

Magnetic Resonance Imaging Validation of Tibial Tubercle Transfer Distance in the Fulkerson Osteotomy: A Clinical and Cadaveric Study



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Purpose: To validate the medialization and anteriorization distances, and the osteotomy angle of anteromedialization tibial tubercle osteotomies using postoperative axial imaging. **Methods:** From March 2004 to August 2015, 117 consecutive patients who underwent anteromedialization osteotomies of the tibial tubercle by a single surgeon were identified. Only patients with pre- and postoperative magnetic resonance imaging (MRI) studies were included. Using MRI multiplanar reformats, distances that the tibial tubercle was translated medially (medialization) and anteriorly (anteriorization) were measured. In addition, the osteotomy angle was measured on the postoperative MRI. The measured values were compared with intraoperative estimates. Tibial tubercle osteotomies were then performed on 3 cadaveric knee specimens and imaged with pre- and postprocedure MRIs to correlate intraoperative measurements with MRI findings. **Results:** A total of 40 patients (41 knees) (34.2%) had both pre- and postoperative MRIs and were included. Compared with intraoperative assessment, MRI measured medialization values average 94.7% (standard deviation [SD] 37.7) of dictated values ($P = .1$). MRI measured anteriorization averaged less than half of dictated values (48.9%, SD 18.2%, $P < .0001$). MRI measured osteotomy angles averaged 67.2% of dictated values (SD 50.3%, $P < .0001$). The steepest osteotomy angle that could be performed without violating the posterior cortex and/or endangering the posterior neurovascular structures was 46.3° . **Conclusions:** Surgeons often overestimate both the anteriorization distance and the osteotomy angle in anteromedialization tibial tubercle osteotomies. The steepest osteotomy angle is less than the 60° described in the literature. Modifications should be considered when more anteriorization is desired with tubercle transfers. **Level of Evidence:** Level IV, retrospective case series.

See commentary on page 198

Tibial tubercle anteromedialization, also known as the Fulkerson osteotomy, is a reliable and effective method for treating symptoms of moderate patellofemoral arthritis or patellofemoral overload as well as for

correcting coronal plane malalignment with a low incidence of complications.¹⁻⁶ First described by Fulkerson in 1983 as a means to realign the extensor mechanism without the necessity of bone graft,⁷ the procedure involves an oblique osteotomy cut of the proximal tibia that moves contact forces and stresses on the patellofemoral joint from the lateral and distal aspects of the patella to the more proximal and medial patella articular cartilage.

Depending on the preoperative symptoms, surgeons can titrate the slope of the anteromedialization osteotomy to preferentially medialize (e.g., to correct coronal plane malalignment often seen with patellar instability) and/or anteriorize the tibial tubercle (to unload the distal patella in cases of inferior pole arthritis or overload). Intraoperatively, the angle of osteotomy is of particular importance. Although medialization may be directly measured along the obliquity of the osteotomy, reference points to measure anteriorization are not in the same sagittal plane, thus making the distance anteriorized difficult to measure

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accurately. The anteriorization distance is instead extrapolated from the directly measured medialization distance and angle of the osteotomy cut using common trigonometry principles: the steeper the cut, the more anteriorized the tubercle becomes after transfer.

Previous *in vitro* studies have shown that the amount of anteriorization that should be performed ranges from 10 to 15 mm.^{4,8,9} The distance anteriorized becomes important when considering contact pressures across the patellofemoral joint. A 1-cm anteriorization has been shown to be the minimum necessary for achieving any statistically significant reduction in contact stresses.⁴ In practice, there is a predilection for more anteriorization when treating patellofemoral arthritis and pain compared with instability; however, too much anteriorization can be complicated by wound healing issues as has been shown in studies reviewing the Maquet procedure (a direct anteriorization that requires bone graft and does not address coronal plane alignment).¹⁰

The purpose of the study was to validate the medialization and anteriorization distances, and the osteotomy angle of anteromedialization tibial tubercle osteotomies using postoperative axial imaging.

Methods

Patient Selection

Before study initiation, the study received institutional review board approval. From March 2004 to August 2015, a list of all patients who underwent anteromedialization osteotomies of the tibial tubercle performed by the senior author (B.E.S.S.) at a single institution was reviewed. A total of 117 patients were ultimately identified. All patients received radiographs (standing anteroposterior, lateral, and merchant views of the knee) and magnetic resonance imaging (MRI) for preoperative planning. A consensus opinion among senior musculoskeletal radiologists at our institution concluded that postoperative advanced axial imaging was necessary to assess accurately the amount of anteriorization and medialization, as radiographs could not adequately account for differences in magnification or rotation without significant variability. Thus, the inclusion criteria were patients with at least 1 additional postoperative MRI. All diagnoses (e.g., patellofemoral instability, arthritis, chondral injuries) were included. The exclusion criteria were patients who underwent concomitant distalization for patellar alta. A total of 40 patients (41 knees) (34.2%) ultimately also had pre- and postoperative MRIs available for review and thus were included in this study.

Intraoperative Assessment of Medialization, Anteriorization, and Osteotomy Angle

At the time of surgery, the authors' preferred surgical technique uses a freehand method with Kirschner wires to determine the slope of the anteromedialization osteotomy

(Fig 1); the osteotomy angle is measured with respect to a perpendicular axis such as the operating room table or floor. Medialization is determined by the distance needed to correct the preoperative tibial tubercle-trochlear groove (TT-TG) distance and is confirmed with the width of a known calibrated osteotome blade (Fig 1 B and C). Anteriorization is extrapolated from the medialization distance and the osteotomy angle using trigonometry principles: anteriorization = medialization \times tangent (osteotomy angle).

MRI Acquisition

MRIs were performed using a standard protocol¹¹ with either a 1.5 or 3 T General Electric MRI preoperatively, and a 1.5 T General Electric MRI postoperatively (to reduce artifact metal instrumentation).¹² For the 1.5 T magnet, the following parameters were used: fast spin echo repetition time/echo time 3,500/24-34; field of view 14-15 cm; 512 \times 256-384; echo train length 8-10; 2 number of excitations, 3-4 mm slice thickness, 0 gap, bandwidth 32 MHz using a dedicated knee coil that varied with the scanner. For studies using the 3 T magnet, the same parameters were used except a resolution of 512 \times 352-416, 1 NEX; bandwidth 64 MHz.

MRI Measurements

Using the picture archiving and communication system workstation (Spectra, Linköping, Sweden), multiplanar reformats of pre- and postoperative axial MRIs were performed to account for rotation and sagittal tilt of the tibia (to ensure that measurements are taken perpendicular to the tibial axis) and to ensure repeatable measurements. A fellowship trained musculoskeletal attending radiologist (D.N.M.) and chief orthopaedic surgery resident (J.N.L.) independently measured the distance from the lateral edge of the fibula to the center of the tibial tubercle (Fig 2, m_d [preoperative image] and m_e [postoperative image]) and the distance from the posterior aspect of the tibia at the joint line to the most anterior aspect of the tubercle (Fig 2, a_d [preoperative image] and a_e [postoperative image]). The difference between the measurements made on the pre- and postoperative MRIs was the distance medialized (medialization) and distance anteriorized (anteriorization), respectively. Of note, this measurement was specifically designed for this study by our fellowship trained musculoskeletal radiologist and not related to the operative technique. The medialization distance measured using the above technique was also compared with the change in the TT-TG distance. On the postoperative MRI, the angle of the osteotomy was measured on the axial cut that visualized the most anterior aspect of the tubercle with respect to the posterior border of the tibia at the joint line (Fig 2F).

Cadaveric Study

Three cadaveric knee specimens were imaged with MRI and subsequently underwent tibial tubercle

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