Tibial Tubercle Osteotomy for Patellar Chondral Pathology in an Active United States Military Population

Tuesday F. Fisher, M.D., Brian R. Waterman, M.D., Justin D. Orr, M.D., Courtney A. Holland, M.D., Julia Bader, Ph.D., and Philip J. Belmont, Jr., M.D.

Purpose: To quantify rates of perioperative complications, secondary surgery, subjective pain relief, and knee-related medical separation in an active military population after a tibial tubercle osteotomy (TTO) for the primary indication of chondral pathology. **Methods:** All active-duty service members undergoing TTO with a minimum of 2 years' follow-up were isolated from the Military Health System database. The exclusion criteria were patients with patellar instability, other periarticular osteotomy, and insufficient follow-up. Demographic information and surgical characteristics were abstracted from the electronic health record and correlated with improvement in pain and medical discharge from the military. **Results:** A total of 76 patients (86 knees) who underwent TTO for patellofemoral chondromalacia were identified with a mean age of 32.3 years. Major and minor complications occurred in four patients (4.7%) and three patients (3.5%), respectively, and the overall improvement in the visual analog scale score after TTO was 1.5 ($P < .0001$). At a mean follow-up of 3.4 years (range, 2.0 to 7.3 years), 37% of patients were unable to return to modified military activity because of knee-related limitations. Junior military rank group ($P = .0084$), age younger than 35 years ($P = .0031$), bilateral TTO procedures ($P = .0294$), and tobacco use ($P = .0218$; odds ratio, 3.29; 95% confidence interval, 1.19 to 9.12) were risk factors for medical separation, whereas absence of concomitant chondral repair ($P = .5408$), previous knee procedures ($P = .9674$), and greater occupational demands ($P = .7062$) were not. **Conclusions:** At short-term to midterm follow-up, 63% of patients successfully returned to military function with a low rate of perioperative complications (8%). The postoperative decrease in pain after TTO is of unknown clinical significance. Age younger than 35 years, junior military rank, bilateral TTO procedures, and tobacco use were significant risk factors for medical separation, whereas absence of concomitant cartilage repair, previous knee procedures, and lower occupational demands were not associated with improved visual analog scale scores or prevention of knee-related medical discharge. **Level of Evidence:** Level IV, therapeutic case series.

From the Department of Orthopaedic Surgery and Rehabilitation, William Beaumont Army Medical Center, El Paso, Texas, U.S.A.

The authors report the following potential conflict of interest or source of funding: J.D.O. receives support from Smith & Nephew, paid presenter or speaker. P.J.B. receives support from SLACK Incorporated, publishing royalties or financial/material support.

The findings presented in this manuscript have been previously presented at the annual meeting of the Arthroscopy Association of North America, Los Angeles, CA, April 2015.

Some authors are employees of the US federal government and the United States Army. The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of Defense or United States government.

Received May 4, 2015; accepted March 22, 2016.

Address correspondence to Brian R. Waterman, M.D., Department of Orthopaedic Surgery and Rehabilitation, William Beaumont Army Medical Center, 5005 N Piedras St, El Paso, TX 79920-5001, U.S.A. E-mail: brian.r.waterman@gmail.com

Published by Elsevier on behalf of the Arthroscopy Association of North America

0749-8063/15389/$36.00

http://dx.doi.org/10.1016/j.arthro.2016.03.027

Articular cartilage injuries have been found to be present in approximately 60% of knee arthroscopies, with grade II and III lesions of the patella among the most common.[1,2] Despite this prevalence, the optimal treatment of symptomatic patellofemoral chondral disease has yet to be determined. Anteromedializing TTO has been shown to result in significant decreases in patellofemoral contact stresses[3,4] and favorable clinical outcomes for the primary or adjunctive treatment of patellofemoral chondral lesions, especially those involving the lateral facet and distal patella.[5-7] The contemporary results evaluating clinical results after TTO are generally favorable, with good to excellent patient satisfaction reported in patients with (71% to 83%)[8-11] or without (72% to 77%)[12,13] concomitant cartilage restoration procedures at a minimum of 2 years' follow-up. Autologous chondrocyte implantation (ACI), when performed in conjunction with TTO, has shown improved patient-reported

outcomes compared with ACI alone.[8-11] However, although patients may have a reliable decrease in pain, many individuals may be unable to resume their previous level of sporting activities or high–occupational demand jobs after TTO.[14]

US military service members have higher rates of lower extremity articular degeneration than age-matched groups within the general population, in large part because of the daily occupational demands inherent to military service and rigorous physical fitness requirements.[15] All Army service members must be able to perform essential military duties, which include the ability to march 2 miles with an additional 40 lb of equipment, deploy in an austere environment for up to 12 months, and conduct tactical field training.[16,17] In addition, all military personnel must pass the semi-annual physical fitness testing, which includes a timed aerobic event, and meet directed weight and body fat composition standards.[16,17] A medical discharge may be initiated if an individual cannot comply with the physical and occupational demands associated with military service and further permanent duty limitations are not practical or feasible. In prior series, overuse knee pain was among the five most common limiting conditions for deployed military service members,[18] indicating a significant threat to peak physical function.

The existing literature assessing younger, high-demand patient populations has inadequately described their ultimate postoperative level of physical activity. Few studies to date have evaluated patient-reported and functional outcomes in athletic populations after TTO,[5,9,12] and no study has reported on military patients' return to a strenuous physical profile. The purpose of this investigation was to quantify rates of perioperative complications, secondary surgery, subjective pain relief, and knee-related medical separation in an active military population after a tibial tubercle osteotomy (TTO) for the primary indication of chondral pathology. We hypothesized that TTO would be successful for decreasing knee pain associated with patellar chondral lesions while preventing medical separation from the military. We also hypothesized that TTO would be more successful when performed in conjunction with a chondral restorative procedure.

Methods

After institutional review board approval, all active-duty military service members undergoing a TTO (Current Procedural Terminology [CPT] code 27418) performed by a military surgeon between October 2006 and March 2012 were identified using the Military Health System Management Analysis and Reporting Tool database. The inclusion criteria were any active-duty military patients who underwent a TTO for patellofemoral chondromalacia (or a chondral defect) at a military treatment facility during the study period, with at least 24 months' follow-up. The exclusion criteria were non–active-duty beneficiaries, individuals with less than 2 years' clinical follow-up, non-TTO periarticular osteotomies about the knee, cases performed for patellofemoral instability, and/or cases not performed for the confirmed diagnosis of chondromalacia of the patella (*International Classification of Diseases, Ninth Revision* code 717.7). This diagnosis was based on findings during previous arthroscopy or provocative clinical examination (e.g., positive patellofemoral grind test, tenderness to palpation on the medial or lateral facet, crepitation, and reproducible pain with compression throughout range of motion) and confirmatory magnetic resonance imaging interpreted and documented in the medical record. If the medical record indicated one or more patellar subluxation or dislocation events or if the documented diagnosis included "patellar instability" or "recurrent patellar dislocation," the patient was excluded. Pertinent demographic data including sex, military rank, and age, as well as clinical variables such as the underlying diagnosis of chondromalacia of the patella, were extracted. To isolate cases with cartilage repair or restoration procedures, concomitant procedures including ACI (CPT code 27412), knee arthroscopy with microfracture (CPT code 29879), and osteochondral autograft (CPT code 27416) were isolated for subsequent analysis. When available, additional data regarding cartilage lesion size and location, as well as radiographic parameters such as tibial tubercle–trochlear groove (TT-TG) distance, were abstracted from the medical record or advanced radiographic imaging.

The US Department of Defense electronic health record was queried for every patient previously identified in the database to confirm the accuracy of procedural coding and to record laterality, body mass index, military occupational specialty, branch of military service, tobacco use, surgical indications, perioperative complications, secondary surgical procedures, clinical course, patient-reported pain scores, and initiation of a medical evaluation board for a medical discharge because of continued, rate-limiting knee complaints. The rank groups used were junior rank (junior enlisted service members [E1 through E6]) and senior rank (senior enlisted non-commissioned officers [E7 through E9], warrant officers [WO1 through WO5], and commissioned officers [O1 through O6]). The military occupational specialties were designated as either combat arms or combat support. Combat arms military occupational specialties (e.g., infantry, cavalry, artillery, armor, special forces, and combat engineers) and military branches (e.g., Marines) primarily engage in tactical, land-based combat and are exposed to more frequent, physically demanding field training and fitness regimens in preparation for combat deployments. The scope of occupational demands inherent to combat support or service support occupations (e.g., human resources, medical, and logistics) does not frequently

require such rigorous training, although baseline physical fitness requirements are still maintained. The Pentagon Defense Manpower Data Center database was cross-referenced to ascertain the occurrence of both preoperative and postoperative combat deployments for service members after TTO.

The primary outcomes of interest were the ability to continue active-duty military function after TTO and improvement in visual analog scale (VAS) score. The VAS represents a patient's self-reported response to being asked about his or her pain level on a 0- to 10-point scale, and this value is recorded before each visit along with pertinent vital signs. In this study we used this pain score at the time of the first orthopaedic presentation for the complaint of knee pain (preoperative) and the score at final orthopaedic follow-up after TTO (postoperative). Standards for medical fitness are outlined in the regulations of the Air Force, Army, and Navy and include the functional abilities required of service members.[16,17,19] The Physical Profile (DA 3349) within the e-Profile electronic profiling system (version 3.17; Medical Operational Data System, Falls Church, VA) is used to record all physical duty limitations as well as completed medical discharges. The e-profiling system and Defense Manpower Data Center database, which documents medical separation paperwork and final board determination and/or current military association, was also cross-referenced for those patients for whom medical discharge was initiated. Therefore, we believed that the initiation of a medical evaluation board and medical discharge were synonymous. The US Physical Disability Agency database and the e-Profile system were additionally queried for each patient included in this study. The e-Profile system is also used to impose permanent limitations on service members with an illness or injury that does not prevent deployment or basic physical requirements needed for remaining on active duty. Patients who remained on active duty despite implementation of a permanent profile such as a modified physical fitness test were considered to have clinical success.

Univariate logistic analysis was used to determine the association between the patient demographic variables, surgical factors, and primary outcome measures (change in VAS score and medical separation after TTO). Significant independent predictors were determined to be those that maintained $P < .05$ with odds ratios (ORs) and 95% confidence intervals (CIs) exclusive of 1. SAS software (version 9.4; SAS Institute, Cary, NC) was used to perform all calculations.

Results

Patient Demographic Data and Surgical Characteristics

After application of the exclusion criteria, a total of 76 active-duty service members were isolated with 86 TTO procedures (66 unilateral and 10 bilateral) at a mean 3.4-year follow-up (SD, 1.4 years; range, 2.0 to 7.3 years). The average time interval between TTOs in the patients with bilateral procedures was 8.8 months (SD, 8.6 months; range, 0 to 31 months), with one patient undergoing simultaneous bilateral TTO (Table 1). The mean age of the patients in this study at the time of TTO was 32.6 years (SD, 6.6 years; range, 21 to 49 years), and the mean body mass index was 28.3 kg/m^2 (SD, 4.0 kg/m^2; range, 20 to 37 kg/m^2). All patients were placed on temporary profile or duty restrictions that limited running, jumping, or marching activities because of their knee pain before surgery. TT-TG distance data were available for 19 patients (25 knees), with a mean value of 16.5 mm (range, 11 to 22.5 mm). Quadriceps angle (Q angle) data were available for 26 patients (32 knees); the mean Q angle was 18.4° (range, 8° to 22°).

Surgical Procedures

Eighty-six TTOs were performed by 42 surgeons at 15 different military treatment facilities. When the type of TTO performed was examined, 75 knees (87%) underwent anteromedialization procedures and 11 (13%) underwent primarily anteriorization procedures of the tibial tuberosity. A total of 25 service members (32%) underwent a concomitant articular cartilage repair or restoration procedure, including 18 ACIs, 4 osteochondral autograft transfers, 2 particulated juvenile allograft cartilage implantations, and 1 microfracture. Among the 86 knees that underwent a TTO for chondromalacia, a total of 42 (49%) had undergone a prior arthroscopic procedure. Most of these procedures were diagnostic arthroscopies with no reported interventions (Table 2).

Medical Separation and VAS Score

The overall improvement in the patient-reported VAS score after TTO was 1.5 (SD, ±2.0; range, −3 to 6), which was statistically significant ($P < .0001$). Improvements in pain scores were similar regardless of patient sex, age group, tobacco use, military rank group, branch of service, combat arms designation, or absence of concomitant chondral procedure (Table 3).

At a minimum of 2 years postoperatively, 37% of service members (n = 28) had a medical separation because of persistent knee limitations whereas 63% either returned to active duty or successfully completed their remaining service commitment. No patients showed significant improvement after initiation of their knee-related medical discharge, given that this typically transpired after a reasonable course of postoperative rehabilitation and other adjunctive treatment. Risk factors for clinical failure after TTO are shown in Table 1 and include junior military rank ($P = .0084$; OR, 8.07; 95% CI, 1.71 to 38.16), age younger than 35 years ($P = .0031$; OR, 5.44; 95% CI, 1.77 to 16.68), bilateral TTO

Table 1. Risk Factors for Medical Separation After TTO (76 Service Members)

	TTO, n	Medical Separation, n (%)	No Medical Separation, n (%)	OR (95% CI)	*P* Value
Sex					
Male	59	24 (41)	35 (59)	2.23 (0.65 to 7.66)	.2035
Female	17	4 (24)	13 (76)	Reference group	
Rank group*					
Junior	56	26 (47)	29 (53)	8.07 (1.71 to 38.16)	.0084
Senior	20	2 (10)	18 (90)	Reference group	
Age					
≥35 yr	31	5 (16)	26 (84)	Reference group	.0031
<35 yr	45	23 (51)	22 (49)	5.44 (1.77 to 16.68)	
Tobacco use					
Yes	23	13 (57)	10 (43)	3.29 (1.19 to 9.12)	.0218
No	53	15 (28)	38 (72)	Reference group	
Bilateral procedure					
Yes	10	7 (70)	3 (30)	5.00 (1.18 to 21.27)	.0294
No	66	21 (32)	45 (68)	Reference group	
Chondral procedure					
Yes	25	8 (32)	17 (68)	Reference group	.5408
No	51	20 (39)	31 (61)	1.37 (0.50 to 3.77)	
Prior procedure					
Yes	42	17 (40)	25 (60)	0.98 (0.42 to 2.32)	.9674
No	44	18 (41)	26 (59)	Reference group	
Branch of service					
Army	48	25 (52)	23 (48)	29.3 (1.48 to 578.57)	.0052
Navy	8	2 (25)	6 (75)	10.4 (0.38 to 285.04)	.5423
Marines	7	1 (14)	6 (86)	6.2 (0.19 to 204.28)	.9458
Air Force	13	0 (0)	13 (100)	Reference group	
Combat arms					
Yes	12	5 (42)	7 (58)	1.27 (0.36 to 4.47)	.7062
No	64	23 (36)	41 (64)	Reference group	
BMI					
≥30	31	13 (42)	18 (58)	1.44 (0.56 to 3.72)	.4457
<30	45	15 (33)	30 (67)	Reference group	
BMI continuous				0.98 (0.87 to 1.10)	.7025
Total	76	28 (37)	48 (63)		

BMI, body mass index; CI, confidence interval; OR, odds ratio; TTO, tibial tubercle osteotomy.
*The junior rank group comprised E1 through E6; senior rank, E7 and above.

procedures ($P = .0294$; OR, 5.00; 95% CI, 1.18 to 21.27), and tobacco use ($P = .0218$; OR, 3.29; 95% CI, 1.19 to 9.12). Interestingly, absence of concomitant chondral restoration ($P = .5408$; OR, 1.37; 95% CI, 0.50 to 3.77), previous knee procedures ($P = .9674$; OR, 0.98; 95% CI, 0.42 to 2.32), and higher occupational demands (e.g., combat arms; $P = .7062$; OR, 1.27; 95% CI, 0.36 to 4.47) were not significantly associated with clinical failure.

Eight service members (10.5%) performed a combat deployment, and all remained on active duty at a minimum of 2 years postoperatively. Table 4 contains pertinent demographic and surgical information, as well as the clinical course, for these patients.

Complications and Reoperation

There were four major local complications in four knees (4.7%). Postoperative fracture through the

Table 2. Medical Separation, VAS Score Improvement, and Complications in Patients With Versus Without Previous Procedures

	Knees	Medical Separation, n (%)	Mean Improvement in VAS Score	Complications, n
Prior procedure	42	17 (40)	1.5	5
ACL reconstruction	6	2 (50)	2.1	1
Diagnostic arthroscopy*	21	6 (28)	1.5	2
Arthroscopic meniscectomy†	10	6 (60)	1.3	1
Arthroscopic lateral release	3	2 (66)	1.3	0
Arthroscopy with microfracture	2	1 (50)	1.5	1
No prior procedure	44	18 (40)	1.5	2

ACL, anterior cruciate ligament; VAS, visual analog scale.
*Includes diagnostic arthroscopy with minimal chondroplasty.
†Does not include total meniscectomy.

Table 3. Occupational Outcomes and Subjective VAS Scores After TTO for Chondromalacia (76 Service Members)

			Mean Pain Score (SD)			
	TTO, n	Medical Separation, n (%)	Preoperative	Postoperative	Mean Difference (95% CI)	*P* Value
Sex						
Male	59	24 (41)	4.9 (1.7)	3.4 (2.1)	0.30 (−0.80 to 1.39)	.5893
Female	17	4 (24)	4.8 (1.9)	3.7 (1.7)		
Rank						
Junior	56	26 (47)	5.0 (1.7)	3.5 (2.1)	0.56 (−0.46 to 1.58)	.2768
Senior	20	2 (10)	4.4 (1.8)	3.4 (1.7)		
Age						
<35 yr	45	23 (51)	5.1 (1.7)	3.7 (2.0)	0.09 (−0.84 to 1.02)	.8587
≥35 yr	31	5 (16)	4.6 (1.8)	3.2 (1.9)		
Tobacco						
Yes	23	13 (57)	5.5 (1.9)	3.9 (2.1)	0.29 (−0.71 to 1.28)	.5653
No	53	15 (28)	4.6 (1.6)	3.3 (1.9)		
Chondral procedure						
Yes	25	8 (32)	4.4 (1.2)	3.6 (1.7)	−0.79 (−1.74 to 0.17)	.1054
No	51	20 (39)	5.1 (1.9)	3.5 (2.1)		
Prior procedure						
Yes	42	17 (40)	5.0 (1.8)	3.4 (2.0)	0.41 (−0.44 to 1.28)	.3371
No	44	18 (41)	5.0 (1.7)	3.5 (2.1)		
Bilateral procedure						
Yes	10	7 (70)	6.1 (2.1)	4.1 (2.1)	0.68 (−0.66 to 2.03)	.3153
No	66	21 (32)	4.7 (1.6)	3.4 (1.9)		
Branch of service						
Army	48	25 (52)	4.9 (1.8)	3.6 (2.0)	−0.17 (−1.35 to 1.01)	.7739
Navy	8	2 (25)	5.0 (1.9)	3.5 (2.3)	0.04 (−2.20 to 2.27)	.9716
Marines	7	1 (14)	4.9 (2.1)	2.9 (2.3)	0.54 (−1.63 to 2.71)	.6082
Air Force	13	0 (0)	4.9 (1.3)	3.5 (1.8)	Reference group	
Combat arms						
Yes	12	5 (42)	4.7 (2.2)	3.8 (2.3)	−0.58 (−1.83 to 0.66)	.3543
No	64	23 (36)	4.9 (1.7)	3.4 (1.9)		
BMI						
≥30	31	13 (42)	4.9 (1.6)	3.5 (1.9)	−0.14 (−1.03 to 0.79)	.7584
<30	45	15 (33)	5.0 (1.8)	3.5 (2.1)		
Total	76	28 (37)	4.9 (1.7)	3.5 (2.0)		

BMI, body mass index; CI, confidence interval; SD, standard deviation; TTO, tibial tubercle osteotomy; VAS, visual analog scale.

osteotomy site occurred in two knees (2.3%), including one patient with revision open reduction—internal fixation (Table 5), and delayed union of the TTO was identified in two additional knees (2.3%). All three minor local complications involved postoperative arthrofibrosis (three knees, 3.5%), including one patient requiring subsequent manipulation under anesthesia and lysis of adhesions. In addition, 10 patients (11.6%) had hardware-related symptoms, all of whom underwent subsequent hardware removal. No patients underwent conversion to a patellofemoral or total knee arthroplasty at short-term to midterm follow-up.

Discussion

This study showed that nearly two-thirds of military service members resumed moderate to high occupational

Table 4. Characteristics and Complications of Service Members Who Deployed After Tibial Tubercle Osteotomy

Patient No.	Sex	Rank Group*	Age, yr	Tobacco Use	Concomitant Chondral Procedure	Bilateral	Branch of Service	Complications of Deployment
1	M	Junior	22	Yes	OAT	No	Army	None
2	F	Junior	29	No	None	No	Army	None
3	M	Junior	30	No	OAT	No	Marines	None
4	F	Junior	30	No	None	No	Air Force	Knee pain and mechanical symptoms
5	M	Junior	38	No	ACI	No	Army	None
6	M	Senior	40	No	None	No	Navy	None
7	M	Junior	40	Yes	None	Yes	Army	Knee pain
8	M	Senior	49	No	ACI	No	Army	Knee pain and mechanical symptoms

ACI, autologous chondrocyte implantation; F, female; M, male; OAT, osteochondral autograft transfer.
*The junior rank group comprised E1 through E6; senior rank, E7 and above.

Table 5. Major and Minor Local Complications After TTO by Procedure (86 Knees)

	n (%)
Major complication	4 (4.7)
Fracture through osteotomy	2 (2.3)
Delayed union of osteotomy	2 (2.3)
Minor complication	3 (3.5)
Arthrofibrosis	3 (3.5)
Reoperation	2 (2.3)
ORIF of TTO	1 (1.2)
Lysis of adhesions	1 (1.2)

ORIF, open reduction–internal fixation; TTO, tibial tubercle osteotomy.

demands within the military at a minimum of 2 years' follow-up after TTO for patellofemoral chondral disease. A principal consideration when performing osteotomy for articular disease in physically active individuals is whether patients are able to return to work and/or their previous level of activity. In a limited series of 36 civilian patients undergoing anteromedializing TTO for patellar maltracking with articular damage, Buuck and Fulkerson[5] reported that 19% and 25% of patients successfully resumed heavy labor and moderate labor, respectively, whereas half only performed sedentary occupations and 6% were disabled without employment. Their study failed to report preoperative occupational demand categories and included a comparatively heterogeneous patient population. Conversely, the occupational categories of all military service members in our investigation would be classified as medium to very heavy, as described in previous studies.[18,20-23] Within this framework, the functional return rates after TTO can be deemed modestly successful. Accordingly, these data can be used as a benchmark for assessing occupational outcomes in other active patient populations with increased physical demands.

Other works documenting return to sporting activity after TTO have been limited by variability in the duration of follow-up and inconsistencies in outcome reporting. Several studies have confirmed that only 37% to 52% of individuals undergoing TTO return to their previous level of athletic function, with or without associated cartilage restoration.[7,8] By comparison, the activity profile of military service members, particularly those in more rigorous military occupations, may eclipse the physical demands seen in analogous athletic civilian populations. This might adversely affect the ability to return to military service and not the ability to return to athletic activities in general. Conversely, the increased rate of patients returning to athletic or military activity in our study could be a reflection of physical fitness as a factor in career advancement, providing increased motivation to return to previous levels of activity and the overall success of TTO in military patients.

Previous investigations have not reported on the determinants of military occupational function after TTO for patellar chondrosis. Age younger than 35 years, junior rank group, bilateral surgery, and tobacco use were associated with an increased risk of clinical failure in our active-duty military patients. Other research has shown that younger patients undergoing TTO with or without concomitant articular cartilage restoration had greater improvements in pain and functional outcome measures, likely because of decreased lesion chronicity and relatively greater remodeling potential.[5,8,10,11] However, younger service members and those within the junior rank group are generally exposed to increased physical demands during military training and combat deployments, and these individuals may be less capable of modifying occupational activity within a military hierarchy. In addition, the rate of medical separation among patients with documented tobacco use was over three-fold greater than that in patients without it ($P = .0218$). Although this did not correlate with an increased rate of complications in this subset (e.g., nonunion), nicotine dependence is a known modifiable risk factor that negative affects local vascular perfusion, soft-tissue healing, and corresponding clinical outcomes. As a result, smoking cessation should be emphasized for patients undergoing periarticular osteotomy to optimize the chance for a successful return to preoperative function.

Realignment or off-loading osteotomy likely represents the most critical intervention for patellar chondral lesions, particularly in the presence of maltracking. More recent clinical data suggest that combined chondral restoration and off-loading TTO may synergistically enhance functional outcomes, especially with diffuse, pan-patellar lesions.[8-11] However, our study did not identify a significant difference in occupational endpoints among military service members with or without a concomitant articular cartilage repair (e.g., microfracture) or restoration procedure (e.g., ACI or osteochondral autograft transfer). Furthermore, military service members undergoing a TTO for a chondral lesion had similar rates of improvement in subjective pain scale scores, irrespective of adjunctive chondral procedures. This could be the result of insufficient power of our study or possible selection bias because patients with patellar instability were intentionally excluded. More rigorous patient standardization, greater statistical power, and broader patient-reported outcome measures may be necessary to fully elucidate the added value of various chondral procedures alongside TTO.

The overall improvement in the patient-reported VAS score after TTO was 1.5. This decrease in the pain score was statistically significant ($P < .0001$). However, it is unknown whether this translates to clinically significant pain relief. According to previous

publications, a relative decrease of 20 to 30 mm on the VAS approximates the minimal clinically important difference,[24-26] but this has not been previously extrapolated to a verbal 10-point self-reported scale. In addition, the small change in average VAS score may be attributable to varying levels of physical function postoperatively.

Among the 86 TTOs in this series, there were a total of 7 local complications (8.1%), of which 4 were major (4.7%) and 3 were minor (3.5%). There were two fractures (2.3%) at the osteotomy site, which is similar to previously reported rates of this complication of 2.0% to 6.0%.[7,12,27,28] Arthrofibrosis occurred in three patients (3.5%) after TTO, although only one individual required manipulation under anesthesia and lysis of adhesions. Buuck and Fulkerson[5] reported that in 6.9% of patients, significant losses of range of motion developed after TTO that warranted manipulation under anesthesia. In our study, only 11.6% of service members had hardware-related pain at the osteotomy site, all of whom underwent surgical removal. Hardware-related symptoms after TTO fixation are not uncommon and vary widely by author, with reported rates of 12% to 81%.[5,7,12,28] In a recent systematic review of complications after TTO, Payne et al.[27] reported a hardware removal rate of 36.7% in 787 TTOs. Although not major sequelae, it is important to note that hardware-related symptoms could develop as a result of frequent bending, crawling, or other load-bearing activities among military service members, prompting secondary return to the operating room.

Although TTO reduces anterior pain and improves overall lower extremity function, its impact on return to work has not been sufficiently explored. Preoperative counseling of physically active patients undergoing TTO should include a discussion of activity modification after this procedure, including the potential for difficulty with kneeling[5] or mild pain with sporting and other high-impact activities. Postoperatively, many patients in this study were placed on permanent profile restrictions to limit the frequency or duration of running, regardless of whether a medical separation was initiated. However, the surgeon's rationale for imposing postoperative restrictions may not necessarily reflect a patient's inability to perform these high-impact activities. For instance, such a restriction may be used as a protective measure against further injury or as a means of preserving longer-term knee function after TTO. In addition, patients with significant occupational demands should have realistic expectations concerning return to previous employment. Further research is needed to clarify more long-term outcomes in patients resuming moderate— to high—occupational demand jobs after TTO. This may afford more effective patient education detailing the risks, economic costs, and psychosocial benefits associated with a return to their chosen occupations.

Limitations

There are limitations to this investigation. First, this is a retrospective evaluation of prospectively gathered data, which restricts the amount of information that could be reliably extracted from pre-existing medical records. Several notable parameters were not consistently available in this study, including validated functional outcome scores, lesion-specific variables (e.g., size, grade, and location of chondral defect), surgical technique (i.e., degree of tibial tubercle translation, type of fixation, and use of bone graft), and radiographic data (e.g., patellar height and TT-TG distance). In addition, half of the patients did not undergo a diagnostic arthroscopy before TTO; therefore, the diagnosis of chondral pathology was based on the operating surgeon's interpretation of advanced imaging. In all instances, we were not able to independently confirm the diagnosis through review of arthroscopic or magnetic resonance images. The lack of routine access to raw radiographic images also precluded independent calculation of the TT-TG distance, the Q angle, and other morphologic data, so these parameters could not be consistently quantified. Second, our military population generally has required, non-modifiable physical and occupational demands that may be difficult to perform after TTO. Third, we acknowledge that a service member may pursue a disability-associated medical separation for secondary gain or as a protective measure to prevent further injury. Fourth, our study may be underpowered to identify additional risk factors for "failure" or "success" after TTO in this population, and these endpoints are subjectively defined. Finally, we acknowledge the presence of possible selection bias after the exclusion of patients with TTO indicated for patellofemoral instability or insufficient follow-up. Although the addition of these patients would contribute greater statistical power, the decision to exclude them was made for numerous reasons. Previously published studies evaluating TTO outcomes did so with a heterogeneous patient population that included patients with both chondral lesions and a high preponderance of patellar instability.[5-10] Admittedly, these pathologies do often present together; however, not all patients with patellofemoral chondral lesions will have patellofemoral instability. The outcomes of patients with TTO for chondral pathology may differ significantly from those of patients with patellofemoral instability, particularly with concomitant medial patellofemoral ligament reconstruction. In recognition of this distinction, we believed that the results of this study may have greater internal and external validity when evaluating a disease- or pathophysiology-specific patient subset undergoing treatment with TTO.

Conclusions

At short-term to midterm follow-up, 63% of patients successfully returned to military function with a low rate of perioperative complications (8%). The postoperative decrease in pain after TTO is of unknown clinical significance. Age younger than 35 years, junior military rank, bilateral TTO procedures, and tobacco use were significant risk factors for medical separation, whereas absence of concomitant cartilage repair, previous knee procedures, and lower occupational demands were not associated with improved VAS scores or prevention of knee-related medical discharge.

References

1. Curl WW, Krome J, Gordon ES, Rushing J, Smith BP, Poehling GG. Cartilage injuries: A review of 31,516 knee arthroscopies. *Arthroscopy* 1997;13:456-460.
2. Widuchowski W, Widuchowski J, Trzaska T. Articular cartilage defects: Study of 25,124 knee arthroscopies. *Knee* 2007;14:177-182.
3. Ramappa AJ, Apreleva M, Harrold FR, Fitzgibbons PG, Wilson DR, Gill TJ. The effects of medialization and anteromedialization of the tibial tubercle on patellofemoral mechanics and kinematics. *Am J Sports Med* 2006;34:749-756.
4. Rue JP, Colton A, Zare SM, et al. Trochlear contact pressures after straight anteriorization of the tibial tuberosity. *Am J Sports Med* 2008;36:1953-1959.
5. Buuck DA, Fulkerson JP. Anteromedialization of the tibial tubercle: A 4- to 12-year follow-up. *Oper Tech Sports Med* 2000;8:131-137.
6. Fulkerson JP, Becker GJ, Meaney JA, Miranda M, Folcik MA. Anteromedial tibial tubercle transfer without bone graft. *Am J Sports Med* 1990;18:490-496. discussion 496-497.
7. Pidoriano AJ, Weinstein RN, Buuck DA, Fulkerson JP. Correlation of patellar articular lesions with results from anteromedial tibial tubercle transfer. *Am J Sports Med* 1997;25:533-537.
8. Gillogly SD, Arnold RM. Autologous chondrocyte implantation and anteromedialization for isolated patellar articular cartilage lesions: 5- to 11-year follow-up. *Am J Sports Med* 2014;42:912-920.
9. Pascual-Garrido C, Slabaugh MA, L'Heureux DR, Friel NA, Cole BJ. Recommendations and treatment outcomes for patellofemoral articular cartilage defects with autologous chondrocyte implantation: Prospective evaluation at average of 4-year follow-up. *Am J Sports Med* 2009;37:33S-41S (suppl 1).
10. Trinh TQ, Harris JD, Siston RA, Flanigan DC. Improved outcomes with combined autologous chondrocyte implantation and patellofemoral osteotomy versus isolated autologous chondrocyte implantation. *Arthroscopy* 2013;29:566-574.
11. Farr J. Autologous chondrocyte implantation improves patellofemoral cartilage treatment outcomes. *Clin Orthop Relat Res* 2007;463:187-194.
12. Jack CM, Rajaratnam SS, Khan HO, Keast-Butler O, Butler-Manuel PA, Heatley FW. The modified tibial tubercle osteotomy for anterior knee pain due to chondromalacia patellae in adults: A five-year prospective study. *Bone Joint Res* 2012;1:167-173.
13. Atkinson HD, Bailey CA, Anand S, Johal P, Oakeshott RD. Tibial tubercle advancement osteotomy with bone allograft for patellofemoral arthritis: A retrospective cohort study of 50 knees. *Arch Orthop Trauma Surg* 2012;132:437-445.
14. Mithöfer K, Peterson L, Mandelbaum BR, Minas T. Articular cartilage repair in soccer players with autologous chondrocyte transplantation: Functional outcome and return to competition. *Am J Sports Med* 2005;33:1639-1646.
15. Cameron KL, Hsiao MS, Owens BD, Burks R, Svoboda SJ. Incidence of physician-diagnosed osteoarthritis among active duty United States military service members. *Arthritis Rheum* 2011;63:2974-2982.
16. *Army Regulation 40-501: Standards of medical fitness*. Washington DC: Department of the Army, 2011.
17. *Air Force Instruction 48-123: Aerospace medicine medical examination and standards*. Washington DC: Department of the Air Force, 2009.
18. Schoenfeld AJ, Goodman GP, Burks R, Black MA, Nelson JH, Belmont PJ Jr. The influence of musculoskeletal conditions, behavioral health diagnoses and socio-economic status on injury-related outcome in a high-demand population. *J Bone Joint Surg Am* 2014;96:e106.
19. Medical examinations. In: *Manual of the Medical Department (MANMED), NAVMED P-117*. Washington DC: Department of the Navy, 2014.
20. Dictionary of occupational titles. Ed 4, revised. Washington DC: US Department of Labor, Office of Administrative Law Judges, 1991. www.oalj.dol.gov/public/dot/references/dotappc.htm. Accessed February 2, 2015.
21. Martins LC, Lopes CS. Rank, job stress, psychological distress and physical activity among military personnel. *BMC Public Health* 2013;13:716.
22. Clyde CT, Goyal N, Matar WY, Witmer D, Restrepo C, Hozack WJ. Workers' compensation patients after total joint arthroplasty do they return to work? *J Arthroplasty* 2013;28:883-887.
23. Lombardi AV Jr, Nunley RM, Berend KR, et al. Do patients return to work after total knee arthroplasty? *Clin Orthop Relat Res* 2013;469:138-146.
24. Emshoff R, Bertram S, Emshoff I. Clinically important difference thresholds of the visual analog scale: A conceptual model for identifying meaningful intraindividual changes for pain intensity. *Pain* 2011;152:2277-2282.
25. Salaffi F, Stancati A, Silvestri CA, Ciapetti A, Grassi W. Minimal clinically important changes in chronic musculoskeletal pain intensity measured on a numerical rating scale. *Eur J Pain* 2004;8:283-291.
26. Farrar JT, Young JP Jr, LaMoreaux L, Werth JL, Poole RM. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. *Pain* 2001;94:149-158.
27. Payne J, Rimmke N, Schmitt LC, Flanigan DC, Magnussen RA. The incidence of complications of tibial tubercle osteotomy: A systematic review. *Arthroscopy* 2015;31:1819-1825.
28. Stetson WB, Friedman MJ, Fulkerson JP, Cheng M, Buuck D. Fracture of the proximal tibia with immediate weight bearing after a Fulkerson osteotomy. *Am J Sports Med* 1997;25:570-574.