Failure of the Patellar Tendon with the Patella Everted versus Noneverted in a Matched-Pair Cadaver Model

James A. Ryan, MD · Kathleen N. Meyers, MS · Paolo DiBenedetto, MD · Timothy M. Wright, PhD · Steven B. Haas, MD

Received: 16 July 2009/Accepted: 24 November 2009/Published online: 29 January 2010
© Hospital for Special Surgery 2010

Abstract Avoidance of patellar eversion during total knee arthroplasty may help to prevent injury to the patellar tendon. The purpose of this study was to compare the load-to-failure of the everted versus the noneverted patella in a cadaveric model. Fourteen cadaver knees (seven pairs) were loaded to failure with the patella everted in one knee and not everted in the other. Mean load-at-ultimate failure in the patella-everted group was $1,111 \pm 572$ N, and in the patella-noneverted group was $1,621 \pm 683$ N ($p=0.01$). Additionally, loads-at-initial-partial failure were lower ($p=0.04$) in the patella-everted compared to the patella-noneverted group, 573 ± 302 N versus $1,115 \pm 358$ N, respectively. A partial failure of the patellar tendon occurred in 100% of the everted specimens, whereas only 57% of the noneverted specimens had partial failure. These findings suggest patella eversion may lead to failure of the patellar insertion at lower loads than when the patella is not everted.

Keywords patellar eversion · knee arthroplasty · patellar tendon · failure

Introduction

In the course of performing a total knee arthroplasty (TKA), the patella is traditionally everted to facilitate exposure of

articular surfaces and to allow placement of retractors and cutting blocks [1]. To this end, the patella can be everted and dislocated laterally or dislocated laterally without patellar eversion. Patellar eversion has been speculated to increase tension across the knee extensor mechanism and to load the insertion site of the patellar tendon in a twisted, non-physiological fashion. This may result in peeling of the patellar tendon from the tibial tubercle and, in some cases, complete disruption of the extensor mechanism [2, 3].

Recently, less invasive TKA has been introduced in an attempt to minimize soft tissue trauma [4]. A key surgical feature of this approach is lateral dislocation of the patella without patellar eversion. This avoids the 180° flip of the patella, loading the patellar tendon in a more physiologic fashion, and should prevent peeling and tendon failure at the insertion site. Supporters of minimally invasive TKA have advocated lateral patellar dislocation without eversion during exposure as a means to reduce injury and trauma to the soft tissues [4, 5]. Several authors advocating minimally invasive technique suggest patellar eversion during TKA may result in significant shortening of the patellar tendon and resultant patellar baja [6–8]. In addition, high-risk patients, i.e., those with rheumatoid arthritis, diabetes mellitus, chronic renal insufficiency, extensor mechanism contractures, osteopenia, or a poorly vascularized patellar tendon, are thought to be at greater risk of patellar tendon avulsion from the tibial tubercle and therefore may benefit from avoidance of patellar eversion [9]. Despite these clinical observations, studies investigating the speculated compromise of the patellar tendon in the everted position are lacking.

The purposes of this study were to determine the ultimate load-to-failure and the load-to-initial-partial failure of the patellar tendon with the patella everted versus noneverted in a matched-pair cadaver model. Thirdly, we wished to determine if the site of failure of the extensor mechanism differed in the everted versus the noneverted loading condition. We hypothesized the load–displacement behavior with the patella everted would be inferior to that when the patella was not everted.

J. A. Ryan, MD · S. B. Haas, MD (✉)
Department of Orthopaedic Surgery,
Hospital for Special Surgery,
535 East 70th Street,
New York, NY 10021, USA
e-mail: Haas@hss.edu

K. N. Meyers, MS · T. M. Wright, PhD
Department of Biomechanics,
Hospital for Special Surgery,
New York, NY, USA

P. DiBenedetto, MD
Clinic of Orthopaedics and Traumatology,
University of Udine, AOU of Udine,
Udine, Italy

Materials and methods

Approval for this project was obtained from the institutional review board of our hospital (protocol number 22121). Bilateral knees were obtained from seven individuals (14 knees) from a national donor program. Specimen inclusion criteria included male, Caucasian, and specimens without a history of cancer or significant trauma to the knees. These rudimentary criteria were chosen to eliminate the potential confounding effects of tissue and bone quality. The knee specimens were harvested from individuals with a mean height of 1.75 ± 0.6 m, a mean weight of 88.3 ± 10.3 kg, a mean body mass index of 28.6 ± 3.7 , and a mean age of 61.7 ± 11.3 years.

The right or left knee was randomly assigned to the patella-everted or the patella-noneverted group; the contralateral knee of the pair was assigned to the opposing group. Thus, each knee specimen was compared to a knee specimen from the same individual (matched-pair).

Each knee was dissected free of soft tissue, including skin, fat, and muscle. The patella, patellar tendon, and proximal third of the tibia were isolated for each specimen. The patellas were potted in a steel, reverse dove-tail mold with bondo cement (Bondo Corp., Atlanta, GA, USA). The proximal tibias were potted in a steel, rectangular mold, also with cement. Each specimen was then mounted onto a servohydraulic mechanical testing device. Care was taken to keep the tissues moist with 0.9% normal saline for the duration of specimen preparation and testing.

In the patellar noneverted group, the patellar tendon was loaded to failure with uniaxial tensile load applied at 55° to the long axis of the tibia in the coronal plane at a rate of 600 N/min (Fig. 1, left). In the patella-everted group, the patellar tendon was everted 180° and loaded to failure along the same vector at the same rate (Fig. 1, right). Load and displacement data were collected continuously for the duration of testing. From the resulting load–displacement

curves, the following dependent variables were determined: (1) load-at-ultimate failure, (2) load-at-initial-partial failure, and (3) location and mechanism of failure. Load-at-ultimate failure was defined as the load (N), required for complete disruption of the extensor mechanism. Load-at-initial-partial failure was defined as the load at the point when the load–displacement curve displayed a drop in load and an increase in displacement, indicating a disruption of the extensor mechanism, though the specimen remained intact.

The location and mechanism of patellar tendon failure were noted for each specimen.

A paired Student's *t* test was used to compare initial and ultimate failure data for the patella-everted group versus the patella-noneverted group. Failure mode was compared using a Fisher exact test.

Results

Everted patellas suffered ultimate failure at lower loads than noneverted patellas ($p=0.01$). Mean load-at-ultimate failure in the patella everted group was $1,111 \pm 572$ N. This was lower ($p=0.01$) than the mean load-at-ultimate failure in the patella-noneverted group of $1,621 \pm 683$ N (Fig. 2). The mean difference between each pair of knees was 510 ± 374 N. Additionally, ultimate failure occurred at a lower load in all seven everted specimens with the everted group failing at on average $69 \pm 21\%$ of the load of the noneverted group.

Load-at-initial-partial failure was also lower in the patella-everted group compared to the patella-noneverted group ($p=0.04$). Load-at-initial-partial failure was 573 ± 302 N for the everted group versus $1,115 \pm 358$ N for the noneverted group (Fig. 3). The mean difference between each pair of knees was 542 ± 543 N. Load-at-initial-partial failure occurred at a lower load in all seven everted specimens with the everted group failing on average at

Fig. 1. Potted and mounted specimens in the noneverted (*left*) and in the everted (*right*) positions are demonstrated in this photograph

Fig. 2. Load-at-ultimate failure was significantly lower with the patella in the everted position compared to the noneverted position ($p=0.01$)

58±34% of the load of the noneverted group. A partial failure occurred in 100% of the everted specimens with loads as low as 157 N, whereas a partial failure occurred in only 57% of the noneverted patellas and always required a higher load than the contralateral everted specimen. In the four noneverted specimens that did not demonstrate partial failure, the load–displacement curves were continuous, without disruption. In contrast, when partial failure occurred, a simultaneous decrease in load and increase in displacement occurred, as demonstrated by a dip in the load–displacement graph (Fig. 4a, b).

In the patella-everted group, all seven specimens failed at the tibial tubercle via peeling of the patellar tendon. In contrast, in the patella-noneverted group, five of the seven specimens failed via disruption of the patellar tendon at mid-substance; the remaining two specimens failed via fracture of the tibial tubercle, a significantly different mechanism of failure ($p=0.02$).

Discussion

The aim of this study was to measure the load-to-failure of the patella tendon loaded in an everted compared to noneverted position. A cadaveric, biomechanical model was used. In this model, patellar tendons loaded with the patella everted always failed at a lower load than when the patella was not everted. In addition, when the patellas were everted, the patellar tendons consistently failed via peeling of the patellar tendon from the tibial tubercle. Intraoperatively, peeling of the patellar tendon is frequently encountered with hyperflexion of the knee and forced lateral retraction of the patella.

Fig. 3. Load-at-initial-partial failure was significantly lower with the patella in the everted position compared to the noneverted position ($p=0.04$)

Fig. 4. a, b Load–displacement curves for pair 1. Note the curve is smooth and without disruption in the noneverted specimen (a); however, a drop in load relative to displacement is noted at approximately 700 N (arrow) in the everted specimen (b). This represented an initial-partial failure of the extensor mechanism

This study has several limitations. First, the cadaver model used was only a gross approximation of the knee in situ during a TKA. Most of the soft tissues were removed, and the model was fixed in a static, rigid construct that did not replicate the mobile knee with abundant soft tissues addressed during TKA. In addition, our applied load represented a single uniaxial force delivered in only one direction. In the course of performing a TKA, the forces acting at the patellar tendon are polyaxial with a significant rotational component. However, with respect to rotation, we can speculate that had a rotational force been introduced, further twisting of the patellar tendon would result, exacerbating the compromise of the everted patellar tendon. Lastly, our model does not account for retractors used in the course of performing a TKA. Excessive traction of the patella and patellar tendon to gain better expose would likely place a larger load on both the everted and noneverted patellas. Despite these limitations, this model replicates the primary force present upon the extensor mechanism during a TKA.

In our cadaver model, partial injury with peeling occurred at significantly lower forces compared to the ultimate failure load of the tendon. These lower levels of force may occur in some patients during TKA leading to partial injury and partial peeling of the tendon. The clinical consequences of this phenomenon may present themselves during rehabilitation following TKA, especially in the early postoperative period and may explain the reported better short-term outcomes in minimally invasive TKA [10–13]. The effects of partial injury and peeling at the tibial tubercle are unknown, but we believe it may potentiate scar formation at this location.

Additional potentially negative affects arising from patellar eversion include complete avulsion of the patellar

tendon from the tibial tubercle. Patellar tendon disruption during or immediately following TKA is a devastating complication. Previous reports note an incidence of about 0.2% [9]. Surgical repair of a ruptured patellar tendon can pose a significant challenge to the reconstructive surgeon, and numerous surgical repair strategies have been explored [14–16]. Despite these repair options, patients are often left with inferior functional results [14–16].

In conclusion, our model supports the hypothesis that complete disruption of the extensor mechanism occurs at a lower load when the patella is in the everted position compared to when it is not everted. In addition, partial failure of the extensor mechanism occurs with the patella in the everted position at a lower load than when it is not everted. This partial failure is thought to occur secondary to the predisposition of the extensor mechanism to peel at the tibial tubercle when it is in the everted position.

Acknowledgements Funding for this project was provided by the Knee Service Fund of the Hospital for Special Surgery, the 535 Orthopaedic Research Foundation, and the Clark and Kirby Foundations.

References

1. Insall J, A midline approach to the knee. *J. Bone Jt. Surg. Am.* 1971; 53: 1584–1586
2. Murray DG, Total knee arthroplasty. *Clin. Orthop. Relat. Res.* 1985; 192: 59–68
3. Lynch AF, Rorabeck CH, Bourne RB, Extensor mechanism complications following total knee arthroplasty. *J. Arthroplast.* 1987; 2(2): 135–140
4. Bonutti PM, Mont MA, McMahon M, Minimally invasive total knee arthroplasty. *J. Bone Jt. Surg. Am.* 2004; 86: 26–32
5. Tria AJ, Coon TM, Minimal incision total knee arthroplasty: early experience. *Clin. Orthop. Relat. Res.* 2003; 416: 185–190
6. Floren M, Davis J, Peterson MG, Laskin RS, A mini-midvastus capsular approach with patellar displacement decreases the prevalence of patella baja. *J. Arthroplast.* 2007; 22(6 Suppl 2): 51–57
7. Weale AE, Murray DW, Baines J, et al, Radiological changes five years after unicompartmental knee replacement. *J. Bone Jt. Surg. Br.* 2000; 82(7): 996–1000
8. Weale AE, Murray DW, Newman JH, et al, The length of the patellar tendon after unicompartmental and total knee replacement. *J. Bone Jt. Surg. Br.* 1999; 81(5): 790–795
9. Patel J, Reis MD, Bozic KJ, Extensor mechanism complications after total knee arthroplasty. *Instr. Course Lect.* 2008; 57: 283–294
10. Haas SB, Manitta MA, Burdick P, Minimally invasive total knee arthroplasty: the mini midvastus approach. *Clin. Orthop. Relat. Res.* 2006; 452: 112–116
11. Haas SB, Cook S, Beksac B, Minimally invasive total knee replacement through a mini midvastus approach: a comparative study. *Clin. Orthop. Relat. Res.* 2004; (428): 68–73
12. Laskin RS, Beksac B, Phongjunakorn A, et al, *Clin. Orthop. Relat. Res.* 2004; (428): 74–81
13. Laskin RS, Minimally invasive total knee replacement using a mini-mid vastus incision technique and results. *Surg. Technol. Int.* 2004; 13: 231–238
14. Crossett LS, Sinha RK, Sechriest VF, et al, Reconstruction of a ruptured patellar tendon with Achilles tendon allograft following total knee arthroplasty. *J. Bone Jt. Surg. Am.* 2002; 84-A(8): 1354–1361
15. Park SS, Kubiak EN, Wasserman B, et al, Management of extensor mechanism disruptions occurring after total knee arthroplasty. *Am. J. Orthop.* 2005; 34(8): 365–372
16. Burnette RS, Berger RA, Della Valle CJ, et al, Extensor mechanism allograft reconstruction after total knee arthroplasty. *J. Bone Jt. Surg. Am.* 2005; 87 Suppl 1(Pt 2): 175–194