fully inserted and the introducer still attached.

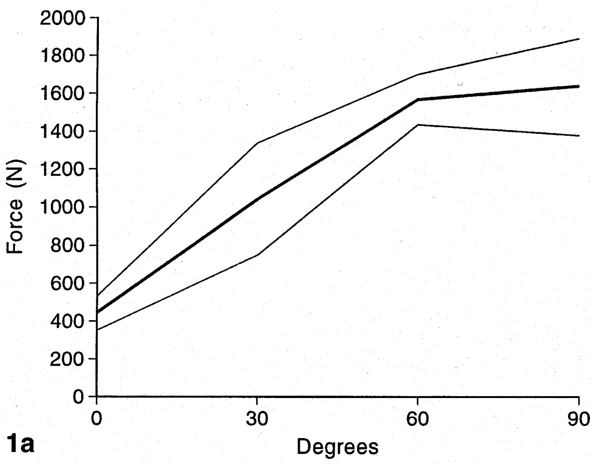
Measurement of patellofemoral contact area

The patellofemoral contact area at 90 degrees of normal flexion involves approximately one third of the total articular surface area of the patella. The articular contact area during insertion of the nail was measured using pressure sensitive film (Perscale ultra low, Fuji Ltd). Two sheets of film were used, one containing a layer of microcapsulated colour-forming material and the other a layer of colour-developing material. At pressures greater than the threshold for the film the microcapsules burst, forming a colour representation of the area of contact. The actual pressures recorded can be calculated from the density of the colour, but for our experiment the pressure sensitive film was used only to measure the contact area. The film was cut to the appropriate shape and size for each specimen and inserted into the patellofemoral joint in a plastic envelope. Following introduction of the nail, the film was removed and the contact area measured on an electronic digitiser. The force divided by the contact area was then used to calculate the pressure on the articular cartilage at each point in the experiment.

All measurements were carried out with a force of 125N directed from the patella through the anterior superior iliac spine. For each specimen, the joint pressure at the patellofemoral articulation was calculated at 90 degrees of flexion prior to introduction of the nail and at 90 degrees of flexion with the nail fully inserted and the introducing handle still attached. The pattern of voltage and therefore force change was evident from the visual display of the oscilloscope as the nail was inserted. The force transducer was calibrated before and after the experiment.

Results

The average joint forces at varying angles of flexion prior to insertion of the nail are shown in Fig. 1 (a) and (b). Maximum forces were recorded between 60 and 90 degrees.



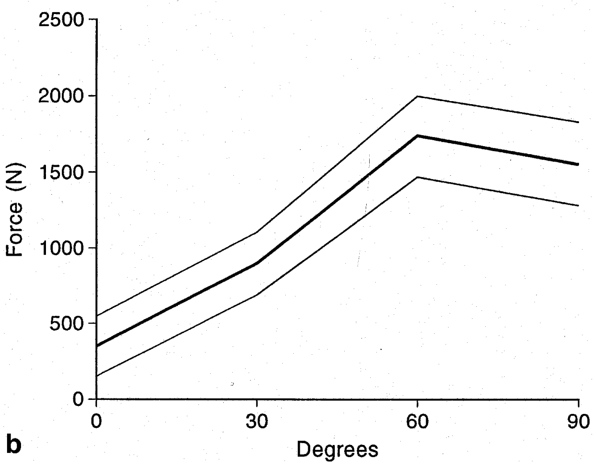


Fig. 1. a Contact forces on the lateral facet at varying degrees of flexion. **b** Contact forces on the medial facet at varying degrees of flexion

Measurements at 90 degrees of flexion, prior to insertion of the nail

The average area of contact at the patellofemoral joint at 90 degrees flexion was 4.98 cm^2. This represents approximately one third of the total surface area of the patella and it was noted to be closer to the proximal than the distal pole.

The average joint force recorded with a quadriceps force of 125 N was 1575 (+/–273) N at the medial facet and 1635 (+/–290) N at the lateral facet. This corresponds to an average pressure of 628 N/cm^2 at the medial facet and an average of 616 N/cm^2 at the lateral facet.

Measurements at 90 degrees flexion with the nail fully inserted and the introducing handle still attached

Medial paratendinous approach. Introduction of the nail via the medial paratendinous approach resulted in slight lateral subluxation of the patella.

The total patellofemoral contact area with the nail fully inserted decreased on average to 2.78 cm^2, or 55% of the baseline value. The area of contact was greater on the lateral facet (1.98 cm^2) than on the medial facet (0.8 cm^2).

Using this approach the average force on the lateral facet increased by 42% to 2337.5 (+/–301) N, while the average force on the medial facet decreased by 70% to 459.2 (+/–330) N (Fig. 2a).

The corresponding average pressures were 1284 (+/–506.9) N/cm^2 on the lateral facet and 587.3 (+/–305.8) N/cm^2 on the medial facet (Fig. 2b). This represents an increase in contact pressure by 108% on the lateral facet, and a decrease in contact pressure of 6.6% on the medial facet.

Transtendinous approach. Introduction of the nail via the transtendinous approach also resulted in slight subluxation of the patella but not to the same extent as with the medial parapatellar approach. In this instance the patella was observed to sublux dorsally and slightly medially. The joint contact force was increased at the medial facet and pressure was increased at both facets, but especially on the medial side.

The average total contact area with the nail fully inserted was 2.64 cm^2 or 53% of the baseline area. The area of contact was slightly greater on the medial (1.53 cm^2) than on the lateral facet (1.11 cm^2).

The average force at the lateral facet decreased by 24% to 1250 (+/–990) N/cm^2 while that on the medial facet increased by 52% to 2396 (+/–119) N/cm^2 (Fig. 3a).

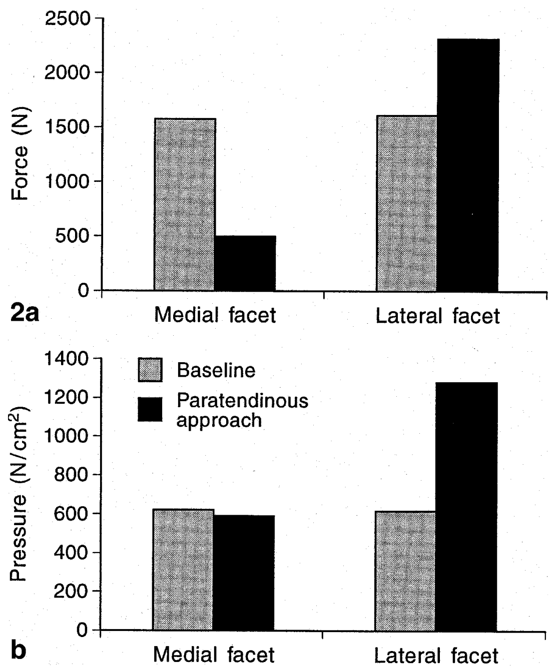


Fig. 2. a Patellofemoral contact forces and **b** pressures using the medial paratendinous approach

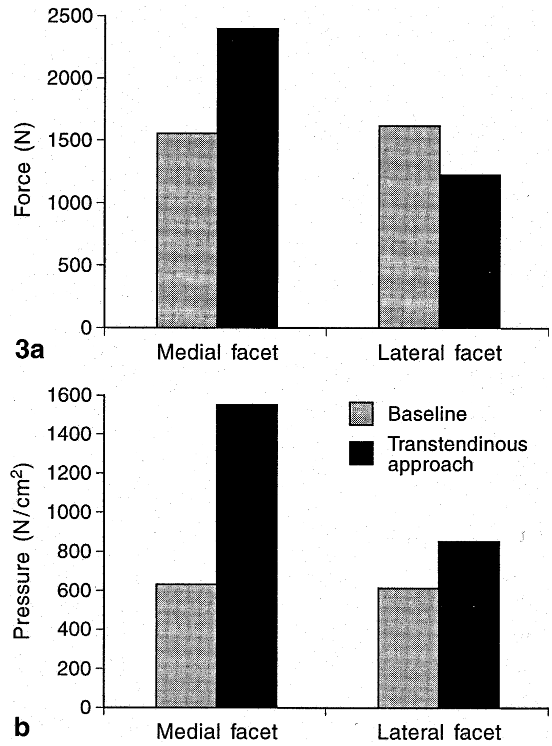


Fig. 3. a Patellofemoral joint forces and **b** pressures using the transtendinous approach

Table 1. Results of statistical tests

Table 1.a Comparison of force and pressure measurements at 90 degrees flexion and following tibial nailing using the medial parapatellar approach

	Force	Pressure
Medial facet	$P = 0.001$*	$P = 0.57$
Lateral facet	$P = 0.001$*	$P = 0.01$*

Table 1.b Comparison of force and pressure measurements at 90 degrees flexion and following tibial nailing using the trans patellar tendon approach

	Force	Pressure
Medial facet	$P = 0.0001$*	$P = 0.0001$*
Lateral facet	$P = 0.41$	$P = 0.53$

*Denotes significance at $P < 0.05$

The corresponding pressures were 850.3 (+/– 677) N/cm^2 on the lateral facet and 1535 (+/–303) N/cm^2 on the medial facet (Fig. 3b). This represents an increase in pressure by 38% on the lateral facet and 144% on the medial facet.

The data were analysed statistically using the Scheffe F test. The level of statistical significance for each test is shown in Table 1. A significant increase in force and contact pressure compared to baseline measurements was found on the lateral facet with the medial paratendinous approach, while a significant increase in force and contact pressure on the medial facet was found using the tendon splitting approach.

Discussion

Contact pressures are difficult to measure in synovial joints, and especially in the patellofemoral joint because of its complex anatomy and biomechanics. In vitro measurements have shown a high degree of variability within and between different studies. Ferguson et al. [7] using pietzoresistive pressure transducers found highly variable pressures in eight joints. A number of other methods including pressure sensitive film [6], plastic indentation foil [8] and air cushions containing electrical contacts [9] have been used but no single satisfactory method has been devised. Furthermore, all anatomical studies are limited by the difficulty in reproducing physiological conditions.

The force sensitive transducer used in this study has not been previously employed in this way. The transducer is thin and robust, making it practical for joint pressure measurements; these devices are semi-quantative, however, and measurements of force must be calculated from a calibration table. The transducer used in our experiments saturated at forces greater than 3000 N, rendering higher measurements than this inaccurate. The patellofemoral contact pressures at 90 degrees flexion in an anaesthetised patient are not known, and for this reason it was not possible to reproduce physiological conditions in these experiments. The applied forces were selected to facilitate joint pressure measurements in the sensitive range of the transducer.

The combination of large muscle forces acting on the small mobile patella, with its incongruent contact geometry, leads to large contact stresses. The patella is adapted to this situation by having the thickest hyaline cartilage in the body, so that its surface can deform to provide greater congruity. Localised loss of cartilage integrity, as in chondromalacia patellae, leads to high localised stresses acting on the underlying bone [2, 11]. The contact stresses on the patellofemoral joint are a function of knee flexion angle [1]. Although the patellofemoral joint becomes more congruent as the patella engages progressively with the trochlear groove during knee flexion, this is accompanied by a greater rate of increase in joint contact forces, due to the angle of the patellar and quadriceps tendons closing as the knee flexes. In our study, peak contact forces were measured in the range of 60–90 degrees of flexion; this observation is consistent with the findings of other authors [6, 13, 14].

Morrison [15] found the average peak stresses on articular cartilage of the tibial plateau during normal walking to be of the order of 80 to 630 N/cm^2. Repo et al. [16] suggested that the structural integrity of articular cartilage is compromised at loads exceeding 2500 N/cm^2. This value is equivalent to the load necessary to cause fracture of the femoral shaft.

Our results demonstrate that insertion of an intramedullary nail in the tibia significantly increases contact pressures at the patellofemoral joint regardless of the approach which is used. Pressures are concentrated on the proximal part of the lateral facet and the adjacent area of the crest of the patella when the medial paratendinous approach is used. The medial facet is unloaded using this approach although a small area remains in contact. The tendon splitting approach also resulted in increased contact pressures. The patella was subluxed slightly medially and was compressed between the nail introducer and femoral condyles.

Statistical analysis of the data showed that the increase in contact pressures using both approaches was significant. Direct comparison of the two approaches was not possible because of the differences in the site of the pressure increases on the patella. The magnitude of these increases was greater with the transtendinous approach, and pressure increases were recorded on both facets. This observation suggests that chondral injury is more likely with the transtendinous approach and it is consistent with the clinical observation that anterior knee pain is more common with this approach [3].

It is noteworthy that flexion of the knee to greater than 100 degrees resulted in minimum contact between the introducing handle and the patella, thus making pressure changes at the patellofemoral joint less likely during insertion of the nail. The flexion angle may be more important than the surgical approach and correct positioning of the limb is recommended.

While our experiments have shown significant increases in contact pressure at the patellofemoral joint in vitro, the clinical significance of this observation depends upon whether or not the corresponding increases in vivo are sufficient to exceed the threshold for chondral injury. Unfortunately, data on contact pressures at the patellofemoral joint at 90 degrees flexion in the anaesthetised patient are insufficient to allow us to extrapolate our results and to make clinical predictions. Nevertheless, pressure changes at the patellofemoral joint have not been previously studied in this situation and our observations might prove to be of value in the elucidation of the aetiology of anterior knee pain.

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