The tensile strength of the medial patellofemoral ligament (MPFL), and of surgical procedures which reconstitute it, are unknown. Ten fresh cadaver knees were prepared by isolating the patella, leaving only the MPFL as its attachment to the medial femoral condyle. The MPFL was either repaired by using a Kessler suture or reconstructed using either bone anchors or one of two tendon grafting techniques. The tensile strength and the displacement to peak force of the MPFL were then measured using an Instron materials-testing machine.

The MPFL was found to have a mean tensile strength of 208 N (SD 90) at 26 mm (SD 7) of displacement. The strengths of the other techniques were: sutures alone, 37 N (SD 27); bone anchors plus sutures, 142 N (SD 39); blind-tunnel tendon graft, 126 N (SD 21); and through-tunnel tendon graft, 195 N (SD 66). The last was not significantly weaker than the MPFL itself.

Acute traumatic dislocation of the patella may occur in normal knees, as well as in those with patellar instability. Conservative treatment, with a period of immobilisation followed by physiotherapy, is associated with rates of redislocation of up to 63%.1-5 Although promising early results have been reported for treatment with a patellar stabilising brace,6 surgical treatment is still favoured. The patella can be displaced laterally most easily when the knee is almost at full extension,7 a position in which it is not located securely in the femoral trochlear groove. It thus appears that a procedure to restore the stability of the medial soft tissues is needed.

The medial patellofemoral ligament (MPFL) is the primary soft-tissue restraint to lateral displacement of the patella. Its contribution is reported to range from 50% to 60% in the range of 0° to 30° of knee flexion.8-10 If the MPFL is divided, the patella displaces and tracks laterally. This can be restored to normal by reconstruction of the MPFL.11,12

Various descriptions of the anatomy of the MPFL have recently been reviewed.13 The ligament passes transversely from the superomedial border of the patella to the medial femoral epicondyle (Fig. 1). It is part of the middle of three soft-tissue layers14 and is adherent to the deep surface of the distal aspect of vastus medialis obliquus (VMO). This may add an active component to its ligamentous function.15 The MPFL has also been found to be innervated and therefore a proprioceptive role has been suggested.16

There have been reports that surgical repair of the MPFL prevents further patellar dislocation,17,18 although most series have combined this with other procedures such as lateral release,19,20 augmentation,21,22 and realignment.23,24 These have been in both acute and chronic cases and it is therefore difficult to compare them. Promising short-term results have been reported for some other methods of reconstruction including transfer of pes anserinus,25,26 semitendinosus tenodesis,27,28 adductor magnus tenodesis,29 hamstring tendon allograft,30,31 or the use of polyester tape.32,33 There have been few studies on the strength of the MPFL or of the loads which it experiences while in use which may help in the design of such corrective procedures. Our aim therefore was to determine the tensile strength of the MPFL and to relate our findings to a range of methods for repair and reconstruction.

Materials and Methods
Preparation of specimens. We used ten right cadaver knees from six women and four men with a mean age of 71.6 years (SD 16.6). None had a history of patellar instability or serious injury to the knee. The cadavers had been stored for up to 72 hours at 4°C before removal of the joints. The specimens were
removed by subcutaneous dissection, and extended from 10 cm proximal to 10 cm distal to the patella. Each was wrapped in a damp cloth, sealed in a polyethylene bag, labelled and stored at -20°C. They were thawed overnight at room temperature when needed.

The knee was then dissected in order to remove all the soft tissues from its lateral side. The quadriceps and patellar tendons were next detached from the patella. On the medial side, the fascia lata (layer 1 of Warren and Marshall) was peeled off vastus medialis and the medial aspect of the knee. The MPFL (part of layer 2) was identified by teasing off the distal fibres of VMO and its proximal edge was dissected free. The capsule of the knee (layer 3) and the synovial folds were then released from the deep aspect of the MPFL. The resulting dissection left an isolated MPFL as the only structure linking the patella to the femur. The specimen was kept moist throughout with a water spray or by being wrapped in a damp cloth. The femur was then fixed into a steel pot 50 mm in diameter using three centralisation screws and bone cement.

**Tensile test.** The pot was mounted horizontally on the base of an Instron 1122 materials-testing machine (Instron Co., High Wycombe, UK), positioned so that the medial femoral condyle was directly under the load cell. The femur was rotated internally so that the line of the posterior femoral condyles was 37 ± 2° to the horizontal. This meant that when the patella was pulled vertically, the MPFL was tangential to the medial femoral condyle. The resulting dissection left an isolated MPFL as the only structure linking the patella to the femur. The specimen was kept moist throughout with a water spray or by being wrapped in a damp cloth. The femur was then fixed into a steel pot 50 mm in diameter using three centralisation screws and bone cement.

**Diagrams showing that for the tensile test the patella is gripped and pulled upwards, with the femur fixed in 37° of internal rotation in order to keep the MPFL tangential to the medial femoral condyle.**

**Methods of repair and reconstruction.** These are illustrated in Figure 3. Each method was tested for each knee, the test sequence being progressively more invasive.

**Repair with sutures.** The failed MPFL was repaired end-to-end with a 2-0 Fiberwire suture (Arthrex Co, Naples, Flor-
ida) in the standard Kessler-suture manner. When the MPFL had ruptured near the medial epicondyle, the repair was made as best as possible to the periosteum.

**Suture anchor plus sutures.** The MPFL was reconstructed with Arthrex biodegradable corkscrew bone anchors 3 mm diameter by 10 mm in length. One anchor was placed into the medial femoral epicondyle and one into the medial border of the patella. A tapping tool was used to make pilot holes, and an anchor with two threads of 2-0 Fiberwire was fixed into each of these holes. The four strands of suture were then tied to their respective partner by a standard surgical knot.

**Tendon graft reconstruction.** The MPFL was also reconstructed with lengths of bovine extensor tendon 5 to 7 mm in diameter in order to simulate hamstring grafts. Two methods of femoral fixation were used, blind-tunnel and through-tunnel, with the method of patellar fixation being identical for both.

**Blind tunnel.** This describes the fixation of the tendon graft to the femur. Using the instruments for an Arthrex blind-tunnel fixation, a tunnel 25 mm in depth and 8 mm in diameter was drilled into the medial femoral epicondyle. The end of the graft was then prepared using a standard whip stitch and loaded on to the screwdriver for insertion into the tunnel. The end of the guide wire with the graft alongside it was inserted into the tunnel, and the graft then fixed by advancing a cannulated Arthrex bioabsorbable biotendonodesis screw 8 mm by 23 mm in size over the guide wire. The fixation was augmented by tying the ends of the whip stitch suture together, one through and one alongside the screw.

**Through tunnel.** A 7-mm tunnel was drilled along the epicondylar axis of the femur. The graft was threaded through this tunnel and secured on the lateral side of the femur with an Arthrex titanium alloy soft screw, 8 mm by 20 mm in size.

For both methods, a 7-mm tunnel was drilled through the patella from its medial to its lateral border. The graft was passed through this tunnel and secured on the lateral side with an Arthrex screw, 8 mm by 20 mm in size.

**Statistical analysis.** The tensile strength of the MPFL, suture repair, suture anchor and blind- and through-tunnels were compared by using a one-way analysis of variance with Student-Newman-Keuls post tests. The level of significance was set at $p < 0.05$.

**Results**

Our results are summarised in Figure 4. The MPFL and the surgical methods of repair showed significantly different strengths ($F = 16.7$ (result of ANOVA test); $p < 0.0001$).

**MPFL strength.** The MPFL failed at a mean tension of 208 N (SD 90), at 26 mm (SD 7) of elongation. Seven failed with a mid-substance tear, while three separated from the femur. After a mid-substance tear, the ligamentous tension reduced but persisted as its fibres became attenuated and slid apart with further elongation. When the MPFL separated from the femur, the ligamentous tension fell rapidly.

**Suture repair.** The suture repair failed at a mean of 37 N (SD 27). This was significantly weaker than the MPFL and the other surgical methods ($p < 0.001$). All repairs failed by the suture cutting through the soft tissues (‘cheese-wiring’) on the femoral side. After reaching a relatively low peak
force, the load remained almost constant as the suture cut through the soft tissues.

**Suture anchors plus sutures.** This reconstruction failed at a mean of 142 N (SD 39), and was significantly weaker than the MPFL and through-tunnel reconstructions (p < 0.05) but not significantly different from the blind-tunnel method (p > 0.05). Seven anchors pulled out of the femur, two pulled out of the patella and in one the eyelet of the anchor snapped releasing the suture. When the anchors failed there was a sudden loss of tension.

**Blind-tunnel tendon graft reconstruction.** The blind-tunnel tendon graft reconstruction failed at a mean of 126 N (SD 21), and was significantly weaker than the MPFL (p < 0.01) and through-tunnel reconstructions (p < 0.05), but not significantly different from the suture-anchor method (p > 0.05). All constructs pulled out of the blind-tunnel on the femoral side. The graft slid past the screw at a relatively constant force until it was pulled out of the tunnel.

**Through-tunnel tendon reconstruction.** The through-tunnel tendon reconstruction failed at a mean of 195 N (SD 66), which was not significantly different (p > 0.05) from the MPFL. All constructs pulled through the femoral tunnel. In some specimens, the graft initially cut through the thin cortical shell and soft cancellous bone of the medial femoral condyle before starting to pull past the fixation of the screw on the lateral side. Thereafter, the graft pulled past the screw at a relatively constant force.

**Discussion**

This study established that the MPFL ruptured at a mean elongation of 26 ± 7 mm. Since the patella must move approximately 50 mm when dislocating, it follows that patellar dislocation must be accompanied by a rupture of the MPFL, which is known to be the primary passive restraint. The MPFL has a mean length of 53 mm and therefore rupture occurred at approximately 49% strain. This is more than is normally found for ligaments e.g. 18% for the PCL.

The mean strength of the MPFL was 208 N. This was higher than anticipated for specimens with a mean age of 72 years, because the MPFL is sometimes transparently thin. Although the MPFL was found in all the knees examined, it is a flimsy structure which was found in only 35% of knees in one study, and in 85% of knees in another. Although we are unaware of earlier data on the tensile strength of the MPFL, evidence to support our findings has been reported by Burks et al, who noted a peak of 209 N at 25 mm of displacement for failure of the MPFL during lateral patellar dislocation. Our failures, seven mid-substance and three at the femoral attachment, are similar to those of other reports in the literature. Lesions of the MPFL have been classified and documented, after lateral patellar dislocation, at open surgery on MRI.

The sutured repairs were weak and demonstrated a mean failure strength of 37 N. This was 18% of the natural MPFL. It related to the attenuation of this naturally very thin structure, both in its mid-substance and at its bony attachment, leaving little substance to support the load on the sutures. It is not surprising that a recent study found that the results, at follow-up at two years, of sutured repairs after acute patellar dislocations were the same as those of conservative treatment alone. Suture repair of a transected MPFL is common in knee replacement, without great risk to patellar stability. While our specimens did not have a traumatic patellar dislocation, several studies have reported a redislocation rate of less than 10% after surgical repair.

The weakness of a sutured repair of the MPFL suggests that an alternative method of reconstruction is desirable while the low rate of dislocation after suturing argues for a minimally invasive procedure. In our study, the strength when suture anchors were used was 68% of the MPFL, and the strength of the through-tunnel tendon grafts was 94% of the MPFL. Indeed, the latter barely differed from an intact MPFL. This is better than after reconstruction of the anterior cruciate ligament in which the immediate fixation strength is only 30% of the strength of the natural ligament. Suture anchors can easily be inserted through two stab incisions, the sutures being passed from one anchor to the other. The materials used can be resorbable. By contrast, the use of a tendon graft involves the additional creation of pathology in the form of a donor site. This can be avoided by the use of either artificial graft or allograft, but still requires tunnels to be drilled and incisions to be made for the placement of screws. These more invasive procedures may not be justifiable.

There are some limitations to our study. Elderly specimens were used and the strength of cancellous bone diminishes with age. We found that the medial cortex of the patella gave a more reliable fixation than the femoral epicondyles, which showed a thin cortex overlying cancellous bone. Younger specimens may be expected to show a greater strength of bony attachment. The findings of our study should thus be regarded as relatively conservative. We used bovine tendon grafts because the hamstrings were attenuated in our specimens and because their mechanical properties did not differ significantly from those of human tendons. The tensile test took place in a straight-line configuration, thus avoiding the complication of interaction with the femur. This was justifiable since the failures matched clinical findings and occurred either at the femoral attachment or in the mid-substance where the loading direction remained physiological. Our study only addressed the immediate strength. The effects of any healing responses were unknown.

Because there has been a variety of interpretations of the anatomy of the MPFL there is still disagreement about some important aspects of surgery for its rupture. In particular, it is clear that the change in length of the MPFL during flexion and extension of the knee depends critically on its femoral attachment. The optimal point of attachment and degree of tensioning are unknown. The MPFL does not
appear to be isometric and may have two functional bands. If a substantial reconstruction such as a hamstring graft is used, over-tensioning may cause problems with patellar alignment.

Problems with stability of the patellofemoral joint are rarely straightforward and may be influenced by other factors such as articular geometry, alignment of the lower limb, rotational deformities, patellar height and ligamentous laxity. This means that in order to achieve stability of patellar alignment, a graft is used, over-tensioning may cause problems with}

References

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