Original Article

The Glenoid Track Paradigm Does Not Reliably Affect Military Surgeons' Approach to Managing Shoulder Instability

Daniel J. Cognetti, M.D., Matthew S. Tenan, Ph.D., A.T.C., Jonathan F. Dickens, M.D., Jeanne C. Patzkowski, M.D., Mark P. Cote, P.T., D.P.T., Ph.D., M.S., C.T.R., Mikael Sansone, M.D., Ph.D., and Andrew J. Sheean, M.D.

Purpose: To report the frequencies of surgical stabilization procedures performed by military shoulder surgeons and to use decision tree analysis to describe how bipolar bone loss affects surgeons' decision to perform arthroscopic versus open stabilization procedures. **Methods:** The Military Orthopaedics Tracking Injuries and Outcomes Network (MOTION) database was queried for anterior shoulder stabilization procedures from 2016 to 2021. A nonparametric decision tree analysis was used to generate a framework for classifying surgeon decision making based on specified injury characteristics (labral tear location, glenoid bone loss [GBL], Hill-Sachs lesion [HSL] size, and on-track vs off-track HSL). **Results:** A total of 525 procedures were included in the final analysis, with a mean patient age of 25.9 ± 7.2 years and a mean GBL percentage of 3.6% ± 6.8%. HSLs were described based on size as absent (n = 354), mild (n = 129), moderate (n = 40), and severe (n = 2) and as on-track versus off-track in 223 cases, with 17% (n = 38) characterized as off-track. Arthroscopic labral repair (n = 428, 82%) was the most common procedure, whereas open repair (n = 10, 1.9%) and glenoid augmentation (n = 44, 8.4%) were performed infrequently. Decision tree analysis identified a GBL threshold of 17% or greater that resulted in an 89% probability of glenoid augmentation. Shoulders with GBL less than 17% combined with a mild or absent HSL had a 95% probability of an isolated arthroscopic labral repair, whereas a moderate or severe HSL resulted in a 79% probability of arthroscopic repair with remplissage. The presence of an off-track HSL did not contribute to the decision-making process as defined by the algorithm and data available. **Conclusions:** Among military shoulder surgeons, GBL of 17% or greater is predictive of a glenoid augmentation procedure whereas HSL size is predictive of remplissage for GBL less than 17%. However, the on-track/off-track paradigm does not appear to affect military surgeons' decision making. **Level of Evidence:** Level III, retrospective cohort study.

From the Department of Orthopedic Surgery, San Antonio Military Medical Center, San Antonio, Texas, U.S.A. (D.J.C., J.C.P., A.J.S.); Rockefeller Neuroscience Institute, West Virginia University, Morgantown, West Virginia, U.S.A. (M.S.T.); Department of Orthopedic Surgery, Duke University Medical Center, Durham, North Carolina, U.S.A. (J.F.D.); Department of Orthopaedics, Institute of Clinical Sciences, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden (J.F.D., M.S.); and University of Connecticut Health Center, Farmington, Connecticut, U.S.A. (M.P.C.).

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Address correspondence to Daniel J. Cognetti, M.D., Department of Orthopedic Surgery, San Antonio Military Medical Center, 3551 Roger Brooke Dr, San Antonio, TX 78234, U.S.A. E-mail: cognettidj@gmail.com

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Both open and arthroscopic approaches have been advocated for the treatment of anterior shoulder instability.[1-4] Proponents of arthroscopic treatment cite acceptable rates of recurrent instability and return to function, as well as relatively benign complication profiles. However, the limits of arthroscopic repair techniques continue to be elucidated, particularly in the setting of bipolar bone loss, with previous thresholds no longer being uniformly accepted.[5-8] Moreover, several recent reports have highlighted the importance of patient-specific factors in predicting rates of recurrent instability after surgical stabilization.[9-12]

Previous efforts to characterize surgeons' preferences for one shoulder stabilization procedure over another have commonly focused on survey-based reports and large, retrospective databases.[13-15] Analyses of the American Board of Orthopaedic Surgery Part II Board Certification and MarketScan databases have consistently observed an increasing prevalence of both arthroscopic stabilization and glenoid augmentation procedures, whereas all other open stabilization procedures continue to be performed less frequently.[13-15] However, the utility of these types of analyses is limited by infrequent reporting of patient- and injury-specific variables, which assuredly affects surgical decision making and diminishes the completeness of these characterizations. Alternatively, a recent survey of members of the American Shoulder and Elbow Surgeons queried respondents regarding the extent to which several patient- and injury-specific variables affected their surgical decision making.[16] This study identified a preference for arthroscopic stabilization in young athletes with little to no bone loss, but the utility of survey-based analyses can be limited by recall bias and/or imprecise generalizations of one's surgical practices. More recently, Bishop et al.[17] published an analysis of 564 surgical procedures, combining intraoperative information with patient-specific demographic and clinical details. Using logistic regression, the authors identified several predictors of surgeons' performance of both remplissage and open Latarjet procedures. However, glenoid bone loss (GBL) was described in rather broad, categorical terms (i.e., GBL < 11%, GBL between 11% and 20%, and GBL between 21% and 30%) that may obscure a more precise understanding of how, exactly, increasing magnitudes of "subcritical" bone loss, assessed as a continuous variable, drive surgical decision making.[17]

Foundational decision tree analysis underlies 2 of the most common machine learning—artificial intelligence algorithms used: random forest analysis and gradient boosting machines. Descriptive decision tree analysis enables researchers to objectively determine which set of circumstances or decisions leads to different outcomes. In this case, the type of surgical procedure performed represents the primary outcome of interest. This analysis provides for the automated grouping of categorical or ordinal variables (e.g., sex) while determining appropriate "split points" on continuous or scalar data (e.g., GBL). These "decisions" for each tree branch are made and internally validated via recursive partitioning until the "best decision" is made.

The purposes of this study were to report the frequencies of surgical stabilization procedures performed by military shoulder surgeons and to use decision tree analysis to describe how bipolar bone loss affects surgeons' decision to perform arthroscopic versus open stabilization procedures. It was hypothesized that military surgeons would perform open stabilization procedures more frequently than what has been reported previously, with a lower GBL threshold for augmentation (i.e., <20%) than what previous treatment algorithms have recommended.

Methods

Study Design

The Military Orthopaedics Tracking Injuries and Outcomes Network (MOTION) database is a standard-of-care platform used across the Military Health System (MHS) to systematically collect patient-reported outcomes and obtain orthopaedic surgery—specific information, which may not be effectively recorded in standard electronic health records from procedure billing. The MOTION platform has been extensively detailed elsewhere.[18] From November 2016 to October 2021, a total of 2,393 intraoperative reports were completed in the MHS for shoulder surgery patients. Of these 2,393 reports, 854 contained Current Procedural Terminology codes for the following: arthroscopic capsulorrhaphy (code 29806); capsulorrhaphy, anterior, with labral repair (Bankart procedure) (code 23455); capsulorrhaphy, anterior, with bone block (code 23460); capsulorrhaphy, anterior, with coracoid process transfer (Latarjet procedure) (code 23462); or capsulorrhaphy, glenohumeral joint, any type multidirectional instability (code 23466). From these reports, the following information was programmatically abstracted: GBL, presence and size of Hill-Sachs lesion (HSL), whether HSL was deemed off-track or on-track, presence and location of labral tears, glenoid procedures performed, humeral head procedures performed, capsular and/or ligamentous procedures performed, any associated biceps tendon treatments, and number of anchors applied. In addition to the surgical information, patient demographic information at the time of surgery was obtained by combining the MOTION intraoperative report with the Department of Defense Enrollment Eligibility Reporting System (DEERS). Patients with isolated posterior labral tears, isolated superior labral tears, or combinations of the two not involving the anteroinferior labrum were excluded.

Preoperative Measurements

Mild HSLs were defined as lesions with a width up to 2 cm and a depth greater than 0.3 cm; moderate defects, a width of 2 to 4 cm and a depth of 0.3 to 1 cm; and severe defects, a width greater than 4 cm and/or a depth greater than 1 cm. GBL was measured via the best-fit circle method, overlaid on the en face glenoid in the sagittal plane. The glenoid track (GT) was assessed by an imaging-based calculation, in which the width of the GBL (d) is subtracted from the diameter (D) of a best-fit circle on the glenoid multiplied by 0.83 ($GT = 0.83D - d$). The GT distance was then compared with the Hill-Sachs interval, which was measured in the axial plane from the infraspinatus insertion laterally to the medial-most margin of the HSL. In cases in which the width of the Hill-Sachs interval was greater than the GT, the HSL was characterized as off-track.[19,20] Both computed tomography and magnetic resonance imaging were acceptable imaging modalities for measuring these bony parameters.

Intraoperative Variable Reporting

Labral tear location was reported using the clock-face method and described as either isolated (i.e., anteroinferior) or combined (i.e., SLAP and anteroinferior; SLAP, anteroinferior, and posterior; or anteroinferior and posterior). The presence of other associated injuries—such as humeral avulsion of the glenohumeral ligament (HAGL), reverse HAGL, anterior labral periosteal sleeve avulsion (ALPSA), glenolabral articular disruption (GLAD), and biceps anchor involvement—was also reported.

Descriptive Decision Tree Analysis for Surgical Procedure Selection

Because the primary goal of this work was to characterize the decision-making process used by orthopaedic surgeons in the MHS when encountering shoulder instability, a decision tree analysis is a natural fit given our large data repository. Although not common in the area of orthopaedics,[21] decision tree analysis has a long history in the business community and operations research.[22] The mathematical framework for the derivation of decision trees was laid out in the seminal monograph of Breiman et al.[23] entitled "Classification and Regression Trees." In fact, this foundational decision tree analysis underlies 2 of the most common machine learning—artificial intelligence algorithms used: random forest analysis and gradient boosting machines. In the present context, descriptive decision tree analysis enables researchers to objectively determine which set of circumstances or decisions lead to different outcomes. In this case, the outcome of interest is what procedures the surgeon decides to perform. This analysis provides for the automated grouping of categorical or ordinal variables (e.g., sex and on-track vs off-track) and determination of appropriate split points on continuous or scalar data (e.g., age and GBL). These decisions for each tree branch are made and internally validated via recursive partitioning until the best decision is made. On the basis of the size of the data set and number of outcomes, we selected a minimum split rule of 15, meaning there must be a minimum of 15 observations in order for a new decision to be attempted. We also empirically set the analysis complexity parameter at 0.05, which stops the algorithm from making a new decision if it will not meaningfully increase the fit of the model to the data. For our analysis, the following variables were available to predict surgeons' decisions: patient age, patient sex, presence and size of HSL, percentage of GBL, and whether an HSL was considered on-track or off-track. The analytical outcomes (i.e., surgical procedures) present in our data set were as follows: arthroscopic labral repair; open labral repair; glenoid augmentation; arthroscopic labral repair and glenoid augmentation; arthroscopic and open labral repair; arthroscopic labral repair and remplissage; and open labral repair and remplissage.

Results

From November 2016 to October 2021, a total of 525 intraoperative records related to anterior shoulder stabilization procedures were entered into the MOTION database. During the defined interval, 448 primary stabilization procedures (85.3%) and 72 revision stabilization procedures (13.7%) were performed by 36 military surgeons. Of the 36 surgeons, 34 (94.4%) were fellowship trained in either shoulder and elbow or sports medicine surgery. Of note, 11 surgeons (32.4%) completed their fellowship training at a single institution (United States Military Academy, West Point, NY). The mean age of patients undergoing shoulder stabilization procedures in this cohort was 25.9 ± 7.2 years, and there were 454 men (87.1%) and 67 women (12.9%). An in-depth description of the labral tear location identified intraoperatively is presented in Table 1. Combined labral lesions were reported in a majority of cases (283 of 525, 53.9%), whereas isolated anterior and/or inferior labral lesions were reported in 46.1% of cases (242 of 525). GBL was observed in a minority of cases (155 of 525, 29.5%), and the mean GBL percentage was 3.6% ± 6.8% (range, 0%-40%). HSLs were characterized, based on size, as absent in 354 cases (67.4%), mild in 129 (24.6%), moderate in 40 (7.6%), and severe in 2 (0.38%). HSLs were also described as either on-track or off-track in 223 cases, with 185 HSLs (83.0%) characterized as on-track and 38 HSLs (17.0%) characterized as off-track.

Table 1. Injury Pattern Characteristics (N = 525)

	Data
Labral tear location	
Anterior	139 (26)
Anterior and inferior	80 (15)
Anterior, inferior, and SLAP	12 (2.3)
Anterior and posterior	38 (7.2)
Anterior, posterior, and inferior	133 (25)
Anterior, posterior, inferior, and SLAP	50 (9.5)
Anterior, posterior, and SLAP	20 (3.8)
Anterior and SLAP	27 (5.1)
Inferior	23 (4.4)
Inferior and SLAP	3 (5.7)
Presence of glenoid bone loss	155 (30)
Glenoid bone loss, %	3.6 ± 6.8 (0-40)
Hill-Sachs lesion (axillary radiograph)	
Absent	354 (67)
Mild	129 (25)
Moderate	40 (7.6)
Severe	2 (0.38)
Glenoid track	
On-track	185 (35)
Off-track	38 (7.2)
NA	302 (58)
Associated pathology	
ALPSA	58 (11)
GLAD	57 (11)
Type of SLAP tear	
Degenerative fraying of superior labrum but attached	78 (15)
Separation of superior labrum and tendon from glenoid rim	76 (14)
Bucket-handle tear of superior labrum with intact anchor	13 (2.5)
Bucket-handle tear of labrum with detached anchor	8 (1.5)
NA	350 (67)

NOTE. Data are presented number (percentage) or mean ± standard deviation (range).

ALPSA, anterior labral periosteal sleeve avulsion; GLAD, glenoid labrum articular disruption; NA, not available.

The distribution of stabilization procedures performed is presented in Table 2. Isolated arthroscopic labral repairs constituted 81.5% of all procedures (428 of 525), including 86.2% of primary shoulder stabilizations (386 of 448 cases), whereas arthroscopic labral repair was performed in 55.6% of revision procedures (40 of 72 cases). The mean number of anchors used for all stabilization procedures was 4.2 ± 2.1 anchors (range, 0-14 anchors). Stabilization procedures were augmented with remplissage in 42 cases, 35 (83.3%) of which were primary stabilization procedures and 7 (16.6%) of which were revision stabilizations. However, only 31.6% of patients with off-track HSLs (13 of 38) underwent arthroscopic labral repair plus remplissage. Open labral repair was performed infrequently as an index operation (1.1%, 5 of 448 cases), but the relatively higher proportion of open labral repairs in the revision setting (6.9%, 5 of 72 cases) reveals a distinct preference in management. Similarly, glenoid augmentation procedures constituted 8.4% of all procedures (n = 44) but only 4.9% of primary procedures (22 of 448 cases), as compared with 29% of revision procedures (21 of 72 cases). The Latarjet procedure comprised 93% of these augmentation procedures (n = 39), equating to 7.4% of all stabilization procedures. Finally, the mean GBL percentage among patients who underwent glenoid augmentation was 20.8% ± 6.8%.

The decision tree analysis (Fig 1) determined that for GBL of 17% or greater, there was an 89% probability of a glenoid augmentation procedure and an 11% probability of arthroscopic labral repair, related to its use in several cases with GBL percentages of 20% and 25% (Table 3). For GBL less than 17% with a moderate or severe HSL, there was a 79% probability of an arthroscopic labral repair with remplissage, whereas if a HSL was absent or mild, there was a 95% chance of an arthroscopic labral repair. Although the presence of an off-track HSL was included in the same decision tree analysis, it did not contribute to the decision-making process as defined by the algorithm and data available.

Discussion

The most important finding of this study was that in both the primary and revision settings, most shoulder stabilization procedures performed by military surgeons were performed via arthroscopic repair, whereas open labral repair and glenoid augmentation were performed less frequently, especially in the primary setting. Positioned between the classically defined critical bone loss threshold and the more recently recognized threshold for subcritical bone loss,[7] decision tree analysis revealed that GBL of 17% or greater reliably predicts a glenoid augmentation procedure performed by military surgeons. The decision tree analysis further determined that GBL less than 17% with a moderate or severe HSL predicts remplissage with arthroscopic labral repair whereas GBL less than 17% with a mild or absent HSL predicts the performance of an arthroscopic labral repair in isolation. Perhaps most notably, the on-track/off-track status was not predictive of military surgeons' decision making based on our analysis.

Currently, the overwhelming majority of shoulder stabilization procedures performed in the United States are performed via an arthroscopic approach. This fact represents a substantial shift away from open, non-glenoid augmentation procedures in recent years, as has been observed in the literature.[13,15,17] Looking back as early as 2003, an analysis of the American Board of Orthopaedic Surgery examination database found that approximately 40% of Bankart repairs were performed via an open approach, but by 2008, the same study and another large database review found that the rate had fallen to around 10%.[13,15] The latter study also found

Table 2. Procedures Performed

	Data
Procedure performed*	
Arthroscopic labral repair	428 (82)
Arthroscopic labral repair and glenoid augmentation	2 (0.38)
Arthroscopic and open labral repair	1 (0.19)
Glenoid augmentation	41 (7.8)
Open labral repair	8 (1.5)
Arthroscopic labral repair and remplissage	40 (7.6)
Open labral repair and remplissage	1 (0.19)
No. of anchors	4.2 ± 2.1 (0-14)
Glenoid procedures (n = 58)	
Latarjet procedure	39 (7.4)
Augmentation	
Allograft	4 (0.76)
Distal clavicle	1 (0.19)
Other	14 (2.7)
Humeral head procedures (n = 46)	
Remplissage	42 (8.1)
Other	4 (0.77)
Capsular and ligament procedures (n = 9)	
HAGL repair	6 (1.2)
Reverse HAGL repair	1 (0.19)
Capsular rent repair	2 (0.38)
Biceps procedures (n = 95)	
Debridement	21 (4.0)
Intra-articular tenodesis	1 (0.19)
Subpectoral tenodesis	53 (10)
Suprapectoral tenodesis	10 (19)
Other	10 (19)
None	199 (38)
NA	231 (44)

NOTE. Data are presented number (percentage) or mean ± standard deviation (range).

HAGL, humeral avulsion of glenohumeral ligament; NA, not available.

*Procedures as classified and included in decision tree analysis (n = 521).

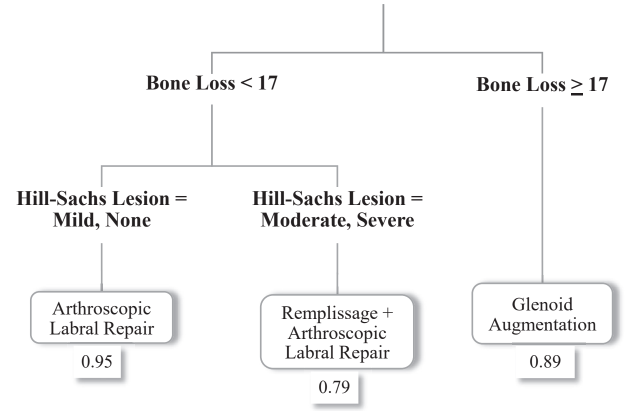

Fig 1. Decision tree analysis.

that the rate of open Bankart repair compared with all other procedures continued to decrease, to approximately 5% in 2012, consistent with results from the MOON (Multicenter Orthopaedic Outcomes Network) group reporting on cases from 2012 to 2017.[13,17] The results of our study show a likely continuation of this trend away from open repairs, as these procedures comprised just 1.9% of all stabilization procedures. However, it does appear that open repair, with its potential for a substantial capsular shift, has maintained a role in the revision setting, accounting for 6.9% of revision procedures (5 of 72) in our study and 11% (15 of 133) in the study from the MOON group.[17]

Aside from open labral repairs, there are a number of other important treatment preferences that can be gleaned by comparison of the results of our study with those of the MOON study.[17] Overall, both studies exhibit strong preferences toward arthroscopic labral repair, with relatively similar utilization rates of remplissage and glenoid augmentation procedures between studies.[17] However, somewhat surprisingly, surgeons in both groups performed glenoid augmentation and/or the Latarjet procedure in only about 5% of primary procedures.[17] Although arthroscopic labral repair is likely favored because of surgeon familiarity[15] and its modest complication profile,[15,24] the low rate of glenoid augmentation procedures being performed primarily signals that surgeons are not necessarily performing the correct surgical procedure at the index operation. To this point, in several instances in our study, there were isolated arthroscopic labral repairs performed for GBL greater than 20% and 25%, despite high failure rates and poor outcomes in this population.[9,25] Additionally, recent results from Rodkey et al.[26] have shown that secondary Latarjet procedures (after failed arthroscopic Bankart repair) have twice the rate of recurrent instability as compared with primary Latarjet procedures, imploring surgeons to more scrupulously consider the limitations of isolated arthroscopic repair at the index operation. This also applies to the use of such procedures in the revision setting, especially given concerns regarding high rates of recurrent instability after revision arthroscopic labral repair.[27] In both the MOON study and our study, glenoid augmentation and/or the Latarjet procedure was performed in upwards of 30% of revisions, showing an appreciation by surgeons of the need for a more robust operation.[17] However, contrary to this finding, isolated arthroscopic labral repair continued to be heavily relied on, making up 55% of revisions in our study and 46% of revisions in the MOON group's study, highlighting a limited consensus on management in the revision setting.[17]

The recognition of bipolar bone loss as the driving factor in the pathogenesis of recurrent shoulder instability has undoubtedly changed the modern shoulder surgeon's decision-making calculus.[20,28,29] However, it is less clear how, exactly, varying magnitudes of bipolar bone loss compel surgeons to choose one procedure

Table 3. Decision Tree Rules

Condition	% in Cohort	Probability of Procedure: Arthroscopic Labral Repair	Glenoid Augmentation	Remplissage and Arthroscopic Labral Repair	Classified Procedure
Glenoid bone loss < 17% and absent or mild HSL	87	0.95	0.01	0.04	Arthroscopic labral repair
Glenoid bone loss ≥ 17%	7	0.11	0.89	0.00	Glenoid augmentation
Glenoid bone loss < 17% and moderate or severe HSL	6	0.14	0.07	0.79	Remplissage and arthroscopic labral repair

NOTE. The written decision rule parameters, visually presented in Figure 1, are displayed. In addition to the information in Figure 1, this table shows the study population distribution (percentage in cohort) and the probability surgeons may have performed an alternative procedure. For example, when glenoid bone loss is less than 17% and a HSL is either absent or mild, there is a 95% chance the surgeon will elect to perform arthroscopic labral repair but there is also a 1% chance of the surgeon performing glenoid augmentation and a 4% chance of the surgeon performing remplissage and arthroscopic labral repair.

HSL, Hill-Sachs lesion.

over another. To that end, Bishop et al.[17] analyzed a number of patient and injury characteristics to assess their influence on management within a comparably sized cohort to our study cohort. They identified several independent risk factors for various surgical modalities, including humeral bone loss, GBL, duration of symptoms, number of dislocations, and revision stabilization for Latarjet procedures, with revision procedure being the only risk factor for open Bankart repair.[17] However, the clinical interpretation of relative risk can be difficult, and an analysis of GBL in terms of categorized ranges—rather than as a continuous collection of specific values—diminishes the precision of characterizations as to how surgical decisions are likely to be made. Furthermore, the use of logistic regression in the MOON study requires consideration of variables in isolation (i.e., independent risk factors), whereas decision tree analysis considers variables in combination, which theoretically is more similar to how a person would actually make a decision. To this end, our study offers a more intuitive interpretation of the outcomes of interest (procedures performed) based on their probability of occurrence given specific sets of circumstances (i.e., patterns of injury described using both categorical and continuous scales). This study also considers HSLs within the context of the GT paradigm. However, a substantial proportion of surgical cases in the data set lacked descriptions of HSLs in these terms, with relatively few off-track lesions undergoing remplissage, suggesting that the surgeons contributing cases to this data set do not routinely apply the principles of the GT paradigm to their decision making. In contrast, our analysis does clearly show that military surgeons were much more likely to make decisions about one procedure over another—more specifically, remplissage—based on HSL size.

Limitations

There are several limitations to this study. First, the data and subsequent analysis are based exclusively on intraoperative information provided by the primary surgeon, without reference to patient-reported outcomes or failure rates. Although demographic information was obtained by cross-referencing the MOTION database with a larger repository of nonclinical personnel records, information pertaining to the circumstances of patients' shoulder instability, participation in contact sports, number of prior instability events, and physical examination findings suggestive of more advanced magnitudes of shoulder instability was not available for analysis. However, given the fact that all patients in this cohort were military service members or beneficiaries, it is reasonable to assume a certain level of homogeneity with respect to the type of physical demands and exposures that are unique to military service. Second, the method of determining the extent of bipolar bone loss was not necessarily uniform among the cases given that both magnetic resonance imaging and computed tomography scanning were considered acceptable imaging modalities and measurements were not independently verified by way of a reviewer blinded to treatment type. Consequently, it is possible that either measurement error or heterogeneous measurement technique could ultimately diminish the predictive capacity of the decision tree analysis.

Conclusions

Among military shoulder surgeons, GBL of 17% or greater is predictive of a glenoid augmentation procedure whereas HSL size is predictive of remplissage for GBL less than 17%. However, the on-track/off-track paradigm does not appear to affect military surgeons' decision making.

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