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Daniel B. Goldberg MD; Trent M. Tamate MD; Morgan Hasegawa MD; Thomas J.K. Kane IV MD; Jae S. You MD; Scott N. Crawford MD

Abstract

The population of Hawai‘i is uniquely connected to the Ocean and to open water sports. Shoulder injuries, particularly those to the rotator cuff, are among the most common injuries sustained to athletes participating in ocean sports such as surfing, paddling, and swimming. In addition, rotator cuff injuries increase in prevalence with advanced age. As a consequence, the number of patients in Hawai‘i who present with an injury to the subscapularis tendon will continue to rise. However, limited research has been done to delineate the involvement of subscapularis injuries in this population. This article covers the anatomy and function of the subscapularis, the epidemiology and classification of tears in this tendon, and the management of tears. The anatomy section will cover innervation, vascular supply and insertional anatomy of the subscapularis tendon. The function of the subscapularis in regards to both stability and motion of the glenohumeral joint will be examined. The focus of the article will then shift to the tears of the subscapularis, starting with an in depth look at the epidemiology and classification of these tears. The article will then cover the different imaging modalities and their utility in regards to subscapularis tears. Finally, the operative and non-operative management and indications for each modality will be discussed in detail.

Keywords
Subscapularis, Rotator cuff, Rotator cable, comma tissue, shoulder, glenohumeral

Abbreviations
MRI = Magnetic Resonance Imaging
SS = Subscapularis

Introduction

The population of Hawai‘i is uniquely connected to the Ocean and to open water sports. Hawai‘i has the second most surfers per capita of any state and Stand-up Paddling, Out-rigger canoeing and swimming are also popular sports among the residents of Hawai‘i. Among surfers, paddlers and swimmers shoulder injuries and particularly those to the rotator cuff are among the most common injuries sustained. However, despite the fact these sports rely heavily on shoulder internal rotation strength, little research has been done to delineate the involvement of subscapularis injuries in this population. The purpose of this article is to review the available research on subscapularis tears and treatment with the aim of bringing awareness to this pathology in Hawai‘i’s sporting demographic.

Methods

Prior to conducting a literature search, inclusion and exclusion criteria were determined. Inclusion criteria included primary research articles, review, systematic reviews, and meta-analysis investigating subscapularis anatomy, tears, and associated pathology. We included studies whose study-population was limited to adult patients, defined by ages of 18 years old or greater. Epidemiologic, anatomic, imaging, operative techniques, and clinical outcome information was attained from these studies. Any series including patients less than 18-years old were excluded.

Literature Search

Literature search was carried out in May 2021 utilizing two different online databases: PubMed and Google Scholar, for all studies published in the English language in the past 20 years. Search was carried out using key terms: subscapularis, subscapularis anatomy, subscapularis tear, subscapularis tear treatment, subscapularis treatment outcomes and subscapularis associated pathology.

Content Abstraction

Five reviewers (DBG, TT, MH, JY, and SNC) independently reviewed studies returned from the initial database search, and articles were included or excluded based on the previously described criteria. These same reviewers then performed the subsequent data extraction that included epidemiology, anatomy, imaging, operative techniques, and clinical outcomes. A total of 58 articles were included in this review.

Epidemiology and Classification

Epidemiology

Rotator cuff tears are one of the most common forms of shoulder pathology, with increasing prevalence as individuals age. Studies have suggested 25% to 30% of adults over age 60 have a rotator cuff tear, and for adults over 80 this percentage is as high as 62%. The prevalence of rotator cuff tears in patients undergoing operative shoulder procedures is higher than the general population and has been estimated at 31.4% - 59%. It has been estimated that 27.4% of rotator cuff tears will include a subscapularis tear, but isolated subscapularis tears are much
less common, comprising only 6.4% - 10% of all rotator cuff tears.3,9,10

Subscapularis tendon tears more commonly occur with additional rotator cuff or biceps pathology. The most common shoulder pathology associated with subscapularis tears is concomitant biceps pathology. Prior studies have suggested between 20% and 90% of subscapularis tears are accompanied by biceps pathology, including biceps subluxation, fraying, tears, and biceps pulley disruption.3,11-15 Another commonly associated pathology is the “anterosuperior” rotator cuff tear, a term coined by Warner, et al, to describe a anterior supraspinatus tear with extension involving the superior border subscapularis tendon.16 Prevalence of this combined tear is between 9.3% and 44.4%.4,10,15-18 This anteroposterior tear is overall less common than a combined infraspinatus and supraspinatus tear, often referred to as a “posterosuperior” rotator cuff tear.5,16,18 Literature concerning combined subscapularis and infraspinatus tears is sparse. In a study by Warner, et al, 14 out of 407 patients with operatively managed rotator cuff tears had combined subscapularis and infraspinatus tears.16 In a study by Zehetgruber, et al, 0 of 332 patients with rotator cuff tears had a combined infraspinatus and subscapularis tear without other rotator cuff tendon involvement.19 Rotator cuff tears involving the subscapularis and infraspinatus are more commonly accompanied by additional rotator cuff pathology.20,21

Classification

There are numerous classification systems available for tears of the subscapularis, however authors have continued to debate their reliability and utility. The 2 most frequently used classification system are the Lafosse10 and Lyons23 systems. In the Lafosse classification system, tears are divided into 5 types. Type I tears are partial lesions of the upper one-third of the tendon, Type II tears are complete lesions of the superior one-third of the tendon, Type III tears include the superior two-thirds of the tendon. Types IV and V both represent complete tears of the tendon, with Type V being differentiated by having greater than Goutallier Stage III fatty degeneration.22 Type V tears also include anterior subluxation of the humerus with subcoracoid impingent.

In the Lyons classification system, tears are broken down into 4 types. Type I tear is a partial-thickness and partial-length tear, Type II is a partial-thickness and full-length tear, Type III is full thickness and full-length, but without retraction and Type 4 is a full thickness and full-length tear with retraction. Thirty-two of the fellowship-trained members of the Multicenter Orthopaedic Outcomes Network (MOON) Shoulder group were surveyed in an attempt to determine the interobserver reliability of these 2 classification systems based on MRI and intra-operative imaging.23 Interobserver reliability was shown to be poor based on MRI and fair based on arthroscopic images. One major weakness of the study identified by the authors, is that surgeons were required to make their assessments based on still images alone and reliability may be improved if surgeons had the ability to dynamically assess the tissue.

Diagnosis

History

As with posterior cuff tears, subscapularis tears occur far more commonly due to gradual degeneration than a traumatic rupture.18 As such the patient may not provide a history of a clear inciting event. However, when traumatic tear occurs, it is commonly due to a hyperextension and external rotation mechanism.24 Subscapularis tears have also been shown to be associated with anterior glenohumeral dislocation.25,26 While patients may complain of pain in the anterior aspect of the shoulder, this pain is not specific for subscapularis pathology and can also be generated from the bicep, acromioclavicular joint or a superior-labrum-anterior-posterior (SLAP) type lesion. Complaints of weakness with activities that require internal rotation, such as tucking in the back of a shirt or buckling a bra strap, may be more specific to subscapularis pathology.27

Physical Exam

The belly-press and lift-off tests are the 2 most frequently utilized tests to assess for tears of the subscapularis tendon. Both tests were described by Gerber and colleagues in 1991 and 1994 respectively. The lift-off test is performed by placing the hand of the affected shoulder on the back, at the mid-lumbar spine, and asking the patient to internally rotate the shoulder to lift the hand away from the back. The test is considered positive if the patient is unable to lift the hand away from the back in this position. The belly-press test is performed with the arm maximally adducted to the side and the elbow flexed at 90°. The patient is asked to hold the palm of the affected arm against their belly and resists, with an internal rotation force, as the examiner attempts to lift the hand away from the patient’s body. The test is considered positive if the patient demonstrates weakness compared to the contralateral side. These 2 tests were later studied using electromyography and it was noted that the belly-press test led to activation of the upper portion of the subscapularis, whereas the lift off test activated the lower portion of the muscle.28 The results of this study led to the development of the theory that a more anterior position of the elbow resulted in increased activation of the upper portion of the subscapularis.

This theory led to the development of the bear-hug test.7 The bear-hug test is performed with the shoulder flexed forward to 90-degrees, moving the elbow as anteriorly as possible. The hand is placed on the contralateral shoulder and the patient attempts to resist the examiner lifting the patients hand. The test is considered positive if the patient cannot maintain the hand against the contralateral shoulder. In the original study
describing the bear-hug examination, the authors noted this exam maneuver to be more sensitive (60%) than the belly-press or (40%), or lift-off test (17.6%). The lift-off test (100%) was more specific than the belly-press (97.9%) or bear-hug test (91.7%). A separate article evaluating the clinical efficacy of these tests found the belly-press (56.8%) to be more sensitive than the bear-hug (18.8%) or the lift-off test (35.1%), while the lift-off test remained the most specific (96.9%). It is logical that clinical tests designed to evaluate the upper portion of subscapularis tendon would be more sensitive, as tears of this tendon routinely propagate from the upper border.

**Imaging**

Radiographs should be obtained as part of the initial workup of shoulder pain. Indirect signs of subscapularis tendon pathology on x-ray may include lesser tuberosity irregularities or anterior subluxation on an axillary view, and evidence of diminished sub-coracoid space on a scapular-Y view. CT scan is rarely utilized for evaluation of subscapularis tears as Magnetic resonance imaging (MRI) has largely replaced it as the modality of choice for evaluation of rotator cuff tears. CT scans, with or without arthrogram may be used for evaluation of rotator cuff tears and fatty muscular degeneration in those with MRI contraindications, with reported sensitivity and specificity of 65% - 85% and 98% - 100% respectively. Ultrasound has become a popular modality for testing rotator cuff pathology, in part because it allows for dynamic testing. However, ultrasound is less reliable at identifying tears of the subscapularis compared to tears of the superior cuff due to interference from surrounding anatomic structures. It has a preoperative sensitivity of 12.5%-16% and specificity of 93-97% in the diagnosis of subscapularis tears. Additional drawbacks include user dependent variability, the inability to detect partial thickness tears, and moderate interobserver reliability.

MRI has largely become the modality of choice for evaluation of rotator cuff tears. As with ultrasound, MRI’s ability to detect subscapular tendon tears is lower than in other rotator cuff tendons. Sensitivities and specificities range from 36%-88% and 90%-100% respectively. Malovolta, et al, included 14 articles in a systematic review assessing the accuracy of MRI for subscapularis tears, and found overall sensitivity was 68% and specificity was 90%, with lower sensitivity and specificity for partial tears. They concluded that while MRI may be an accurate method, it appears to have lower accuracy in comparison with other rotator cuff tears. In an effort to address the perceived inferiority of MRI in detecting subscapularis tears, some authors have advocated for a systematic reading approaches or utilization of alternate MRI views, which demonstrated improved sensitivity and specificity compared to prior literature. Pfirmann, et al, utilized particular findings such as leakage of contrast under the subscapularis tendon, presence of subscapularis fatty infiltration and biceps abnormalities, while Adams, et al, developed a system of imaging evaluation including evaluating axial T2-weighted images, presence of biceps subluxation, fatty infiltration and atrophy of the muscle, and presence of tears on a sagittal oblique view.

Other authors have suggested alternative MRI techniques which allow for optimal body positioning of patients and may enhance radiographic detection of tears.

**Treatment**

**Non-operative Management**

Unfortunately, there is limited evidence available to guide treatment due to the frequent occurrence of concomitant pathology and a dearth of well-designed randomized controlled trials. Nonoperative management of subscapularis tendon tears is similar to that involving other parts of the rotator cuff. Options include activity modification, analgesics and anti-inflammatoryatories, corticosteroid injections, and physical therapy. Indications for surgical versus nonsurgical treatment also mirror that of the posterosuperior cuff. Older, less active patients with chronic degenerative tears are generally considered candidates for conservative treatment. In comparison, acute traumatic tears may benefit from surgical repair in order to prevent tear progression, tendon retraction, and muscle atrophy. Failure of attempted nonoperative management is an indication for surgery.

Treatment in the presence of advanced fatty degeneration remain controversial. Traditionally, rotator cuff tears with advanced fatty degeneration are considered poor candidates for repair. A retrospective review of 52 patients with isolated full-thickness subscapularis tears and Grade 3 or 4 Goutallier fatty degeneration found no difference in pain and functional outcome scores at 2-years when comparing nonoperative and operative management. A 78.6% retear rate was seen in the surgically treated group. The surgical group had worse baseline scores and experienced greater improvement than the nonsurgical group, however, this may have been due to concomitant tenotomy or tenodesis of the biceps. Of note, no evidence of tear progression into the supraspinatus was seen in either group. Advocates of surgical repair argue that it restores the role of the subscapularis in anterior restraint of the humeral head through tenodesis, even without intact contractile function. Contraindications to surgical repair include medical comorbidities that preclude surgery and the presence of glenohumeral arthropathy.

**Operative Evaluation and Management**

Similar to their results when assessing interobserver reliability of tear classification, Smucny, et al, showed only fair interobserver reliability when determining surgery versus no surgery for subscapularis tears based on either MRI or arthroscopic images. Arthroscopic evaluation remains the gold standard for diagnosis of subscapularis pathology. The standard posterior viewing portal is used to visualize the integrity of the subscapularis, footprint, biceps sling, and quality of the long head of the biceps tendon.
The articular surface of the subscapularis tendon can be more readily assessed by arthroscopy, and partial tears can be identified. The biceps tendon can be evaluated for medial subluxation or evidence of tendinopathy, including fraying, at the level of the sling. A bare area over the subscapularis footprint on the lesser tuberosity can indicate an occult, partial articular sided tear. Techniques to further improve visualization have been described. Use of a 70-degree arthroscope can provide views around the anterior aspect of the humeral head. The “posterior lever push,” as described by Burkhart, can increase visualization in the subcoracoid space by 5 mm - 10 mm. In the lateral decubitus position, this is accomplished by an assistant pushing the proximal humerus posteriorly while simultaneously applying an anterior pressure on the distal humerus.

Arthroscopic repair of subcapsularis tears can be challenging given the difficulties with obtaining adequate visualization and instrumentation. Intraoperatively, subscapularis repair should be performed prior to other procedures due to the risk of fluid extravasation and swelling, which can compress the subcoracoid space. Proper portal placement is crucial. The standard posterior portal is used for viewing. An anterosuperolateral portal is placed just off of the anterolateral tip of the acromion, angled 5 to 10 degrees towards the lesser tuberosity. The relatively parallel orientation of this portal in relation to the subscapularis allows it to be used as the primary working portal for tendon mobilization and suture passage. The standard anterior portal is made slightly more medial, just lateral to the tip of the coracoid. It’s angled 30 to 45 degrees towards the lesser tuberosity and is used for suture anchor placement.

In the setting of a retracted tear, the “comma sign” is used to locate the leading edge of subscapularis tendon. It is an arc of tissue in the shape of a comma, which represents the avulsed medial sling of the biceps, specifically the fibers of the coracohumeral and superior glenohumeral ligaments, as it attaches to the superolateral border of the torn subscapularis.

Associated procedures include biceps tenotomy/tenodesis and coracoplasty. Failure to address an unstable long head of the biceps tendon can stress the subsequent subscapularis repair. In addition, biceps tenotomy/tenodesis removes a possible pain generator and can improve functional outcomes when incorporated with subscapularis repair. Biceps tenodesis can be combined with the subscapularis repair to improve efficiency and cost savings. This can be accomplished either through simultaneous suture passage through both tendons or separate suture passage secured through the same suture anchor. The resulting construct provides secure tenodesis of the biceps at the superior-lateral border of the subscapularis footprint.

Coracoplasty has been recommended to decompress the subcoracoid space and prevent abrasion by the coracoid tip on the subscapularis repair. In this procedure, 2 mm - 10 mm of tissue is burred off of the tip of the coracoid. However, recent studies have called the necessity of coracoplasty into question. A study of 62 patients with isolated full-thickness subscapularis tears repaired in single-row fashion compared 2-year outcomes with or without coracoplasty. The study found no differences in pain, functional outcomes, strength, range of motion, or retear rates. It was theorized that a shorter coracohumeral distance may be the result of anterior translation of the humeral head following a subscapularis tear, and not the cause.

Mobilization of the subscapularis tendon is necessary for a tension-free repair. A window is created in the rotator interval above the upper border of the subscapularis in order to increase visualization and ease suture passage. Skeletonization of the posterolateral coracoid to the level of the coracoid neck further improves tendon mobilization. Suture placement just medial to the junction between the “comma” and the upper border of the subscapularis utilizes the vertically oriented fibers of the “comma” as a lateral rip-stop. In cases of chronic tears that cannot be reduced to the native footprint, the subscapularis can be medialized up to 5 mm to avoid excess tension. Due to native retroversion of the humeral head, it is often necessary for the surgeon to position their hand close to the patient’s jaw when preparing the anchor insertion site.

Recommendations for the number of suture anchors required varies, however, it is generally accepted that 1 anchor is needed for each centimeter or tear length in the superior-inferior direction. This roughly translates to 1 anchor for tears < 50%, and 2 anchors for tears > 50%. The superolateral edge of the subscapularis, referred to as the “leading edge,” is especially important to address. It is thought of as the initial tear site with progression heading inferiorly and serves as the anterior attachment of the rotator cable, decreasing stress on the adjacent supraspinatus. Repair of tears involving this area of the subscapularis can be addressed in multiple ways. Single anchor fixation has demonstrated sufficient biomechanical strength and significant improvements in functional outcomes. Addition of a second anchor placed superolaterally near the entrance of the bicipital groove has demonstrated increased footprint coverage.

The argument of single versus double-row fixation reflects that of repairs involving the posterosuperior cuff. Biomechanical studies confirm the superiority of double-row repair with regards to ultimate load to failure and construct stiffness specifically in the subscapularis tendon. Double-row repair also provides better footprint coverage at the expense of increased time and added implant costs. Single-row repair is the only option for tendons not mobile enough to allow double-row fixation. Studies evaluating outcomes between single and double-row fixation for isolated tears of the subscapularis have been mixed. In a retrospective review of isolated full-thickness subscapularis tears with Grade 2 fatty infiltration or less, no difference was
In the event of a massive irreparable tear, tendon transfer, most commonly of the pectoralis major, is an option. This procedure is indicated for young, active patients with an intact or repairable posterosuperior cuff and no glenohumeral arthropathy. Tendon transfer may help to rebalance the forces acting on the humeral head. Improved patient reported outcome scores, range of motion and strength in forward flexion, abduction and internal rotation have been seen when pectoralis major tendon transfer is performed in the setting of irreparable isolated subscapularis tears. Decreased external rotation motion has been noted. Good outcomes were also achieved in patients with multiple tendon involvement as long as the other injured tendons were able to be repaired. The worst outcomes with tendon transfer are in shoulder arthroplasty patients and those with anterior instability, as the pectoralis major does not exactly replicate the force vector of the native subscapularis.

Conflict of Interest

None of the authors identify a conflict of interest.

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References
Cervical Ossification of the Posterior Longitudinal Ligament (OPLL) in Native Hawaiians and/or Polynesians: A 3-year Retrospective Demographic and Descriptive Pilot Study

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Abstract

Ossification of the posterior longitudinal ligament (OPLL) is a disease characterized by the replacement of the posterior longitudinal ligament with ectopic bone and cartilage. Historically, the disease was described as highly prevalent in Japanese and other Asian populations. However, recent studies suggest OPLL may have a higher prevalence in non-Asian communities than previously believed. To date, there are no demographic or epidemiologic studies examining OPLL in Native Hawaiian or Polynesian communities. The purpose of this study was to review the demographics and comorbidities of a cohort of patients with OPLL from the author’s institution, designated as either Native Hawaiian and/or Polynesian (NHP) or Non-Native Hawaiian and/or Polynesian (NNHP). Demographic findings from this study were similar to previous literature demonstrating higher rates of OPLL in men and older patients with an average age of 56 years in the NHP group and 65 years in the NNHP group. There were no statistically significant differences in the rates of type II diabetes mellitus, coronary vascular disease, chronic kidney disease, or hypertension between NHP and NNHP groups. The NHP group exhibited statistically higher rates of obesity when compared to the NNHP group. Obesity’s risk in the development or progression of OPLL in the NHP population has not been examined and requires additional investigation. This study serves as a beginning for further demographic and epidemiologic investigations into OPLL in Native Hawaiian and Polynesian communities to facilitate improved identification of those at risk and guide diagnosis and treatment of these patients.

Keywords

Ossification of posterior longitudinal ligament, Native Hawaiian, Polynesian, Spine

Acronyms and Abbreviations

CDC = Centers for Disease Control and Prevention
CKD = chronic kidney disease
CT = computed tomography
CT = computer tomography
CVD = coronary vascular disease
DMII = diabetes mellitus type II
HTN = hypertension
ICD-10 = International Classification of Disease-10
NHP = Native Hawaiian and/or Polynesian
NNHP = Non-Native Hawaiian and/or Polynesian (NNHP)
OPLL = ossification of the posterior longitudinal ligament
PLL = posterior longitudinal ligament

Introduction

Ossification of the posterior longitudinal ligament (OPLL) is a disease characterized by the replacement of the posterior longitudinal ligament (PLL)—the ligamentous tissue spanning the dorsal surface of the vertebral bodies—with ectopic bone and cartilage. The normal function of the PLL is to provide resistance against hyperflexion. This function becomes compromised in OPLL as proliferating fibroblast-like chondrocytes and osteoblasts disrupt the native ligament with cartilaginous tissues and form ossification and hyalinoid degeneration centers.1,2 This pathologic process results in narrowing of the spinal canal, which can cause the symptoms of OPLL and lead to myelopathy, especially in the cervical spine.3,4

Upon presentation, 28% to 39% of patients will have clinical signs and symptoms of myelopathy.5,6 OPLL is most frequently observed in the cervical spine, but rates of associated lesions at other spinal levels have been estimated to be as high as 56%.7 Onset of OPLL is more common in men than women with a 2:1 or 3:1 ratio, with a predominance in the sixth or seventh decade of life.6,8 Plain radiographs, dynamic imaging, computed tomography (CT), and magnetic resonance imaging are all critical in the initial workup of patients with OPLL. The Japanese Ministry of Public Health and Wellness classification system, based on a lateral radiograph, is the most commonly used classification system, but an axial CT is crucial for determining disease severity and canal compromise.6 A study by Matsunaga, et al, demonstrated that the natural history of OPLL is related to the presence of myelopathy on initial presentation. In this study, 20% of patients without original myelopathy became myelopathic during the 17-year follow-up. At the 30-year follow-up, this number increased slightly to 29%.6 If myelopathy is present upon initial exam, approximately 64% of patients may go on to further clinical deterioration and worsening myelopathy if conservative management is chosen.6 Prognosis worsens as symptoms worsen, with some estimates suggesting that 89% of patients with Nurick grade 3 or 4 myelopathy will progress towards confinement in a wheelchair or bed rest when treated conservatively.3

Treatment is determined by the degree of neurologic dysfunction. Conservative management is often reserved for patients with absent or mild symptoms, Nurick grade 1 or 2.9 With
conservative management, worsening radiographic evidence of disease rates range from 42-58%, with increased risk of hospitalization for spinal cord injury.\textsuperscript{3,4,10,11} Surgical treatment is considered the treatment of choice for patients with moderate to severe disease or progressively worsening myelopathic symptoms. As with other degenerative myelopathies, the goal of surgical treatment is decompression of the neural elements and maintenance, augmentation, and restoration of spinal alignment and biomechanical stability.\textsuperscript{9}

As this disease was beginning to gain recognition and understanding, it was found to have a high incidence in Japan, resulting in a special commission for the investigation of the disease in 1975.\textsuperscript{12} Once coined “The Japanese Disease,” further epidemiologic studies of the disease have described demographic, clinical, and radiographic findings in other racial and ethnic groups, such as Whites, Blacks, non-Japanese Asians, and Hispanics.\textsuperscript{13,14} The incidence rate varies from 0.8% to 4.6%, and prevalence of cervical OPLL between 0.6% to 6.3%, with rates varying based on ethnic groups being studied and the geographic locations of the studies.\textsuperscript{8,15} Other studies have investigated associations with comorbid conditions such as diabetes, hypertension, cardiovascular disease, and renal disease.\textsuperscript{3,16–20}

Spine surgeons at the authors’ institution have anecdotally noted a relatively high incidence of OPLL in Native Hawaiian and/or Polynesian patients. To the authors’ knowledge, there have been no studies examining the epidemiology of OPLL in these populations. This study aims to begin further demographic and epidemiologic investigations into OPLL in Native Hawaiian and Polynesian communities to facilitate improved identification of those at risk and guide the diagnosis and treatment of these patients.

Subjects and Methods

This study was a retrospective review of medical records from a level one trauma center in Hawai‘i, from January 1, 2017, to December 31, 2019, totaling 3 years. Human Subjects Institutional Review Board approval was obtained, and strict adherence to the protocol was implemented.

All patients with an International Classification of Disease-10, Tenth Edition (ICD-10) code for cervical spondylopathies, and charts examined to identify a listed diagnosis of OPLL. These were identified over a 3-year period, which satisfied the inclusion criteria for the study. Patient’s charts were then examined for exclusion criteria was limited to missing data regarding comorbid conditions documented in their electronic medical record and patients aged less than 18 years. All patients were then categorized by race and ethnicity as either Native Hawaiian and/or Polynesian (NHP) or Non-Native Hawaiian and/or Polynesian (NNHP). Race and ethnicities were self-reported by patients and were recorded in the electronic medical record. Additionally, comorbid conditions, such as diabetes mellitus type II (DMII), hypertension (HTN), chronic kidney disease (CKD), and coronary vascular disease (CVD), were chosen for investigation due to their inclusion in prior studies investigating comorbid conditions.\textsuperscript{18,20–22} Their presence was determined based on a current ICD-10 coded diagnosis within each patient’s chart. Furthermore, HTN was also assessed by determining if a patient’s average systolic or diastolic blood pressure (in mm Hg), measured by the average of blood pressure readings during patient visits, met the American Heart Association’s diagnostic criteria, which was a systolic blood pressure greater than 130 mm Hg and diastolic blood pressure greater than 80 mm Hg, respectively.\textsuperscript{23} Obesity was determined by the presence of an active ICD-10 diagnosis code for obesity or an average body mass index (BMI) of 30 or greater, which is recognized as obesity by various health organizations such as the World Health Organization and the Centers for Disease Control and Prevention.\textsuperscript{24,25}

Dependent variables included all comorbid conditions (No/Yes). The primary independent variable was race/ethnicity (NHP or NNHP). All independent and dependent variables above were considered dichotomous and coded and analyzed using IBM SPSS (Version 24). Normality of distribution analyses was conducted to assess skewness and kurtosis. A Welch’s $t$-test was performed to determine if there was a statistically significant difference in average age between NHP and NNHP patients with OPLL. Data were found to be parametric, so therefore chi-square analyses were conducted. Results were considered significant at $P < .05$, with confidence intervals set at 95%.

Results

Demographics

A total of 138 patients met the inclusion criteria. Of the initial patients identified, 25 had missing demographic and descriptive data, and 1 was younger than 18 years. Of the 112 patients available for analysis, 29% were female (32 of 112), and 71% were male (80 of 112). There was no statistically significant difference between female and male distribution in NHP and NNHP patients with OPLL. Data were found to be parametric, so therefore chi-square analyses were conducted. Results were considered significant at $P < .05$, with confidence intervals set at 95%.

Comorbid Conditions

Rates of comorbid conditions within NHP and NNHP groups can be found summarized in Table 1. There were no statistically significant differences in the rates of DMII ($c^2 = 1.44$, $P = .23$,\textsuperscript{9}}

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df = 1), CVD ($\chi^2 = 0.01, P = .93, df = 1$), HTN ($\chi^2 = 0.45, P = .50, df = 1$), or CKD ($\chi^2 = 0.05, P = .82, df = 1$) between NHP and NNHP in this study. NHP patients were statistically more likely to be obese when compared to NNHP patients ($\chi^2 = 14.68, P < 0.001, df = 1$). These findings are summarized in Table 2.

### Table 1. Rates of Comorbid Conditions Among Native and Non-Native Hawaiian and/or Polynesian Patients With Ossification of the Posterior Longitudinal Ligament

<table>
<thead>
<tr>
<th>Condition</th>
<th>Native Hawaiian and/or Polynesian n= 38 (%)</th>
<th>Non-Native Hawaiian and/or Polynesian n= 74 (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>DMII</td>
<td>22 (58%)</td>
<td>34 (46%)</td>
<td></td>
</tr>
<tr>
<td>CVD</td>
<td>9 (24%)</td>
<td>17 (23%)</td>
<td></td>
</tr>
<tr>
<td>CKD</td>
<td>9 (24%)</td>
<td>19 (26%)</td>
<td></td>
</tr>
<tr>
<td>Obesity</td>
<td>29 (76%)</td>
<td>30 (41%)</td>
<td></td>
</tr>
<tr>
<td>HTN</td>
<td>20 (53%)</td>
<td>34 (46%)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CVD, coronary vascular disease; CKD, chronic kidney disease; DMII, Diabetes mellitus type II; HTN, hypertension

### Table 2. Demographic and Comorbid Conditions Among Native and Non-Native Hawaiian and/or Polynesian Patients With Ossification of the Posterior Longitudinal Ligament

<table>
<thead>
<tr>
<th>Condition</th>
<th>Native Hawaiian and/or Polynesian n= 38 (%)</th>
<th>Non-Native Hawaiian and/or Polynesian n= 74 (%)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
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<tr>
<td>Female</td>
<td>10 (26%)</td>
<td>22 (70%)</td>
<td>.70</td>
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<tr>
<td>Male</td>
<td>28 (74%)</td>
<td>52 (30%)</td>
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</tr>
<tr>
<td>DMII</td>
<td></td>
<td></td>
<td>.23</td>
</tr>
<tr>
<td>Yes</td>
<td>22 (58%)</td>
<td>34 (46%)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>16 (42%)</td>
<td>40 (54%)</td>
<td></td>
</tr>
<tr>
<td>CVD</td>
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<td></td>
<td>.93</td>
</tr>
<tr>
<td>Yes</td>
<td>9 (24%)</td>
<td>17 (23%)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>29 (76%)</td>
<td>57 (77%)</td>
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</tr>
<tr>
<td>CKD</td>
<td></td>
<td></td>
<td>.82</td>
</tr>
<tr>
<td>Yes</td>
<td>9 (34%)</td>
<td>19 (76%)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>29 (26%)</td>
<td>55 (74%)</td>
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</tr>
<tr>
<td>Obesity</td>
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<td></td>
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<tr>
<td>Yes</td>
<td>29 (76%)</td>
<td>30 (40%)</td>
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<tr>
<td>No</td>
<td>9 (24%)</td>
<td>44 (59%)</td>
<td></td>
</tr>
<tr>
<td>HTN</td>
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<td>.5</td>
</tr>
<tr>
<td>Yes</td>
<td>20 (53%)</td>
<td>34 (46%)</td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>18 (47%)</td>
<td>40 (54%)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: CVD, coronary vascular disease; CKD, chronic kidney disease; DMII, Diabetes mellitus type II; HTN, hypertension. *statistically significant

### Discussion

Orthopedic spine and neurosurgeons at the authors’ institution have anecdotally stated that there appears to be a high prevalence of OPLL within NHP communities. To date, there haven’t been any demographic or descriptive studies of OPLL in NHP communities. Historically, the disease has been described as having a preponderance in Asians, but more recent research has suggested that the prevalence of OPLL is higher in other racial groups due to increased awareness and surveillance. As such, this study stands as the first demographic or descriptive analysis of OPLL within NHP communities.

Previous studies have found that men are two to three times more likely to be diagnosed with cervical OPLL. This study had similar results with an approximately 3:1 ratio of men to women in NNHP and NHP populations. The mean age of diagnosis in our study was 61.6 years in combined groups. These findings are similar to previous studies, which stated that patients with OPLL are generally between 50 to 60 years old, implying a degenerative nature to the disease process. Interestingly, there was a statistically significant difference in average age between patient groups. This warrants further investigation into any potential risk factors contributing to the earlier development of disease within NHP patients and could prompt earlier and improved disease surveillance within NHP communities. In this study, 34% of the patients identified as NHP as compared to 27% of Hawai’i’s population identifying as Native Hawaiian or other Pacific Islander in a recent survey, though this census data included populations that are not historically considered Polynesian. The higher percentage of NHP patients in this study compared with Hawai’i’s population demographics may suggest a correlation between OPLL and NHP race/ethnicity. A direct association could not be analyzed between race/ethnicity and OPLL in this study due to design. Any such relationship would require further analysis, including examining potentially confounding variables such as socioeconomic status or healthcare access.

In our small cohort, the NHP group had a statistically higher rate of obesity when compared to the NNHP group. However, our study’s design does not allow for a direct cause and effect analysis. The link between obesity and OPLL remains unclear, but previous literature has suggested that obesity may lead to altered metabolism, upregulation of insulin, and concomitant biochemical homeostatic alterations. This may result in ectopic bone formation and OPLL, though the exact pathophysiologic mechanism has yet to be determined. The 74% rate of obesity among the NHP group in this study is higher than the 52% of Native Hawaiian/Pacific Islander persons in the United States identified as obese. This high rate of obesity in OPLL patients is consistent with previous literature focusing on other racial groups, but previous research has suggested a correlation between OPLL and NHP race/ethnicity. A study compared with Hawai’i’s population demographics may have anecdotally stated that there appears to be a high prevalence of OPLL within NHP communities.
ethnic groups, which may present as a confounding variable and would need to be controlled in future studies examining any association.38,39 Other risk factors associated with OPLL include diet, genetic predisposition, and physical activity, which were not evaluated in this study due to the logistical challenges in obtaining this information retrospectively.37,40–44

There are limitations to this study. A significant limitation was the method by which race and ethnicity were determined. Hawai‘i has the highest rate of multiracial residents in the United States.45 This makes reporting on demographic data difficult due to the incredibly high ethnic and racial heterogeneity rates. It is possible that individuals did not report full racial or ethnic makeup or were simply unaware of it. In addition, although rates of obesity have been documented to be higher in the NHP populations compared to other racial or ethnic groups, it is important to recognize this observation is confounded by a complex interplay of socioeconomic factors and health care access.2,10,39,46,47 Any future analysis between the link of obesity and OPLL should recognize these additional considerations. A related issue plaguing the comparison between NHP and NNHP groups is the lack of subset analysis between ethnically Japanese individuals. As mentioned, OPLL first gained notoriety as a “Japanese Disease.” While it has been shown to have higher than believed prevalence in other populations, prior studies have shown it to have a higher prevalence than other Asian ethnic groups.15 As such, it could be of interest in future studies to compare an NHP to a group of ethnically Japanese individuals living in Japan as well, in addition to a conglomerated NNHP group as done in this study.

Another limitation is the small sample size. The small sample size obtained in this study is not surprising given the low incidence of OPLL in the general population. It has also been suggested that the general incidence and prevalence may be underreported since many patients are asymptomatic or do not receive a proper diagnosis.27 Additionally, this study evaluated patients diagnosed with cervical OPLL, which suggests patients with isolated thoracic or lumbar OPLL were not captured through cervical OPLL specific ICD-10 coding. There is also a possibility that NHP patients with cervical OPLL were not all captured due to improper ICD-10 coding. Likewise, this study identified individuals with OPLL by diagnosis in chart, without determining how symptomatic each individual was. In future studies, efforts should be made to determine which individuals with OPLL received treatment, abnormal physical findings, and clinical presentation for further subgroup analysis. Future research to further explore the true prevalence, relative risk, and association of comorbid conditions of OPLL in the NHP population would require a controlled cohort sample.

Conclusion

This study provides a novel demographic and descriptive analysis of NHP with a diagnosis of OPLL. This study reiterates reports of a higher prevalence of OPLL in men and older patients, which remained in subgroup analysis within the NHP population, though the average age of diagnosis was found to be younger in NHP patients. In addition, this study suggests NHP patients diagnosed with OPLL have statistically higher rates of obesity than NNHP patients, which may be determined to be a potential risk factor in future studies. The true epidemiology of OPLL in the NHP community remains unclear. Nevertheless, this pilot study provides valuable information for future prospective case-controlled analyses to investigate potential epidemiologic ties between OPLL and the NHP populations. In doing so, medical providers may better understand who is at risk, improve diagnostic capabilities, and optimally treat those within NHP communities.

Conflict of Interest

None of the authors identify a conflict of interest.

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References
When Do Patients Return to Driving After Outpatient Foot and Ankle Surgery?

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Abstract

Counseling patients regarding when to return to driving following a foot and ankle procedure can be difficult, and 6 to 9 weeks is often recommended based on brake reaction times quoted in the literature. However, patients are ultimately responsible for the decision to drive. We aimed to determine when patients actually return to driving following outpatient foot and ankle surgery, what influences their decision, and whether any adverse events were experienced. Thirty-seven patients who underwent a right-sided foot and ankle procedure by a single orthopedic surgeon in an outpatient surgery center between September 2016 and December 2017 were recruited retrospectively for this study. Seventeen patients met inclusion criteria and participated in a telephone survey that inquired about their experiences and attitudes regarding return to driving following right-sided foot or ankle surgery. Of the patients surveyed, 100% drove a motor vehicle as their primary mode of transportation. Ten patients (59%) recalled having a discussion with the surgeon regarding when to resume driving, of which only 4 (23.5%) returned to driving at the suggested time they remembered. One patient (6%) returned to driving 2 weeks sooner, and 1 patient (6%) returned to driving 4 weeks later than recommended. No patient reported experiencing a driving-related adverse event. This study suggests that despite surgeons’ recommendations, patients are returning to driving sooner than traditionally recommended. The surgeon’s advice regarding when to return to driving may not be as influential as a patient’s own self-assessment of their readiness to operate a vehicle after outpatient foot and ankle surgery.

Keywords

Foot and ankle surgery; Outpatient surgery; Safety; Return to driving

Abbreviation

SDM = shared decision making

Introduction

Foot and ankle surgery make up a significant portion of orthopedic procedures performed, and many of these procedures are now being done in the outpatient setting due to reduced costs and improved outcomes.1,2 With outpatient procedures, patients can return home within 24 hours of their operation with better pain control, fewer complications, and higher satisfaction. One study by Huntley, et al.,2 shows that patients undergoing outpatient foot and ankle procedures are younger, more functionally independent, and less likely to have medical comorbidities than their inpatient counterparts. They found that the average age for an outpatient ankle procedure is 47.8 years, compared to 61.8 years for inpatient, suggesting a younger and healthier population that may wish to or feel more confident returning to driving sooner.2 Moreover, this younger and more functional population may be eager to return to their daily routines that require the ability to drive.

Orthopedic surgeons are, thus, placed in a position of counseling a patient on when it will be safest to return to driving after a surgical procedure. In general, however, orthopedic surgeons are typically not well versed in local laws or their responsibilities regarding counseling patients on returning to driving.3,5 This is likely attributed to the fact that there are no federal guidelines and variable state guidelines regarding returning to driving after a surgical procedure. Therefore, the recommendation on when to return to driving has been primarily based on brake times and periods of immobilization. Egol, et al, tested patients at 6, 9, and 12 weeks following surgical treatment of right ankle fractures and found that brake times returned to the normal baseline value at nine weeks postoperatively.6 In a similar study, Egol, et al.,7 evaluated patients with major right lower extremity trauma and found that brake times returned to acceptable limits 6 weeks after the initiation of weight-bearing. Based on these studies, among others, the recommendation for safe return to driving following surgical treatment of lower extremity fractures is 6 to 9 weeks.6-8

While these recommendations serve to guide orthopedic surgeons and patients, it must be acknowledged that there are many factors apart from healing time that affect a person’s ability to drive after lower extremity surgery, such as the side of the operation—right versus left, the specific procedure performed, postoperative immobilization in a splint or cast, completion of physical therapy, narcotic use, and patient motivation.9 Return-to-driving decisions are made daily by orthopedic surgeons and, not infrequently, with some degree of patient-physician conflict when physician recommendations do not meet patient expectations. To our knowledge, few studies have evaluated the patient’s decision-making process. Furthermore, no studies have reported whether or not a patient’s return to driving was successful based on reported adverse events such as tickets or accidents. The purpose of this study is to determine when the patient actually returns to driving after outpatient foot and ankle surgery, which factors influence their decisions, and whether or not their first journey was successful. We hypothesize that patients return to drive after outpatient foot and ankle procedures sooner than recommended and that recommendations from their orthopedic surgeon play only a minor role in their decision-making process.
Methods

After obtaining Institutional Review Board approval, patients who underwent an elective right-sided foot or ankle procedure performed by a single fellowship-trained foot and ankle surgeon in an outpatient surgery center between September 2016 and December 2017 were retrospectively recruited for this study. Inclusion criteria included age between 18 and 70 years, no systemic disease, no neurologic condition, possession of a valid driver’s license, and previous operative management of a right-sided foot or ankle condition within 1 year of the study start date and are at least 2 weeks post-operation. Thirty-seven patients were identified, of which 17 agreed to participate in the telephone survey after completion of verbal consent. Eighteen patients could not be reached, and 2 declined.

Most patients were placed in either a splint, boot, surgical shoe, or cast following the operation. Postoperative weight-bearing instructions varied according to the procedure performed. Generally, patients were non-weight-bearing for several weeks and utilized crutches as a mobility aid. All patients were verbally advised to avoid driving for a minimum of 6 to 8 weeks after surgery. This “return-to-driving policy” is in print as part of a surgery information packet that was also given to each patient. Ultimately, the senior surgeon determined each patient’s fitness to return to driving on a case-by-case basis.

Patients were contacted 1 to 16 months postoperatively and were asked to participate in an anonymous telephone survey that included the following questions: (1) Is driving your primary mode of transportation?; (2) Did you have a discussion with your surgeon regarding when you should return to driving a car?; (3) If you did have a discussion with your surgeon, what was your surgeon’s recommended time frame to return to driving?; (4) Prior to returning to driving a car did you seek any advice from your insurance company or legal counseling regarding when it would be safe to drive?; (5) When did you actually return to driving a car after your procedure?; (6) When you returned to driving a car, did you experience any adverse events such as tickets or accidents?; (7) When you returned to driving a car were you still using narcotic pain medications? If ‘yes’, was this during the day, night, or both?; (8) When you returned to driving a car, how long was your first journey?; and (9) When you returned to driving a car, were you comfortable driving?

Exclusion criteria included the following: (1) any patients who did not drive a car preoperatively, (2) any patients whom experienced a postoperative complication requiring reoperation or hospitalization within 3 months of their initial procedure, and (3) any patients who underwent any other operative procedure within 3 months of their initial procedure.

Results

Of the 17 patients who responded to this survey, 100% drove a motor vehicle as their primary mode of transportation. Ten patients (59%) remembered having a discussion with the surgeon regarding return to drive timing. Of these 10 patients, 6 (35%) could recall the specific time frame recommended to them, of which only 4 (24%) returned to driving at the suggested time they remembered, ranging from 2 to 14 weeks. One patient (6%) returned to driving 2 weeks sooner than recommended, and 1 patient (6%) returned to driving 4 weeks later than recommended. One patient (6%) was recommended never to return to drive.

Nine patients (53%) could not recall the specific time frame to return to drive suggested by the surgeon. Among these 9 patients, the average return to drive time was 8.8 weeks. One patient (6%) returned to drive in 1 week, 4 patients (24%) returned to drive in 6 to 8 weeks, and the remaining 4 (24%) returned to drive in 10 to 14 weeks.

No patient reported experiencing an adverse event during their first time driving after surgery. One patient (6%) was still using narcotics at the time of their first drive. Eight patients recalled their first drive length to be less than 15 minutes, and 8 patients reported their first drive time between 15 to 30 minutes. One patient could not recall their first drive length.

Twelve patients (71%) reported wearing some form of immobilization during their first drive, but only 4 reported immobilization to the right side. At the time of first drive, 9 patients (53%) reported still using an assistive device daily. All 17 patients reported feeling comfortable with the decision to drive.

Discussion

This study demonstrated that despite a majority of patients (59%) undergoing foot and ankle surgery recall having a discussion with their surgeon regarding when to return to driving, only 35% of these patients recalled the specific time frame being given. Furthermore, the recommendation was not always followed, with some patients returning to driving earlier and some patients returning later than recommended. This suggests that a surgeon’s recommendation does not heavily influence a patient’s decision to return to driving.

Interestingly, of those patients who did not recall the surgeon recommending a specific time frame, they returned to driving on average 8.8 weeks after their procedure. This falls within the recommendations of 6-9 weeks.6,7 The consistency in return to drive time with these patients and the literature suggests that patients are in tune with their driving capabilities and personal situations. This information provides valuable insight into the more prominent role patients should be taking in the shared decision-making process.
The concept of shared decision making (SDM) is gaining emphasis in the current health care landscape. In short, SDM is the process of involving the patient in clinical decision-making. It is linked to improved patient satisfaction, enhanced ability to recall discharge instructions, more positive outcomes, and reduced costs. In our study, several observations were noted that point towards the potential need for incorporation of SDM in the discussion of when to return to drive. First, only 35% of patients remembered having a conversation with the surgeon about when to return to drive. This finding is in line with previous literature demonstrating that 40% to 80% of the medical information provided by health care practitioners may be forgotten by patients shortly after an outpatient encounter. This points to the possibility that perhaps a conversation alone is not sufficient in educating the patient, and depending on patient education level, media and other educational materials could be utilized in that aspect of the SDM process. Second, it was observed that 100% of patients reported feeling comfortable when they returned to drive, and there were no adverse outcomes reported. This suggests that a patient’s decision to drive is based heavily on their own self-assessment. The patients’ self-awareness should also be taken into account in the SDM process.

One major limitation to this study is the retrospective nature of this study and the timing following surgery for the patients. The patients in this study were contacted up to 16 months after their operation, which can greatly affect the accuracy of the information reported by the patients. This factor greatly predisposes the patients to recall bias. Another limitation to this study is that there was no attempt to differentiate between automatic and manual transmissions. This limitation could be a factor in patients with left-sided procedures and can misrepresent the data. A third limitation to this study is the use of a telephone survey, which limits response rate and can be affected by patient willingness to answer questions over the phone. Although calls were made with a business number associated with the physician’s office and standard protocols made it very clear that surveys were anonymous, patient willingness to participate in the survey was seemingly low. In that light, another limitation of this study includes the number of patients in this study who responded out of the identified eligible patients. Of the patients identified as eligible to participate in this study, only 46% of patients were willing to participate.

**Conclusion**

This study suggests that while most patients, on average, followed the suggested 6- to 9-week waiting period before driving, some patients are returning to driving following outpatient foot and ankle procedures sooner than recommended. Importantly, all patients’ return to driving reported feeling comfortable with their decision to drive and no patient experienced an adverse outcome. The wide range of return-to-drive time frames seen in this study suggests that surgeon advice regarding return to driving may not be as influential as a patients’ self-assessment of their ability to operate a vehicle following their outpatient procedure. Additional studies would be helpful in further evaluating the individual factors that influence a patient’s decision to return to drive and the influential role the physician has in the SDM process.

**Conflict of Interest**

None of the authors identify a conflict of interest.

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Sesamoid Avascular Necrosis and Stress Fracture Treated with Core Decompression and Biologic Augmentation

Victoria A. Scala MD; Christian K. Kikuchi MD, FAAOS

Abstract
Sesamoid bone disorders are disabling conditions with limited treatment options. This case report describes a 17-year-old football player with avascular necrosis (AVN) in both the tibial and fibular hallux sesamoids with a concomitant non-displaced stress fracture of the tibial hallux sesamoid. After a short period of conservative management, the patient underwent open sesamoid core decompression with an application of concentrated bone marrow aspirate and amnion matrix. After postoperative physical therapy, the patient achieved a painless range of motion of the first metatarsophalangeal joint. He returned to full athletic activities by 6 months postoperatively. Core decompression with biologic augmentation is a viable treatment option for sesamoid AVN. Earlier surgical intervention for sesamoid AVN can also be considered, particularly in younger active patients.

Keywords
sesamoid, avascular necrosis, great toe, bone marrow aspirate, stress fracture

Acronyms and Abbreviations
AVN = avascular necrosis
CAM = Controlled Ankle Motion
CBMA = concentrated bone marrow aspirate
MSCs = mesenchymal stem cells
MRI = magnetic resonance imaging
MTPJ = metatarsophalangeal joint
STIR = short tau inversion recovery

Background
Limited treatment options exist for debilitating hallux sesamoid bone disorders. If conservative nonoperative management fails, sesamoidectomy is the mainstay of operative treatment but can result in mechanical complications.1,2 This case report describes a case of avascular necrosis (AVN) of both hallux sesamoids with a concomitant stress fracture of the tibial sesamoid successfully treated with core decompression and application of concentrated bone marrow aspirate (CBMA) with amniotic membrane matrix.

Case Presentation
A 17-year-old high school senior and varsity wide receiver experienced gradually worsening pain to his left great toe during the football season. During a late-season game, he developed sudden inability to walk or put pressure on the left plantar forefoot. There was no definitive trauma or injury event. He initially presented to a podiatrist who obtained x-rays and immobilized the patient in a Controlled Ankle Motion (CAM) boot. Three weeks later, the patient was referred to an orthopedic clinic with continued gradual worsening of left forefoot pain. On examination, he was found to have a severely antalgic gait and severe tenderness to palpation over the tibial hallux sesamoid with ecchymosis in this area. Foot alignment was normal. Radiographs of the left foot demonstrated no sesamoid fracture or proximal retraction of the tibial sesamoid suggestive of a plantar plate tear. Non-contrast magnetic resonance imaging (MRI) demonstrated AVN in both the tibial and fibular hallux sesamoid with non-displaced stress fracture of the tibial hallux sesamoid (Figure 1).

Treatment options, including operative and nonoperative management, were discussed at length. The proposed surgery was open sesamoid core decompression with application of CBMA harvested from the proximal tibia. The patient and his parents opted for surgical management, and he underwent surgery 7 weeks after the onset of acute pain. During the surgery, bone marrow aspirate was first harvested from the proximal tibia via a percutaneous anterolateral biopsy punch. The medial and lateral hallux sesamoids were then approached via a plantar L-shaped incision. A 0.045 K-wire was used to perform a core decompression confirmed under fluoroscopy. Arthrex Amnion matrix (Arthrex, Inc., Naples, FL, USA), derived from placental tissue, was soaked in bone marrow aspirate concentrate and then applied over the medial and lateral hallux sesamoids.

The patient was made non-weight bearing for 2 weeks postoperatively. After the sutures were removed, the patient was made heel weight bearing in a forefoot offloading shoe for 1 month. At 6 weeks postoperatively, the patient was not tender to palpation over the surgical site. Physical therapy was initiated, and weight bearing was advanced as tolerated. The patient underwent an initial 6-week physical therapy regimen to gradually introduce loading to the medial forefoot. At 9 weeks postoperatively, first metatarsophalangeal joint (MTPJ) range of motion was 80% of the contralateral side with some stiffness in dorsiflexion. At 15 weeks postoperatively, his range of motion improved, but he had mild pain on single-limb heel rise. Physical therapy was extended for a further 6 weeks, and the patient was advised to slowly progress to light-impact activities. At discharge from physical therapy, the patient achieved painless range of motion in the first MTPJ equivalent to the contralateral side (20 degrees of flexion and 70 degrees of extension). The patient returned to full athletic activities at 6 months postoperatively, with plans to play football in college.
Figure 1. Magnetic resonance imaging of sagittal (A-D) and axial (E and F) views. T1-weighted (A, C, E) and short tau inversion recovery (STIR) (B, D, F) sequences of the left tibial (A and B), fibular (C and D), and both (E and F) sesamoids. T1 sequences demonstrate hypointense signal in both sesamoids (A, C, E). STIR sequences demonstrate hypointense signal in the tibial sesamoid with non-displaced transverse fracture and edema in the plantar subcutaneous fat (B, F) and mostly hypointense signal with speckled peripheral hyperintense signal in the fibular sesamoid (D, F).

Discussion

The hallux sesamoids perform an important role in normal weight bearing and foot biomechanics. During the gait cycle, the sesamoid complex can transmit forces as high as >300% of body weight during push-off and disperse this impact on the metatarsal head. The flexor hallucis longus tendon lies between and is protected by the sesamoids as it crosses the first MTP joint. The hallux sesamoids improve the power of the first MTP joint flexion by increasing the moment arm of the flexor hallucis brevis.

Renander first described hallux sesamoid avascular necrosis (AVN) in 1924. The prevalence of this seemingly rare condition is unknown. Contributing factors to the etiology of hallux sesamoid AVN may include chronic microtrauma leading to disruption of blood flow, and mechanical overload from activities or foot alignment disorders such as pes cavus, hindfoot valgus. Although the medial sesamoid may experience increased contact forces than the lateral sesamoid during the normal gait cycle, it is unclear which sesamoid is at greater risk for AVN.

A trial of nonoperative management for up to six months has typically been recommended as first-line treatment for sesamoid AVN. Initial interventions may include rest, ice, compression, elevation, nonsteroidal anti-inflammatory medications, offloading the first MTP joint with alternative footwear, and a period of non-weight bearing. Conservative treatment for stress fracture of the sesamoid yielded a low return rate to sport of 64%. However, the success rate of nonoperative management for sesamoid AVN is unknown due to its low prevalence. Furthermore, a prolonged period of non-weight bearing for up to 6 months may lead to unacceptable deconditioning in young active patients.

Sesamoidectomy is the mainstay of surgical management after conservative management has failed. However, sesamoidectomy may result in loss of push-off strength that can be noticeable in a dancer or athlete. Removal of both sesamoids could also result in a cock-up deformity due to the loss of flexor hallucis brevis function. Although a systematic review of sesamoidectomy for hallux sesamoid disorders by Shimozono, et al, demonstrated a high rate of return to sports in the short term after surgery (94.4% return to sport with 90.0% at previous level), there was a high complication rate of 22.5% with a revision rate of 3.0%. Complications included hallux valgus for medial sesamoidectomy, hallux varus for lateral sesamoidectomy, loss of range of motion of the first MTPJ, weakness of plantarflexion strength, and transfer metatarsalgia.

Sesamoid sparing treatments avoid the mechanical complications of sesamoidectomy. Although core decompression has not been specifically studied in sesamoid AVN, studies exist for its use in other areas. Core decompression is a widely accepted treatment for early AVN of the femoral head, and augmentation with CBMA has demonstrated improved results compared to core decompression alone. Core decompression can also successfully treat patients with early AVN of the talus.

Biologic agents further show therapeutic potential in the treatment of sesamoid AVN. CBMA has been specifically studied in the treatment of sesamoid disorders. CBMA contains progenitor cells, including mesenchymal stem cells (MSCs), hematopoietic stem cells, and endothelial progenitor cells, as well as growth factors, including bone morphogenetic proteins and platelet-derived growth factor. Concentrating harvested bone marrow aspirate appears to be advantageous in foot and ankle surgery where there is limited physical space for biologic implantation.
A retrospective cohort of 13 patients with sesamoid disorders (2 with AVN) who received an injection of CBMA to the affected sesamoid demonstrated 84.6% treatment success rate at an average of 19.1 months of follow-up. Of note, the postoperative protocol used for this cohort differed from the one presented in this case report. Patients were kept non-weight bearing for the first 2 weeks, followed by full weight bearing in an orthotic offloading the first MTP joint for 3 months. Patients could then return to play after 3 months.\textsuperscript{14}

Placental tissue derivatives may further enhance the healing environment for sesamoid AVN. Placental tissue is a source of MSCs, extracellular matrix, and an array of growth factors for tissue repair and regeneration.\textsuperscript{15} In foot and ankle surgery, placental tissues have demonstrated benefit in treating diabetic foot ulcers, chronic wounds, and plantar fasciitis.\textsuperscript{16-18} Although animal models have demonstrated increased bone healing with the application of placental tissues,\textsuperscript{19,20} further studies in human subjects are needed to fully understand their efficacy and capabilities.

### Conclusion

This case demonstrates core decompression with biologic augmentation as a viable treatment option for sesamoid AVN. Due to the uncertainty of nonoperative management in sesamoid AVN, earlier intervention could be considered as part of a shared decision-making process, particularly in younger active patients. Further research is warranted comparing core decompression of sesamoid AVN with and without biologic augmentation, including longer follow-up.

### Conflict of Interest

None of the authors identify any financial disclosures or conflicts of interest.

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What’s New in Geriatric Acetabular Fractures

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Abstract

The incidence of acetabular fractures in the geriatric population is growing, yet the optimal treatment algorithm remains a controversial topic among orthopaedic surgeons. This review highlights key studies published over the past 5 years on the outcomes of various treatment options for geriatric acetabular fractures. Topics include surgical timing, mortality and risk factors, nonoperative treatment, open reduction internal fixation, and acute total hip arthroplasty.

Keywords

Acetabular fractures; Geriatric; Mortality; Nonoperative treatment; Open reduction internal fixation; Total hip arthroplasty

Acronyms and Abbreviations

CRPP = closed reduction percutaneous pinning
ORIF = open reduction internal fixation
QLP = quadrilateral surface
THA = total hip arthroplasty

Introduction

Over the past 30 years, the incidence of acetabular fractures in the geriatric population has more than doubled. Despite this growing trend, the treatment of this new common injury remains anything but routine. Based on the work of Letournel and Judet, age greater than 60 years and poor bone quality have long been viewed as primary indications for the non-operative treatment of acetabular fractures. Mata, et al, showed that geriatric acetabular fractures with secondary congruence could predictably be treated non-operatively with good functional outcomes. Reported outcomes following non-operative treatment, however, have not been uniformly positive. Surgical conversion rates to total hip arthroplasty (THA) of 15% and mortality rates of 24% at 1 year have been reported. On the other hand, early fixation has not demonstrated any improvement in outcomes with conversion arthroplasty and 1 year mortality rates of 25% and 28%, respectively. More recently, primary THA has gained importance for select individuals. This includes those with articular impaction, femoral head chondral injury, and posterior wall involvement. However, large population studies and long-term data are lacking.

Currently, there are no clinical practice guidelines for the treatment of acetabular fractures in the elderly. Not surprisingly, there is significant variation in how this injury is treated across the nation, with no consensus on what is optimal. The multitude of studies published in recent years reflects our need and desire to better understand this difficult to treat injury. The purpose of this review is to highlight the recent literature over the past 5 years surrounding the evaluation and treatment of acetabular fractures in the geriatric population.

Mechanism of Injury and Fracture Pattern

A systematic review was performed by Goyal, et al, to determine the injury profile of geriatric acetabular fracture patients. Forty-eight studies, representing 7,876 patients, met inclusion criteria. Mean patient age was 72 years. The most common mechanism of injury included a fall from low height (47%), followed by motor vehicle accident (29%). Based on the Letournel and Judet fracture classification system, the most common pattern was the associated both-column fracture seen in 19% of patients. This was followed closely by anterior column posterior hemitransverse (17%), anterior column (17%), and posterior wall fractures (13%). These results are consistent with the predominance of low-energy trauma and anterior column involvement that have been previously reported, but also suggest that high-energy fractures can be frequent.

Surgical Timing

The importance of surgical timing has been compared between geriatric acetabular and hip fracture patients in two level III studies. Glogovac, et al, retrospectively reviewed 183 acetabular fractures (mean age 76 years) treated with internal fixation and found that surgical fixation within 48 to 72 hours resulted in no significant decrease in mortality at 30 days, 6 months, or 1 year. In a second retrospective review, Harrison, et al, analyzed 53 acetabular fractures (mean age 76 years) treated with internal fixation or combined fixation plus arthroplasty and found that surgical delay greater than 72 hours resulted in longer hospital stay, but no increased risk for mortality at 30 days, 90 days or 1 year. These results suggest surgical timing may be less critical for geriatric acetabular fractures. This is in contrast to geriatric hip fractures, in which there is a clear decrease in mortality associated with early surgery (ie, within 48 hours). One explanation is that acetabular fracture fixation may not improve postoperative mobilization to the same extent since full weight bearing is typically not allowed.

Mortality

Early mortality rates have also been compared between geriatric acetabular and hip fractures. Khoshbin, et al, demonstrated that acetabular fractures in those ≥60 years are at significantly greater risk of early mortality compared to those with hip fractures.
their retrospective, matched cohort study, the 30-day mortality rate following acetabular fracture fixation was significantly higher when compared to hip fractures that underwent internal fixation or hemiarthroplasty (Odds ratio 1.9, 95% Confidence Interval [CI] 1.1-3.3). Setzelberger, et al,\textsuperscript{17} found no difference in 30-day mortality between a matched cohort of acetabular and hip fractures patients >60 years. This was despite a significantly higher perioperative complication rate in the acetabular fracture group (68% versus 48%, P < .001). At 1 year, however, mortality was significantly lower in the acetabular fracture group (18% versus 36%; P = .005). Mortality at 1 year in the acetabular fracture group was associated with intraoperative blood loss >1L and postoperative wheelchair mobilization.

There is poor consensus regarding the mortality benefit associated with operative compared to non-operative treatment. Firoozabadi, et al, demonstrated that open reduction internal fixation (ORIF) resulted in a lower risk for early mortality compared to non-operative treatment.\textsuperscript{18} In their retrospective review of 156 acetabular fractures (mean age 78 years) presenting to Harborview Medical Center (Seattle, WA), the 1-year mortality rate for those in the ORIF group was 12% compared to 44% in the non-operative group. Of the 51 patients who died in the first year, 42 (84%) were treated non-operatively. Furthermore, the 1-year mortality rate for those treated with 4 to 6 weeks of skeletal traction alone was 79%. In contrast, other studies demonstrated no difference in 1-year mortality between operative and non-operative treatment.\textsuperscript{19,21} In a multi-center retrospective review of 454 acetabular fractures (mean age 73 years), Gary, et al,\textsuperscript{21} found the unadjusted 1-year mortality rate of non-operative treatment to be significantly higher than operative treatment (21% vs 13%, P = .01). However, when adjusted for patient age, gender, energy of mechanism, and Charlson comorbidity index, no significant increase in hazard of death for non-operative treatment was detected (P = .6). The authors concluded that when confounding factors are taken into account, operative treatment does not increase or decrease early mortality.

Sarcopenia, or age-related decreased muscle mass, has been utilized as an objective measure of frailty in the elderly. Recently, sarcopenia has also been used to predict early mortality among geriatric acetabular fracture patients. A retrospective study from the Journal of Bone and Joint Surgery found a 42% incidence of sarcopenia in a cohort of 99 acetabular fracture patients older than 60 years old.\textsuperscript{22} Sarcopenia was determined using the skeletal muscle cross-sectional area at the third lumbar vertebral body on an abdominal and pelvic axial CT scan. Males with a skeletal muscle index <55.4 cm\textsuperscript{2}/m\textsuperscript{2} and females <38.5 cm\textsuperscript{2}/m\textsuperscript{2} were diagnosed with sarcopenia. The 1-year mortality of sarcopenic patients was significantly higher compared to non-sarcopenic patients (29% vs 12%, P = .04). Mitchell, et al,\textsuperscript{23} measured sarcopenia utilizing a ratio comparing the average cross-sectional area of the psoas muscle and fourth lumbar vertebral body on axial CT scan. In their retrospective review of a combined group of 146 operatively and non-operatively treated acetabular fractures (mean age 70 years), sarcopenia was found to be an independent predictor of 1-year mortality when controlling for multiple patient factors.\textsuperscript{24} The 1-year mortality rate in sarcopenic patients was 32% compared to 14% or less among others. Sarcopenia was found to be more likely in older patients and females (P < .001).

Mortality rates beyond 1 year have also been reported. Ryan, et al,\textsuperscript{3} reported a mortality rate of 24% at 2 years in a series of displaced acetabular fractures treated non-operatively. Survival rates at 2 - 5 years have ranged between 75-86% following ORIF and 30-68% following THA.\textsuperscript{24,25} Navarre, et al,\textsuperscript{26} found that the function and general health of those who do survive beyond 1 year from surgery may return to that of the general population by 2 years.

**Nonoperative Treatment**

No prior study has utilized a validated assessment tool to investigate the functional outcomes of geriatric acetabular fractures treated non-operatively. Ryan, et al,\textsuperscript{3} utilized the Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)\textsuperscript{27} and the short form 8 (SF-8)\textsuperscript{28} health index scores to assess the functional outcomes of 27 displaced acetabular fractures (mean age 76 years) treated conservatively. Each fracture in this series met at least 1 operative indication: joint incongruity, femoral head medialization, articular impaction, and/or intra-articular fragments. Fractures with posterior wall instability were excluded. Age and medical comorbidities were the most common reason for non-operative treatment. Non-operative treatment consisted of early physical therapy. All patients were restricted to flat foot or non-weight bearing except for two patients who were allowed to weight bear as tolerated. At a mean follow-up of 2 years, WOMAC\textsuperscript{27} and SF-8\textsuperscript{28} health index scores were surprisingly good, and comparable to an operatively treated cohort. However, it is important to point out that 24% of patients were deceased by one year and the surgical conversion rate among those living was 15%.

Other studies, in particular those using self-reported measures, have not shown the same favorable functional outcomes following non-operative treatment. Baker, et al,\textsuperscript{29} evaluated the outcomes of 49 patients (mean age 80 years) with “associated type” acetabular fractures. All patients were treated non-operatively due to physiologic frailty. The authors found a significant reduction in mobility and living independence at 1 year, with only 35% returning to their baseline ambulation status and 69% maintaining habitation in their own home. Walley, et al,\textsuperscript{19} retrospectively reviewed 49 acetabular fractures (mean age 81 years) treated non-operatively and found that only 29% had returned to their pre-injury ambulation status at a mean of 16 months. Surprisingly, this was slightly better, although not statistically significant, than the operative cohort (24%).
Fracture Fixation

Acetabular fracture fixation in osteoporotic/osteopenic bone is technically challenging. Inadequate fixation of the frequently involved quadrilateral surface (QLS) can result in secondary medialization of the femoral head, persistent disability, and subsequent reoperation. A biomechanical study published in the Journal of Bone and Joint Surgery demonstrated the effectiveness of fragment-specific QLS buttress plating when compared to conventional plating methods.21 Twenty-four pelvic Sawbones® models with anterior column posterior hemitransverse fractures underwent fixation with one of four methods: (1) Suprapelvic QLS buttress plating; (2) Intrapelvic QLS buttress plating; (3) Suprapelvic reconstruction plating; or (4) Intrapelvic reconstruction plating. Each pelvic model underwent cyclic loading at partial and full weight-bearing conditions. Fracture displacement did not exceed 1.1 mm in any model. However, under both cyclic loading conditions, suprapelvic reconstruction plating demonstrated significantly greater stiffness compared to infrapelvic reconstruction plating (P = .006 and P = .026). No differences were found between suprapelvic reconstruction plating and either QLS buttress plating technique. The authors recommended fragment-specific QLS buttress plating as an acceptable alternative to suprapelvic reconstruction plating, especially when a less invasive anterior pelvic approach is desired. Additionally, the authors recommended against infrapelvic reconstruction plating of osteoporotic anterior column posterior hemitransverse fractures in order to preserve fixation strength.

Sanders, et al31 investigated factors that influence outcomes following ORIF of geriatric acetabular fractures in order to help guide treatment decisions. Seventy-eight fractures (mean age 70 years) treated with ORIF were retrospectively reviewed. A poor outcome was defined as THA conversion or radiographic osteoarthritis with an Oxford Hip Score32 <34. At a mean follow-up of 4.3 years, sixteen (20%) patients required reoperation. Eleven of these patients underwent conversion total hip arthroplasty. The 7-year joint survivorship including those considered to have a poor outcome was 60%. The only significant predictor of outcome on multivariate regression analysis was reduction quality. Based on Matta grade,3' an imperfect (2-3 mm) or poor (>3 mm) reduction was associated with a 3.3 times greater likelihood of a poor outcome (P = .002). Non-anatomic reduction rates were highest among associated both column fractures. In a sub analysis comparing low and high-energy mechanisms of injury, low-energy trauma was more likely to be associated with a poor outcome and a lower 7-year joint survivorship. The general treatment algorithm recommended by the authors included ORIF whenever an anatomic reduction is feasible. On the other hand, arthroplasty should be considered whenever a non-anatomic reduction is likely. In particular, this includes low-energy associated both column fractures as the ability to achieve and maintain an anatomic reduction is likely compromised.

A systematic review of geriatric acetabular fracture management by McCormick, et al33 found ORIF to be associated with the highest non-fatal complication rate. The pooled outcomes of non-operative treatment, ORIF, closed reduction percutaneous pinning (CRPP), and acute THA with or without fixation were compared in 38 studies. This represented 3947 fractures with a mean age of 72 years. The non-fatal complication rate of patients treated with ORIF was 37.8%. This was significantly higher than all other treatment options (P < .01). Anatomic reduction (<2 mm displacement) following ORIF was achieved in just 55% of cases, which was significantly better than 23% following CRPP (95% CI 11.4-34.8%). Not surprisingly THA conversion rates were lower following ORIF (26%) compared to CRPP (15%) (OR 0.49, 95% CI 0.32-0.77). Both ORIF and CRPP had higher conversion THA rates compared to non-operative treatment. The authors suggest that internal fixation alone should be cautiously considered in geriatric acetabular fractures due to the substantial risk for non-fatal complications and THA conversion.

Total Hip Arthroplasty

Immediate weight bearing following primary THA can lead to acetabular cup instability if inadequate cup fixation is present. Marmor, et al34 provided insight into acetabular cup fixation strategies by utilizing 3-dimensional computer tomography (CT) to map out stable articular bone stock and available bone corridors for screw fixation. The 3-dimensional CT scans of 97 acetabular fractures (mean age 75 years) were retrospectively reviewed. The acetabular dome was found to be the most commonly available stable articular surface (77%), followed by posterior (40%) and anterior (22%) articular surfaces. All fractures (100%) had an available sciatic buttress corridor, while 78% had an available gluteal pillar corridor for screw fixation. Additionally, 65% of fractures had at least 3 bone corridors available for screw fixation. These results suggest stable cup fixation can be achieved in most geriatric acetabular fractures with the use of appropriately placed screws. Future studies are needed, however, to determine optimal acetabular cup fixation constructs.

In a separate study, Marmor, et al35 demonstrated that immediate assisted weight-bearing does not compromise acetabular cup fixation for fractures involving up to 50% of the posterior wall and 25% of the acetabular rim. In this biomechanical study, a representative fracture model was created using the CT scans of 18 posterior wall acetabular fractures (mean age 77 years). This “averaged” fracture pattern, consisting of 50% of the posterior wall and 25% of the acetabular rim, was recreated in 6 paired hemipelvis cadavers (mean age 81 years). A multi-holed acetabular shell was impacted into each specimen and secured with four column screws. A reconstruction plate was used to fix the posterior wall fracture prior to cup insertion in one-half of each hemipelvis, such that one hemipelvis was treated with THA alone and the other half with combined THA plus ORIF.
Cyclic loading up to 4 times body weight resulted in <150 \mu m of cup motion in all specimens. No significant difference in cup motion was found between specimens that did or did not receive direct fixation of the posterior wall fracture.

Morrison, et al, demonstrated that THA in the setting of a prior acetabular fracture may be associated with significantly lower 10-year implant survivorship and more major complications when compared to THA performed for primary osteoarthritis or avascular necrosis. In this level III case-control study, the 10-year THA survivorship for those with a prior acetabular fracture was 70% as compared to 90% for those without ($P<.001$). Initial fracture management (non-operative or ORIF) did not influence 10-year survivorship in the acetabular fracture group. Regarding major complications, the acetabular fracture group had a higher likelihood of infection (7% vs 0%, $P=.03$), dislocation (11% vs 3%, $P=.05$), and severe heterotopic ossification (43% vs 16%, $P<.001$).

Weaver, et al, retrospectively evaluated revision surgery rates in geriatric acetabular fracture patients treated with ORIF or primary THA and found a high rate of conversion arthroplasty within 2 years following ORIF. However, the overall reoperation rate did not reach statistical significance when ORIF was compared to the primary THA group (30% vs. 14%, $P=.12$). The authors did note that this was likely due to a type II error. Revision surgery following THA was most commonly due to infection, followed by instability, and symptomatic heterotopic ossification. In this same study, patients tended to have better hip function following THA compared to ORIF based on Harris Hip Scores (82 vs 63, $P=.06$) and short form 36 pain scores (48.4 vs 35.4, $P=0.04$).

Two studies compared THA plus ORIF (ie, combined approach) with ORIF alone and found that a combined approach is associated with a lower risk for revision surgery. Borg, et al, prospectively followed 27 acetabular fractures (mean age 72 years) treated with a combined approach or ORIF alone. At 3 years, no patient in the combined group required further surgery (100% hip joint survival), while the hip joint survival in the ORIF group was just 29% (see Figure 1). Lont, et al, retrospectively reviewed 55 acetabular fractures (mean age 77 years) treated with ORIF alone or primary THA combined with posterior column plating and use of a cup cage construct. Implant survival was higher in the combined group at both 1 (100% vs 74%) and 2-year follow-up (91% vs 52%). Dome impaction was noted to be associated with poor prognosis when treatment included ORIF alone.

Jauregui, et al, published the first meta-analysis on the complications of acute THA for elderly patients with acetabular fractures. Their final analysis included 21 studies, representing 430 acetabular fractures. This included the previously mentioned studies by Weaver, et al, Borg, et al, and Lont, et al. All arthroplasty procedures were performed in combination with some type of fixation. Mean patient age was 72 years. The overall complication rate was 20%, resulting in a revision rate of 4.3% at a mean follow-up of 44 months. The most common complication was heterotopic ossification (HO) at 19.5%. However, only 6.8% were considered clinically significant (Brooker grade III and IV). This indicates that most cases of HO are not clinically relevant. The next most common complication was postoperative hip instability (6.1%). The direction of dislocation or surgical approach used was not mentioned. Additionally, deep infection occurred at a rate of 3.8%. Both
the dislocation and deep infection rates reported in this study were higher than known rates associated with primary THA for osteoarthritis. The authors attributed this to the traumatized soft tissue envelope of the hip and longer surgery times (mean 176 min), respectively. Despite the less than ideal results reported in this study, select individuals acetabular fractures in the elderly: a critical analysis review. JBUJS Rev. 2016;10(1):e1. doi:10.2106/JBUJS.RVW.15.00090


Conflict of Interest

None of the authors identify a conflict of interest.

References


Outcomes After Hip Labral Reconstruction Using Peroneus Longus Graft: A Novel Graft Experience

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Abstract

Currently, there is no consensus on the ideal graft for hip labral reconstruction. The purpose of this study was to describe the surgical technique and report the short-term outcomes after hip labral reconstruction using a peroneal longus allograft. Eleven patients diagnosed with femoracetabular impingement and irreparable damage to the acetabular labrum underwent labral reconstruction with a peroneus longus allograft. The average follow-up time was 227 days (range: 26-457 days). Pre-operative radiographic measurements included an average pre-operative center edge angle of 29.0° (range: 19° to 37°) and an average alpha angle of 62.9° (range: 55° to 71°). All patients underwent femoroplasty, with additional procedures including 7 acetabuloplasties and 6 microfractures. The average visual analogue score for pain improved from 4.91±2.17 preoperatively to 3.85±2.0 postoperatively but this was not significant (P=.26). No patients sustained post-operative complications or allograft failures during follow up. Compared to other acetabular labral reconstruction options, the strength and shape of the peroneus tendon may best replicate the native hip labrum. The current findings of no immediate post-operative complications or early failures suggests the peroneus longus allograft may be a viable option for hip labrum reconstruction.

Keywords

peroneus longus graft; hip labrum reconstruction; labrum allograft; arthroscopy; hip labrum; arthroscopic hip

Acronyms and Abbreviations

FADIR: flexion, adduction, and internal rotation
PL: peroneus longus
VAS: Visual Analog Scale

Introduction

Currently, hip labral reconstruction is reserved as a primary surgery for irreparable labral tears or as a salvage, revision surgery for failed labral repairs. Ideally, labral reconstruction is performed on nonarthritic hips in non-obese patients with irreparable labral tears who have failed conservative treatment including nonsteroidal anti-inflammatory treatment and physical therapy.1 Cadaveric studies have shown intraarticular pressure of the hip can be restored within normal physiologic parameters with labral reconstruction.2 Restoration of the physiologic intra-articular pressure is clinically relevant as it helps maintain articular space and reduce surface contact pressures, potentially slowing the progression of osteoarthritis.3 Compared to patients undergoing simple debridement, patients undergoing reconstruction have reported higher satisfaction and improved modified Harris hip scores.4,5 With improved patient outcomes and expanding surgical indications, hip labral reconstruction is likely to become more popular in the near future.6

Although previous research favors an arthroscopic surgical approach to labral reconstruction, the graft choice remains controversial.6 Previous studies have evaluated the use of autograft harvested from the indirect head of the rectus, the iliotibial band, and the gracilis tendon, as well as allografts from the iliotibial band or tensor fascia lata; however, none have been shown to be superior.7 Furthermore, there is a lack of literature examining specific biomechanical and physical properties of various grafts and the possible limitations associated with them.

Peroneus longus (PL) allograft has not been previously described for hip labral reconstruction, however, it has been used for knee cruciate ligament and meniscus reconstruction. Because the labrum is a meniscal analogue and hamstrings are commonly used in ACL reconstructions, the PL is a possible alternative for hip labral reconstruction.8,9 Theoretically, the peroneus longus graft might be biomechanically superior to other graft options due to its size and durability, which may translate to improved clinical outcomes. This study will briefly describe the surgical technique and report the short-term outcomes on a small patient cohort undergoing hip labral reconstruction using PL allograft.

Methods

This institutional approved (HPHRI# 2020-092) retrospective chart review included a consecutive cohort of patients who underwent hip labral reconstructions from December 2015 to January 2021. Clinical evaluations and surgical procedures were performed by a single, fellowship-trained orthopedic surgeon. During the study period, patients presenting with hip pain and clinical signs of hip labral pathology underwent a radiograph assessment, including weight-bearing anteroposterior radiographs, lateral frog leg radiographs, and a magnetic resonance image (preferably an arthrogram) of the hip. All patients met the standard indications for labral reconstruction, including failed symptomatic management with conservative treatment, clinical appearance, and/or intraoperatively confirmed findings of labral derangement.
Abbreviated Surgical Technique

Each hip arthroscopy was completed using standard equipment, with the patient supine on a specialized fracture table (Hana®, Mizuho OSI, Union City, CA, USA). A standard anterolateral viewing portal was created slightly anterior to the greater trochanter using fluoroscopic guidance. Through this portal, the feasibility and appropriateness of labral repair or reconstruction was evaluated based on the condition of labral tissue and acetabular cartilage. Next, a mid-anterior portal was created at the apex of an equilateral triangle referencing the greater trochanter and a line drawn parallel to the anterior superior iliac spine (Figure 1). Utilizing these 2 portals for viewing or instrumentation, hip labral tissue and acetabular cartilage were again evaluated and debrided of free flaps, nonviable tissue and delaminated cartilage (Figure 2).

Measuring with the shaver head as a reference, the size of the labral deficit and graft size needed were estimated. An additional 1 cm was added to the measured length and the PL allograft tendon was truncated to size. A thorough acetabular rim chondroplasty and labral debridement were performed with primary goals of achieving a stable remnant labral end and a bony surface with high healing potential. Osseus work (acetabuloplasty/femoroplasty) was done to correct the cause of impingement (pincer/cam) before any tendon work was performed and ensure a viable recipient graft bed.

Single-loaded suture anchors were placed along the length of the debrided acetabular edge. The peroneus longus graft was inserted through the mid-anterior portal and manipulated into its final position. One limb of the previously placed suture anchor was then passed around the graft. The graft was manipulated into position according to the primary surgeon’s preference, with the goal of filling the labral defect and reconstituting the anatomic geometry of a native hip labrum. Sutures were then tied to create a stable healing construct (Figure 3). The reconstruction was evaluated by taking the limb off traction, reassessing the position of the graft, and evaluating the establishment of an intra-articular seal.

Post-Operative Care

Following surgery, patients were limited to touch down weight-bearing for 4 weeks. Range of motion was limited to 90° flexion, 0° of hip extension, and neutral rotation with external rotation only allowed during resting positions. Subsequently, the patients were progressed incrementally to weight-bearing as tolerated. Patients were permitted to start bicycling immediately after surgery and they were progressed to more demanding activities such as elliptical training and running on a case-by-case basis.

Data Analysis

Data collected included patient demographics and historical treatment of hip pain, including narcotic use and previous surgeries. Pre-operative clinical variables were collected from the office visit immediately preceding surgery including visual analogue scoring for pain (VAS), and positive physical exam findings. Pre-operative radiographs were reviewed by the senior surgeon, and the center edge angle, Tonnis angle, and alpha angle were calculated. Peri-operative variables included location and length of labral tear, graft size, Outerbridge graded articular cartilage, and surgical procedures performed. Postoperative VAS scores and narcotic use were also collected.
Figure 2. Various arthroscopic images of the procedure. A: The labrum is detached from approximately 12 o'clock to 3 o'clock with a chondral rim injury. Otherwise, the cartilage of the acetabulum and femoral head is preserved. B: A cam lesion is identified at the anterior femoral neck. C: A view of the femoral neck after the cam lesion was removed. D: Suture anchors were placed along the chondrolabral junction after the labral and acetabular debridements were performed. E/F: The peroneus longus graft is shuttled from the midanterior portal with manipulation into its appropriate position.

Figure 3. Final construct with a stable acetabular chondrolabral junction and newly reconstructed superolateral acetabular labrum.
Results

Overall, 11 patients underwent hip reconstruction with the PL allograft during the study period, with an average post-operative follow-up time of 227 days (range: 26-457). Patient demographics included an average age of 32±5.9 years old, average body mass index of 26.5±2.9 kg/m², and 8 males (73%). All patients had a positive FADIR test. Previous treatment history included 1 patient taking narcotics for pain and 1 patient with a previous labral repair. Radiographically, the average center edge-angle was 29.0°±5.3° (range: 19°-37°) and the average alpha angle was 62.9°±5.4° (range: 55°-71°). Three patients had advanced disease with Tonnis scores of 2, and 5 patients (45.5%) had a positive crossover sign.

Intra-operative findings were consistent with labral derangement requiring hip labral reconstruction such as poor labral tissue quality (N=5) and irreparable labral tears (N=6). For patients with irreparable labral tears, the average tear length was 3.38 ±0.67 cm. Five were located at the 12-to-3 o'clock position, and 1 was a complete radial tear. Intra-operative assessment of the articular cartilage revealed 7 patients with Outerbridge Grade IV damage. All patients underwent femoroplasty, and 7 patients (63.6%) underwent acetabuloplasty. Microfracture was performed on 6 of the 7 patients with Grade IV articular cartilage damage.

At the most recent clinic post-operative clinic visit, mean pain score was 3.87±2.05, which was improved from preoperative pain score of 4.91±2.17 (P=.26). One patient required chronic narcotic medication preoperatively. No post-operative complications or failures were noted during follow-up.

Discussion

Arthroscopic hip procedures have become increasingly popular, and the number of hip labral reconstructions is likely to continue to grow.16 Many unknowns currently exist, and there is no consensus for the most effective graft for optimal surgical and clinical goals. A recent systematic review evaluated and compared various grafts and found no significant differences among grafts in terms of outcomes, however, nearly all included studies were of low-level evidence with small sample sizes, demonstrating the need for more data in the literature.17

Previous biomechanical and clinical studies propose an ideal labral graft diameter of 8 mm in diameter to adequately achieve the best suction-seal.2,4 Labral heights <6 mm (as found in gracilis grafts) were suggested to be too small, lowering the threshold to suction-seal failure and creation of hip instability.2,18 Labral graft diameters significantly larger than 8 mm (eg, tibialis anterior grafts) can create a mechanical block to adequate intra-articular compression when the limb is off traction.17 In comparison, the PL graft has been reported to have a mean diameter of 8.3 mm,4 making it fractions of a millimeter away from an ideal graft diameter postulated to meet surgical and clinical goals.9 Furthermore, having an optimally sized graft diminishes the need for additional intraoperative modifications (eg, tubularization) that are often required when using the iliotibial graft, thereby decreasing intraoperative time.9

In addition to proper graft shape and size, the chosen graft must possess significant tensile strength to support the cyclic stress cycles seen in the hip. Previous studies have suggested that hamstring allografts have similar biomechanical tensile properties as native acetabular labrum with semitendinosus hamstring graft even demonstrating better resistance to elongation behavior then the native hip labrum.13 Studies have reported the PL tendon has tensile strength equivalent or superior to hamstring graft, which might infer superior mechanical strength and toughness ideal for hip labrums.10,12,19 This strength has not been shown to be influenced by graft donor age, indicating age screening for this graft may be unnecessary.13 This potentially creates a widened donor pool of an easily obtainable, available, and durable graft.

The current early results indicate peroneus longus is a viable graft alternative for hip labral reconstruction with no catastrophic failures or infections at an average follow-up of 227 days (Range: 26-457). Of the 11 patients undergoing hip labral reconstructing with peroneus longus tendon allograft, pain improved from mean VAS scores of 4.91 to 3.85, but this improvement was not statistically significant (P=.26). Although pain did persist in some patients, this was not unexpected as up to 25% of patients have been shown to require conversion to a total hip arthroplasty after a failed acetabular labral reconstruction.21 These patients will continue to be followed closely. Currently, there are plans to collect specific clinical data and ROM measurements to allow for direct graft comparison in the future. Further long-term and higher-level studies are needed in this new field of orthopedic sports surgery.

Conflict of Interest

None of the authors identify a conflict of interest.

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References


A Cadaveric Study Measuring Femoral Nerve Tension During Anterior Total Hip Arthroplasty Approach

John P. Livingstone MD; Trent M. Tamate MD; Andrew K. Richardson MD; Jeffery K. Harpstripe MD

Abstract

Femoral nerve palsy is a rare but devastating complication of anterior total hip arthroplasty. Its etiology is still unknown, but several studies have suggested that anterior acetabular retractors may place the femoral nerve at increased risk. This study hypothesized that hip extension and traction places tension on the femoral nerve, offering an additional explanation for the development of femoral nerve palsy. A spring device was secured across 6 transected femoral nerves from 5 lower extremity cadavers and the hip was extended and pulled into traction with and without retractor placement. The change in spring length was used to determine femoral nerve tension. The average spring length changed +8.83 mm with hip extension, +3.73 mm with traction, -0.7 mm with traction and placement of the anterior acetabular retractor, and -1.15 mm with extension and placement of the femoral retractor. Femoral nerve tension was greatest with hip extension followed by traction. Acetabular and femoral retractor placement decreased average femoral nerve tension in both traction and hip extension. This may be due to medialization of the femoral nerve by the retractors, reducing the overall distance traveled, and thereby reducing tension. Previous studies have found femoral nerve pressure to be greatest during anterior acetabular retractor placement. It is likely that both pressure and tension contribute to femoral nerve palsy. Careful retractor placement, staying safely on anterior acetabular bone, and efficient femoral preparation to decrease time under hip extension and traction may help to minimize the risk of femoral nerve palsy.

Keywords

Femoral, nerve, tension, traction, stretch, palsy, neurapraxia, total, hip, arthroplasty, joint, replacement

Abbreviation

MEP = motor evoked potential

Introduction

Femoral nerve palsy is an uncommon but devastating complication of anterior total hip arthroplasties. Studies have estimated the incidence to range from 0.21% to 1.1%. Despite this low incidence, nerve palsy is the most common reason for medical litigation for total hip arthroplasty. The etiology of femoral nerve palsy during anterior total hip arthroplasty is still unknown but several studies have suggested that anterior acetabular retractors may place the femoral nerve at an increased risk of being damaged. A study published in 2000 measured femoral nerve pressure with an electronic pressure transducer placed adjacent to the femoral nerve. This study demonstrated that in-vivo pressure around the femoral nerve increased significantly when the anterior acetabular retractor was placed during an anterior total hip arthroplasty. A significant increase in pressure was only found with anterior acetabular retractor placement and was not noted to change significantly during the rest of the procedure.

Another study from 2018 measured motor evoked potentials (MEPs) during direct anterior total hip arthroplasty and found that MEPs decreased to 54% of their preoperative amplitude when the anterior acetabular retractor was placed. Lastly, a cadaveric study from 2019 found that the anterior acetabular retractor was closest to the femoral nerve when placed in the 90° orientation along the acetabulum. These papers suggest that the anterior acetabular retractor places the femoral nerve at risk due to its proximity to the nerve, increased pressure around the nerve, and associated decrease in MEPs.

The hypothesis of this study was that extension of the hip during anterior total hip arthroplasty would lead to significant tension on the femoral nerve, similar to how hip flexion and knee extension can conversely affect the sciatic nerve. With the femoral nerve running anteriorly over the brim of the pelvis, extension of the hip would intuitively tension the nerve during femoral preparation and may be another cause of femoral nerve palsy. It was hypothesized that both retractor placement and femur traction would increase femoral nerve tension as well.

Materials and Methods

Five fresh lower extremity cadavers were utilized for this study. The specimens were transected at various levels ranging from L1 to L3. A total of 6 femoral nerves were dissected from these 5 specimens.

The direct anterior (modified Hueter) approach was used to perform the proximal femur osteotomy as if an anterior total hip arthroplasty was going to be completed. The femoral nerve was identified through the ilioinguinal approach. The nerve was tracked distally as it crossed over the anterior brim of the pelvis (Figure 1). A spring device was created to measure the tension placed on the femoral nerve. This device consisted of a clear acrylic tube, 9.4 mm in diameter and about 70 mm in length, with a thin 6mm diameter extension spring placed within the tube. The tube was then capped on either end with washers so that the spring would not fall out of the tube during testing. A 0-vicryl suture was tied to both ends of the spring and exited the tube through the central holes of the washers (Figure 2). The femoral nerve was transected about 3 cm proximal to the anterior brim of the pelvis and the spring device was secured to both ends of the transected nerve proximal and distal to the spring device with the free ends of the suture. The device was...
pre-tensioned so that the spring was in some extension before manipulation (Figure 3). The device was also ensured to be proximal to the anterior rim of the pelvis so that it would lie flat along the iliopsoas muscle. The length of the spring was measured with digital calipers in five different settings. The length of this spring was used as a proxy to estimate changes femoral nerve tension. The first setting was when the hip was in a neutral position while supine on the table with no retractors placed within the anterior total hip incision. The second setting was when axial traction was applied through the foot with the hip in a neutral position. The third setting was when axial traction was applied through the foot and the anterior acetabular retractors were placed to adequately visualize the acetabulum. During the first specimen exposure, 8 kg of axial traction was required for adequate visualization of the acetabulum. This amount of axial traction was utilized for the remaining specimens for consistency. The fourth setting was when the hip was extended and externally rotated so that the cut end of the proximal femur could be adequately visualized. The fifth and final setting was when the hip was extended and externally rotated and the femoral retractor was placed around the posteromedial femur for femoral visualization. The foot was wrapped in a self-adherent elastic wrap and a mechanical spring scale was attached to the foot so a consistent amount of traction could be obtained with each specimen. Extension of the hip was obtained by placing the specimen on the edge of a table and supporting the contralateral leg on a mayo stand while the dissected leg was lowered into extension off of the table (Figure 4).
Figure 3. The spring device is secured to either end of the transected femoral nerve. The left photo demonstrates the initial position without retractor placement, extension, or traction. Note that the spring is pre-tensioned and is not in its resting state. The right photo demonstrates traction without retractor placement. Orientation: medial left, proximal up.

Figure 4. The specimen can be seen here with the hip in extension and external rotation with the femoral retractor in place. The specimen was positioned on the edge of the table with the contralateral leg on a mayo stand. A ratcheting strap was used to secure the specimen to the table.
Results

A total of 6 femoral nerves from five cadaveric specimens were analyzed in this study. Specimens 4L and 4R were from the same cadaveric specimen with 4L representing the left femoral nerve and 4R representing the right femoral nerve. Traction was noted to increase spring length in all but 1 specimen where it had no effect. The average change in spring length after traction was +3.73 mm. Placement of the anterior acetabular retractor after traction was applied was noted to decrease spring length in all but one specimen where it was noted to lengthen slightly by 0.3 mm. The average change in spring length with the placement of the anterior acetabular retractor after traction was -0.7 mm. Extension increased spring length in all specimens by an average of +8.83 mm. The placement of the femoral retractor while in extension decreased spring length in four of six specimens with an average change in spring length of -1.15 mm (Tables 1A and 1B, Figure 5).

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Initial (A)</th>
<th>Traction (B)</th>
<th>Traction With Anterior Acetabular Retraction (C)</th>
<th>Extension (D)</th>
<th>Extension With Femoral Retraction (E)</th>
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</tr>
<tr>
<td>4L*</td>
<td>18.5</td>
<td>19.3</td>
<td>17.5</td>
<td>22.6</td>
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<tr>
<td>4R*</td>
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<tr>
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<td>20.9</td>
<td>20.2</td>
<td>26.0</td>
<td>24.9</td>
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</table>

* 4L represents the left femoral nerve and 4R represents the right femoral nerve

<table>
<thead>
<tr>
<th>Specimen</th>
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<th>C-B</th>
<th>D-A</th>
<th>E-D</th>
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<td>-0.6</td>
<td>1.5</td>
<td>-1.6</td>
</tr>
<tr>
<td>4L*</td>
<td>0.8</td>
<td>-1.8</td>
<td>4.1</td>
<td>0.2</td>
</tr>
<tr>
<td>4R*</td>
<td>0.9</td>
<td>-0.5</td>
<td>5.7</td>
<td>-3</td>
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<tr>
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<td>0.3</td>
<td>8.8</td>
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<tr>
<td>Average</td>
<td>3.73</td>
<td>-0.7</td>
<td>8.83</td>
<td>-1.15</td>
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* 4L represents the left femoral nerve and 4R represents the right femoral nerve

Figure 5. A graphical representation of spring length (mm) changing with traction, extension, and/or retractor placement.
Discussion

Our study found that femoral nerve tension as measured by spring length was greatest while the hip was in extension during femoral preparation and that anterior acetabular retractors decreased femoral nerve tension. This is in contrast to a previous study which found that pressure around the femoral nerve increased most when the anterior acetabular retractors were placed. This study utilized an electronic pressure transducer to measure the pressure around the femoral nerve throughout an anterior total hip arthroplasty. The electronic pressure transducer was placed adjacent to the nerve while an anterior total hip arthroplasty was performed through a Watson-Jones anterolateral approach. This study did not find a significant change in pressure when the femur was prepared or during any other part of the surgery.4 This difference in findings is likely due to the fact that our study measured tension and the previous study measured pressure. They estimated pressure on the femoral nerve by placing the pressure transducer adjacent to the nerve. During hip extension or traction, the femoral nerve likely does not experience any increase in pressure because it is not in a confined space that would significantly decrease in volume with positional changes. If the pressure transducer was placed directly between the femoral nerve and the anterior brim of the pelvis, there may have been an increased pressure reading during hip extension as the femoral nerve was tensioned over the pressure transducer and the anterior brim of the pelvis. This was not likely done, however, since positioning the pressure transducer so intimately along the femoral nerve would likely place the femoral nerve at greater risk for damage or nerve palsy.

In the study by Ishimatsu, the use of MEPs also provided information in regard to the in vivo function of the femoral nerve when anterior acetabular retractors were placed.6 This study noted that MEPs decreased to 54% of their preoperative amplitude when anterior acetabular retractors were placed. Unfortunately, MEPs were not measured during any other parts of the anterior total hip arthroplasty so it is unknown if MEPs decreased during hip extension or traction.7 This study was also completed with the patient supine without the use of a traction table.

Our study demonstrated that, on average, placement of retractors during both hip extension and traction decreased spring length. This study also found that hip extension and traction increased spring length, with the former having the greatest effect. This finding implies that femoral nerve tension was increased with extension and traction and decreased with retractor placement. The authors expected nerve tension to increase with retractor placement since it has been shown to decrease MEPs and increase pressure adjacent to the nerve. One explanation for this finding is based on the anatomy of the femoral nerve. The femoral nerve naturally runs in a more lateral position over the iliopsoas muscle as it crosses over the anterior brim of the pelvis. When the anterior acetabular and femoral retractors were placed, the femoral nerve was noted to move medially as the retractor was brought up to visualize the acetabulum or the femur. It is possible that by moving the nerve more medially it can then take a more direct and shorter path, reducing the tension on the nerve. One cannot conclude, however, that extension and traction are more likely to lead to a femoral nerve palsy than anterior acetabular retractor placement. Nerve palsies may occur through either compression or tension of the nerve. Both of these forces may be responsible for a femoral nerve palsy with anterior acetabular retractors placing the most pressure on the nerve while extension and traction create the most tension. Similar to the study by Yoshino, et al, this study also noted the close proximity of the anterior acetabular retractors to the femoral nerve.6 The authors noted that if the retractor doesn’t stay on bone, it could easily puncture through the iliopsoas and be placed directly on the femoral nerve (Figure 6).

The purpose of creating the spring device used for this study was to have a direct measurement of the tension of the femoral nerve rather than an indirect measurement of pressure seen in the study by Slater, et al.4 The authors initially attempted to visualize the tension of the femoral nerve by placing 2 sutures in the femoral nerve and measuring the distance between these sutures as the leg was pulled into traction or extension with and without retractors. The distance between the sutures did not change with these maneuvers. This implied that the femoral nerve was likely experiencing tension but its elasticity was not visually appreciated. An analogy to this would be how a steel cable can be under significant tension but there is no appreciable change in its length. By transecting the femoral nerve and securing our spring device between its cut ends, the tension can be more easily visualized. There are several limitations to the use of the spring device, however. First, the device needed to be placed so that it would not limit or alter the normal path of the femoral nerve. This was theoretically accomplished by keeping the device small and placing it over the iliopsoas before the femoral nerve crosses over the anterior brim of the pelvis. This would allow the nerve to glide and stretch in an anatomic position over the anterior brim of the pelvis. Second, the spring length needed to be measured from outside of the acrylic tubing which meant that the calipers had to be visually compared to the spring itself rather than by making direct physical contact with the spring. It would be ideal if the spring itself could make contact with the calipers for more accurate measurement but the acrylic tube around the spring was needed to decrease any friction that the spring may have encountered if it was placed directly into the soft tissues and to prevent debris from building up within the spring which would have prevented it from compressing fully. The spring was pre-tensioned in its initial position to remove any slack from the femoral nerve prior to applying traction, extension, and/or retractors. The amount of pre-tensioning was not consistent amongst specimens but this should not affect the results of this study since the change in length of a spring is linearly related to the force applied based on Hooke’s law. The springs were never noted to deform and were kept well within their elastic region with testing.
Figure 6. This photo demonstrates how the anterior acetabular retractor, circled in red, can be mistakenly placed directly over the femoral nerve if the retractor is not kept on the acetabulum.
There are other limitations to our study as well. The anterior acetabular and femoral retractors were placed in similar positions in every specimen but the amount of force applied to the retractor was not controlled. The force applied to the retractor was kept to a minimum by only pulling on the retractor enough for adequate visualization of the acetabulum or femur. This was felt to be acceptable since this is a realistic amount of force that would be used during an actual anterior total hip arthroplasty. This study was also limited by a small number of specimens.

Future studies are needed to evaluate the effects of extension and traction on the femoral nerve. Another study measuring MEPs throughout the entire anterior total hip arthroplasty rather than just before and after anterior acetabular retractor placement may provide further insight into the effects of positioning on the femoral nerve.

In conclusion, this study demonstrated that femoral nerve tension as measured by spring length increases with hip extension during anterior total hip arthroplasty. Tension on the nerve was also increased during axial traction but to a lesser extent. The tension on the femoral nerve was noted to decrease when both anterior acetabular and femoral retractors were placed. This may be due to the medialization of the femoral nerve which may decrease its overall length traveled, thereby reducing its tension. The findings of this study in combination with previous studies suggest that the femoral nerve likely experiences maximum compressive forces with anterior acetabular retractor placement and maximum tension during hip extension and traction. Both of these forces may contribute to femoral nerve palsies in anterior total hip arthroplasty. Unfortunately, hip extension, traction, and retractor placement are all necessary components of a safe and successful anterior total hip arthroplasty with current total hip arthroplasty technology. Therefore, careful retractor placement, staying safely on anterior acetabular bone, and efficient femoral preparation to decrease time under hip extension and traction may help to minimize the risk of femoral nerve palsy.

**Conflict of Interest**

None of the authors identify a conflict of interest.

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**References**

An Online Learning Tool to Obtain, Optimize, and Interpret Radiographs During Total Hip Arthroplasty

John P. Livingstone MD; Makoa Mau BS; Jeffery K. Harpstrite MD

Abstract

Total hip arthroplasty (THA) is a common orthopedic procedure which has been growing in popularity with the elderly population. With more surgeons completing anterior THAs, intraoperative radiographs have become commonplace. Unfortunately, there is a lack of education in regard to obtaining, optimizing, and interpreting these radiographs. The purpose of this study was to develop and test the efficacy of an online learning tool that medical students, residents, and C-arm technicians could use to improve their understanding of THA radiography. The learning tool taught users how to obtain an optimal AP pelvis radiograph and how to interpret radiographs so THA components could be placed in their optimal position. This learning tool was sent to medical students, orthopedic surgery residents, and C-arm technicians along with a pre-test, post-test, and feedback survey. Twenty users (eleven medical students and nine orthopedic surgery residents) completed the learning tool. Post-test scores (M=96.4%, SD=2.9%) were significantly greater than pre-test scores (M=68.3%, SD=23.9%) for all users (t=5.5069, P<.0001). The user’s level of training was positively correlated with pre-test scores. Surveys from the users revealed that the learning tool provided significant learning opportunities, was relatively easy to understand, but was slightly too long. Users felt that this learning tool would be best suited for senior medical students, junior orthopedic surgery residents, and C-arm technicians. With the positive results of this study, the authors hope to further develop this learning tool for widespread adoption and to develop similar learning tools in the future.

Abbreviations

3D = three-dimensional
AP = anteroposterior
MS = medical student
PGY = post-graduate year
SD = standard deviation
THA = total hip arthroplasty

Introduction

Total hip arthroplasty (THA), often referred to as total hip replacement surgery, is a common surgical procedure in orthopedics that continues to grow in popularity as the elderly population increases.1-3 All orthopedic surgery residents are expected to be able to perform a THA by the end of their residency and a significant portion of their residency is dedicated to learning this procedure. Since anterior THAs have become more prevalent in recent years,4 intraoperative radiographs have become a standard part of THAs. There is an abundance of literature on how surgeons can utilize these radiographs to optimize the positioning of the acetabular and femoral components, but there seems to be a lack of education in regard to obtaining and interpreting these radiographs.

The importance of proper component positioning has been emphasized in the literature since Lewinnek first described his safe zones in 1978.4 Even though the optimal positions of these components are still debated to this day,5-8 the surgeon cannot accurately determine the position of these components without optimal radiographs. Optimal radiographs can be difficult to obtain and maintain during surgery due to patient specific anatomy and positioning9,10 in addition to difficulties communicating with C-arm technicians. There have been six publications since 2009 proposing different universal C-arm languages to improve this communication deficit.9,11 but to the authors’ knowledge, none of these have become standardized in orthopedic education. Studies have shown that fluoroscopy time during anterior THAs decreases by greater than 50% as new surgeons complete their first 40-100 cases.12,13 When reviewing the available resources for orthopedic surgery residents, there is a paucity of information in regard to obtaining optimal radiographs for total hip arthroplasty. This may explain why new surgeons have greater fluoroscopy times.

The purpose of this study was to develop a freely available, interactive, online learning tool that residents, medical students, and C-arm technicians could utilize to obtain, optimize, and interpret radiographs during THAs. The learning tool would provide users with educational content followed by multiple choice questions to test their understanding of the previous topic. The first chapter would teach users how to obtain an optimal anteroposterior (AP) pelvis by maneuvering the C-arm or operating table. This chapter would emphasize the importance of communicating with the C-arm technician or anesthesiologist in control of the operating table. The second chapter would teach users about the optimal positioning of the acetabular component and what maneuvers are required to obtain this position. The users would be tested on their ability to identify and correct mispositioned acetabular components and to estimate the anteversion and inclination of a given acetabular component. The final chapter would teach users about the optimal positioning of the femoral component and how leg positioning can affect femur radiographs. The users would be tested on their ability to identify and correct leg length and femoral offset. To assess the efficacy of this learning tool, a pre-test and post-test would be given to all learning tool users.

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Methods

The online learning tool was developed using Google Forms™, a freely available online survey generator. This software was chosen since it is easy to use, free, and one of the most popular survey generators that users would be familiar with. The opinions of the authors of this study in addition to current literature on the subject were used to develop the content of this learning tool.

Users would be shown suboptimal AP pelvis radiographs, acetabular component positions, and femoral component positions in each of the three chapters of this learning tool. They would then be asked to identify how the radiograph or components were suboptimal and what steps were needed to make a correction. In order to generate these images, three-dimensional (3D) models of the pelvis, femur, and THA components were either obtained from freely available online sources such as thingiverse.com or created by one of the authors of this paper. These models were merged together in a freely available 3D software called AutoDesk Fusion 360°. Digital joints were created between the femur and pelvis so the femur could be internally/externally rotated, adducted/abducted, or extended/flexed into any position. Likewise, the acetabular and femoral components could be adjusted to any position to simulate mispositioned components. To generate a realistic radiograph, this 3D model was rendered in a frosted glass material with a black background and specific lighting. The virtual camera used to look at this 3D model could then be moved into various positions to show how patient positioning and C-arm positioning can affect the simulated radiograph (See Figure 1).

The pre-test, learning tool, and post-test were sent to medical students, orthopedic surgery residents, and C-arm technicians. Their email addresses were collected as necessitated by the software to prevent a user from repeating either the pre-test or post-test. The learning tool consisted of 82 individual pages divided into three chapters. Following each teaching topic, users were tested with multiple-choice questions. If a wrong answer was chosen within the learning tool, the user would be shown the question slide again until the question was answered correctly. When the correct answer was chosen, the user would be taken to a review slide for additional explanations and topic review.

The first chapter taught the user about the radiographic signs of an optimal AP pelvis (see Figure 2). It then taught the user about how the motions of the operating table and C-arm will change the radiograph of the pelvis. Initially, users were tested on a single C-arm or operating table motion. After progressing through questions on individual motions, several motions were then combined. The questions would increase in difficulty by initially providing the user with answer choices containing images of the C-arm or operating table motions in addition to their written descriptions (see Figure 3). This was designed to help users associate the motions with their descriptors. As the questions advanced, the user would have to choose from descriptors only. This was designed to replicate the conditions of the operating room where the surgeon has to rely on using these descriptors to communicate the desired movements of the C-arm or operating table to staff.

![Figure 1. A simulated radiograph of a suboptimal AP pelvis.](image-url)
Figure 2. A simulated radiograph demonstrating the radiographic signs of an optimal AP pelvis.

Figure 3. An example of the answer choices available in the early section of the first chapter where operating table motions and their descriptors were shown as answer choices. Later in the chapter, the questions became more difficult and only descriptors would be given as answer choices.
The second chapter focused on acetabular component positioning. Inclination and anteversion were explained using examples of mispositioned acetabular components (see Figure 4). Users were then taught about how to change the amount of anteversion or inclination by moving their hand relative to the patient as if they were holding the insertion device for the acetabular component. Since there is still a lack of consensus on optimal acetabular component positioning, an inclination of 40° and anteversion of 20° based on an AP pelvis were chosen to be optimal for this learning tool. These values are within Lewinneck’s safe zone and are common amongst arthroplasty surgeons, including the senior author of this study. Users were then given questions which asked them to correct mispositioned acetabular components by moving their hand in a certain direction. Finally, users were asked to estimate the amount of inclination or anteversion. A brief discussion of parallax and distortion were included in this chapter since these phenomena can have a significant impact on acetabular component positioning.

The third and final chapter taught the user about femoral component positioning and the effects that femur positioning can have on component positioning. First, users were taught how to measure femoral offset and length. They were then shown various examples of how abduction/adduction, flexion/extension, and internal/external rotation will change the appearance of the femur on the radiograph. This was accomplished with both still images (see Figure 5) and video animations created in the 3D software. Users were given questions on femur offset and length prior to a brief survey. The survey asked users about their opinions on the learning tool, who they thought the learning tool was best suited for, and provided space to write comments. Likert scales from 0-5 were used to assess the learning potential, topic difficulty, question difficulty, and length of this learning tool.

A pre-test and post-test were created to assess the efficacy of the learning tool. The pre-test asked users for their level of training, experience with THAs, and if they had any formal training on C-arm language/communication. The pre-test and post-test contained 31 scored questions which were worth a total of 38 points. These were the same questions that were used in the learning tool but the order of the answer choices for each question were randomized. The data from these were collected via Google Forms and were exported into Microsoft Excel for data analysis. A paired T-test was used to calculate any significant difference between mean pre-test and post-test scores amongst all users. This statistical test was also used to calculate any significant difference between pre-test and post-test scores within each user’s level of training. This would help determine which levels of training the learning tool was best suited for. All statistical tests were calculated using ©GraphPad.com.
Results

A total of 20 users completed the pre-test, learning tool, and post-test. Eleven of these users were medical students ranging from first year medical students (MS1) to third year medical students (MS3) and the other nine users were orthopedic surgery residents ranging from post-graduate year 1 (PGY-1) to post-graduate year 5 (PGY-5). One C-arm technician completed the pre-test but did not complete the learning tool or post-test so their data was not included in the study. Only two users, a PGY-2 and PGY-5 resident, had received any type of formal training on C-arm language. Seven users had never seen a THA, four users had only observed a THA, four users had assisted with a THA, and five users had performed a THA.

There was a significant difference in pre-test (M=68.3%, SD=23.9%) and post-test scores (M=96.4%, SD=2.9%) amongst all users (t=5.5069, P<.0001). When comparing scores amongst users by training levels, there was a positive correlation between years in medical training and pre-test scores. MS1s scored the lowest on the pre-test (M=46.7%, SD=18.4%) while the PGY-5 resident scored the highest at 94.7%. When comparing the pre-test and post-test scores between these groups, there was a significant improvement in scores amongst MS1s (46.7% to 95.7%, P < .0001) and PGY-3s (92.1% to 96.5%, P = .0377). Statistical significance was not found amongst the groups with two users (MS3, PGY-1, PGY-4) and could not be calculated for the single user groups (MS2, PGY-5) (see Table 1). The questions with the lowest pre-test and post-test scores were asking users to estimate the anteversion or inclination of the acetabular component in degrees without any reference. All users had completed the post-test within 24 minutes of completing the learning tool.

<table>
<thead>
<tr>
<th>Level of training</th>
<th># of users</th>
<th>Mean Pre-test score</th>
<th>Pre-test SD</th>
<th>Mean Post-test score</th>
<th>Post-test SD</th>
<th>Paired t-test</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>8</td>
<td>46.7%</td>
<td>18.4%</td>
<td>95.7%</td>
<td>3.7%</td>
<td>&lt;.0001</td>
</tr>
<tr>
<td>MS2</td>
<td>1</td>
<td>50.0%</td>
<td></td>
<td>97.4%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS3</td>
<td>2</td>
<td>72.4%</td>
<td>16.7%</td>
<td>94.7%</td>
<td>3.7%</td>
<td>.2487</td>
</tr>
<tr>
<td>PGY-1</td>
<td>2</td>
<td>78.9%</td>
<td>11.2%</td>
<td>97.4%</td>
<td>0.0%</td>
<td>.2578</td>
</tr>
<tr>
<td>PGY-2</td>
<td>1</td>
<td>86.8%</td>
<td></td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PGY-3</td>
<td>3</td>
<td>92.1%</td>
<td>0.0%</td>
<td>96.5%</td>
<td>1.5%</td>
<td>.0377</td>
</tr>
<tr>
<td>PGY-4</td>
<td>2</td>
<td>90.8%</td>
<td>5.6%</td>
<td>96.1%</td>
<td>1.9%</td>
<td>.2952</td>
</tr>
<tr>
<td>PGY-5</td>
<td>1</td>
<td>94.7%</td>
<td></td>
<td>100.0%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>All users</td>
<td>20</td>
<td>68.3%</td>
<td>23.9%</td>
<td>96.4%</td>
<td>2.9%</td>
<td>&lt;.0001</td>
</tr>
</tbody>
</table>
In the feedback section of the learning tool, users chose an average of 4.50 on the Likert scale when asked “How much did you learn from this learning tool?” with 0 representing “nothing” and 5 representing “a lot”. Users chose an average of 2.20 on the Likert scale when asked “How difficult was it for you to understand the topics in this learning tool?” and 2.40 when asked “How difficult were the questions in this learning tool?” with 0 representing “not difficult at all” and 5 representing “extremely difficult”. Users chose an average of 3.45 on the Likert scale when asked “What do you think about the length of this learning tool?” with 0 representing “too short” and 5 representing “too long” (see table 2). When comparing this feedback with user training levels, the MS1s found that they learned the most with an average score of 4.75 while the PGY-5 resident learned the least with a score of 2. The rest of the feedback was relatively similar across training levels.

Users felt that the learning tool was most appropriate for senior medical students, junior orthopedic surgery residents, and C-arm technicians. 90% of users felt that the learning tool was best suited for PGY-1s and only 25% of users felt that it was appropriate for PGY-4s and PGY-5s (see Figure 6).

<table>
<thead>
<tr>
<th>Training</th>
<th>Learning potential: 0=none 5=a lot</th>
<th>Difficulty understanding topics 0=not difficult at all 5=extremely difficult</th>
<th>Difficulty with questions 0=not difficult at all 5=extremely difficult</th>
<th>Length of learning tool 0=too short 5=too long</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS1</td>
<td>4.75</td>
<td>2.75</td>
<td>2.75</td>
<td>3.375</td>
</tr>
<tr>
<td>MS2</td>
<td>5</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>MS3</td>
<td>4.5</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>PGY-1</td>
<td>5</td>
<td>1.5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>PGY-2</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>PGY-3</td>
<td>4</td>
<td>1.6666666667</td>
<td>1.333333333</td>
<td>3</td>
</tr>
<tr>
<td>PGY-4</td>
<td>5</td>
<td>2.5</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>PGY-5</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Mean</td>
<td>4.50</td>
<td>2.20</td>
<td>2.40</td>
<td>3.45</td>
</tr>
</tbody>
</table>

Table 2

Figure 6. A bar chart of the users’ opinions on who this learning tool would be best suited for.
Discussion

This learning tool proved to be an effective method of teaching medical students and orthopedic surgery residents about optimizing and interpreting radiographs during total hip arthroplasty. This learning tool was able to teach users how to obtain an optimal AP radiograph and how to optimally place total hip arthroplasty components under fluoroscopy. To the authors’ knowledge, this is the first educational tool which focuses on obtaining, optimizing, and interpreting radiographs during total hip arthroplasty.

Free online resources such as hipandkneebook.com have excellent information about component positioning and the radiographic markers of the pelvis during THA. Unlike this learning tool, however, it does not explain how one can obtain these optimal radiographs and component positions. This disconnection between identifying the problem (ie, a suboptimal radiograph) and educating readers on how to solve it (moving the C-arm or patient) is prevalent in published literature as well. This connection is likely engrained in the minds of most arthroplasty surgeons but, in the author’s experience, it is generally not well-established in orthopedic surgery residents. By having an intimate understanding of the 3D relationship between the C-arm, the patient’s anatomy, and the components, skilled surgeons can limit radiation exposure and operating time. Gaining this understanding can require years of training and several studies have shown that surgeons have longer fluoroscopic times when they first start performing anterior THAs. Communication between surgeons and C-arm technicians can be difficult when performing THAs. This is often seen when C-arm technicians are not familiar with the C-arm language that is being used by the surgeon. With numerous studies proposing different C-arm languages, this is not surprising. Rather than focusing on a particular C-arm language, this learning tool used a variety of different descriptors used in the proposed universal C-arm languages. The hope was that this would familiarize the users with the most common descriptors so they could easily operate with different surgeons and C-arm technicians.

The results of this study demonstrated that this learning tool was most effective in first year medical students and seemed to be effective in residents up to a PGY-3 level. At the authors’ institution, residents complete their arthroplasty rotation during PGY-3 which is likely why PGY-3 to PGY-5 residents had significantly higher pre-test scores than all other users. These results align with the user’s feedback that the learning tool was best suited for more senior medical students and junior orthopedic surgery residents. 80% of users felt that this tool would be suited for C-arm technicians in training, but there were no complete responses from C-arm technicians to validate this.

Overall, the feedback from this learning tool was positive. Most users noted that they learned a significant amount from the learning tool and that the topics and questions in the learning tool were mid-range in difficulty. Several users commented that the learning tool was too long, but the mean Likert score was 3.45/5 in this regard suggesting that most users were comfortable with the length of the learning tool.

There are several strengths to this study. The learning tool recorded the timestamps for completion of the pre-test, learning tool, and post-test and found that all users completed the post-test within 24 minutes of completing the learning tool. This reduces the chances of recall bias effecting the post-test scores. Another strength of this study is that the authors only utilized freely available software and 3D models to generate the learning tool making it easily reproducible. By generating a 3D model of a pelvis, the authors were able to avoid using radiographs from prior surgical cases or taking additional radiographs during future cases for the purposes of this project. The 3D model could generate any combination of pelvic obliquity, tilt, or component positions that would not likely be seen even in a large sample of surgical radiographs.

There are several limitations of this study as well. The authors were only able to recruit 9 orthopedic surgery residents with the remaining 11 users being medical students, mostly MS1s. The authors were also unable to recruit any MS4s or C-arm technicians to take part in this study. A larger sample size would have given us more feedback about how this learning tool can best be utilized and would have provided greater statistical power. Based on our data, a minimum of three users per academic level would be required to reach statistical significance when comparing pre-test and post-test scores. Another limitation of this study is that the real-world application of this learning tool was not tested. In an ideal study design, the authors would monitor the fluoroscopic times of residents before and after performing a THA and track their communication skills via surveys. There were some difficulties when making the learning tool via Google Forms™. As the length of the learning tool increased, the software became progressively slower which made it difficult to edit. Additionally, this software can be cumbersome when generating pathways for specific answer choices, so the authors elected to only create pathways for correct answer choices.

The use of this freely available, interactive, online learning tool improves the understanding of THA radiography and component positioning for users in a variety of stages of medical training. With the data and feedback obtained from this study, the authors plan to improve the learning tool and create a higher quality experience for users. The authors would like to collaborate with other institutions to test the next iteration of this learning tool and broaden its use in medical education. As online learning becomes more prevalent, especially since the COVID-19 pandemic, the authors hope that new, more interactive learning tools such as this one can be incorporated into many aspects of medical education, especially orthopedics. Procedures like
pelvic fixation, femoral neck fixation, and intramedullary fixation could benefit from an interactive learning tool similar to the one created for this study. The authors hope that learning tools such as this one can be implemented on a widespread basis to ultimately improve the surgeon’s understanding of radiographs during a THA and hopefully improve patient outcomes.

**Conflict of Interest**

None of the authors identify a conflict of interest.

**References**


**Appendix**

To access the learning tools, use the following links:

**Pre-test**

For actual completion: https://forms.gle/2kcsSMab56rcCdRN7
For prefilled pre-test: https://docs.google.com/forms/d/1X_Cjigg7S9DjAExSEREUrUaZ3z6w2ZwC4UZB0Hxq/xix/prefill

**Learning tool**

For actual completion: https://forms.gle/1JNjMYSjLyLVG1v9A
For prefilled learning tool: https://docs.google.com/forms/d/115dPQXBtUEQbnHj-vX_xw8BrD3yRBR9SN2Z3tz7E-Y/prefill

**Post-test**

For actual completion: https://forms.gle/aVVxjydMmCaWnwx47
For prefilled post-test: https://docs.google.com/forms/d/15sdPQXBtUEQbnHj-vX_xw8BrD3yRBR9SN2Z3tz7E-Y/prefill

To access the learning tools, use the following links:

For prefilled pre-test: https://docs.google.com/forms/d/1X_Cjigg7S9DjAExSEREUrUaZ3z6w2ZwC4UZB0Hxq/prefill
For prefilled learn tool: https://docs.google.com/forms/d/1JJ5zjmiSfAldAHJjwHQ89WVY/6fEoUeB6Q9eG3Q/prefill

For actual completion: https://docs.google.com/forms/d/15sdPQXBtUEQbnHj-vX_xw8BrD3yRBR9SN2Z3tz7E-Y/prefill

For actual completion: https://forms.gle/2kcsSMab56rcCdRN7
For prefilled pre-test: https://docs.google.com/forms/d/1X_Cjigg7S9DjAExSEREUrUaZ3z6w2ZwC4UZB0Hxq/xix/prefill

**Pre-test**

For actual completion: https://forms.gle/2kcsSMab56rcCdRN7
For prefilled pre-test: https://docs.google.com/forms/d/1X_Cjigg7S9DjAExSEREUrUaZ3z6w2ZwC4UZB0Hxq/xix/prefill

**Learning tool**

For actual completion: https://forms.gle/1JNjMYSjLyLVG1v9A
For prefilled learning tool: https://docs.google.com/forms/d/115dPQXBtUEQbnHj-vX_xw8BrD3yRBR9SN2Z3tz7E-Y/prefill

**Post-test**

For actual completion: https://forms.gle/aVVxjydMmCaWnwx47
For prefilled post-test: https://docs.google.com/forms/d/15sdPQXBtUEQbnHj-vX_xw8BrD3yRBR9SN2Z3tz7E-Y/prefill

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The HJH&SW encourages authors to use the appropriate diacritical markings (the ‘okina and the kahakō) for all Hawaiian words. We recommend verifying words with the Hawaiian Language Dictionary (http://www.wehewehe.org/) or with the University of Hawai‘i Hawaiian Language Online (http://www.hawaii.edu/site/info/diacritics.php).

Authors should also note that Hawaiian refers to people of Native Hawaiian descent. People who live in Hawai‘i are referred to as Hawai‘i residents.

Hawaiian words that are not proper nouns (such as keiki and kūpuna) should be written in italics throughout the manuscript, and a definition should be provided in parentheses the first time the word is used in the manuscript.

Examples of Hawaiian words that may appear in the HJH&SW:
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2. Supplements should treat broad topics in an impartial and unbiased manner. They must have educational value, be useful to HJH&SW readership, and contain data not previously published elsewhere.

3. Supplements must have a sponsor who will act as the guest editor of the supplement. The sponsor will be responsible for every step of the publication process including development of the theme/concept, peer review, editing, preliminary copy editing (ie, proof reading and first round of copy editing), and marketing of the publication. HJH&SW staff will only be involved in layout, final copy editing and reviewing final proofs. It is important that the sponsor is aware of all steps to publication. The sponsor will:
   a. Be the point of contact with HJH&SW for all issues pertaining to the supplement.
   b. Solicit and curate articles for the supplement.
   c. Establish and oversee a peer review process that ensures the accuracy and validity of the articles.
   d. Ensure that all articles adhere to the guidelines set forth in journal’s Instructions to Authors page, especially the instructions for manuscript preparation and the statistical guidelines.
   e. Obtain a signed Copyright Transfer Agreement for each article from all authors.
   f. Comply with all federal, state, and local laws, rules, and regulations that may be applicable in connection with the publication, including ensuring that no protected health information appears in any article.
   g. Work with the editorial staff to create and adhere to a timeline for the publication of the supplement.
   h. Communicate any issues or desired changes to the HJH&SW staff in a timely manner.

4. Upon commissioning a supplement, the sponsor will be asked to establish a timeline for the issue which the sponsor and the HJH&SW editor(s) will sign. The following activities will be agreed upon with journal publication to take place no later than 24 months after signing. Extensions past the 24 months will be subject to additional fees based on journal publication rates at that time:
   • Final date to submit a list of all articles, with working titles and authors
   • Final date for submitting Word documents for copy editing
   • Final date for submitting Word documents for layout
   • Final date to request changes to page proofs (Please note that changes to page proofs will be made only to fix any errors that were introduced during layout. Other editing changes will incur an additional fee of $50 per page.)

5. The cost of publication of a HJH&SW supplement is $5,000 for an 8-article edition with an introduction from the sponsor or guest editor. Additional articles can be purchased for $500 each with a maximum of 12 articles per supplement. This cost covers one round of copy editing (up to 8 hours), layout, online publication with an accompanying press release, provision of electronic files, and indexing in PubMed Central, SCOPUS, and Embase. The layout editor will email an invoice for 50% of the supplement to the designated editor for payment upon signature of the contract. The remaining will be due at the time of publication. Checks may be made out to UCERA.

6. The sponsor may decide to include advertisements in the supplement in order to defray costs. Please consult with the HJH&SW advertising representative Michael Roth at 808-595-4124 or email rothcomm@gmail.com for assistance.
7. Supplement issues are posted on the HJH&SW website (http://www.hawaiijournalhealth.org) as a full-text PDF (both of the whole supplement as well as each article). An announcement of its availability will be made via a press release and through the HJH&SW email distribution list. Full-text versions of the articles will also be available on PubMed Central.

8. It is the responsibility of the sponsor to manage all editorial, marketing, sales, and distribution functions. If you need assistance, please contact the journal production editor. We may be able to help for an additional fee.

9. The editorial board reserves the right of final review and approval of all supplement contents. The HJH&SW will maintain the copyright of all journal contents.

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1. The sponsor contacts the HJH&SW editors (hjhsw@hawaii.edu) to discuss the supplement topic, estimated timeline, length and cost. HJH&SW staff will review the journal requirements for articles and share our review process with the sponsor. **Time frame: 2 weeks**

2. The sponsor will complete the draft contract and pay a non-refundable deposit of $2500 or half the contract value. **Time frame: 3 days**

3. The sponsor will solicit articles for the supplement. **Time frame: 3-6 months**

   Articles must comply with:
   - Instructions for Manuscript Preparation and Submission of Research Articles
   - Instructions for Manuscript Preparation and Submission of Columns
   - HJH&SW Statistical Guidelines
   - HJH&SW Style Guide for Native Hawaiian Words and Phrases
   - AMA Manual of Style. A free summary can be found here.

4. The sponsor will oversee the article selection, peer review, and editing process. We recommend that time be allowed for at least two rounds of reviews for each article. **Time frame: 3-6 months**

   - Ensure that each article includes Institutional Review Board (IRB) review and approval, and a statement disclosing any conflicts of interest.
   - Obtain a Copyright Transfer Agreement signed by all authors for each article.

5. **Optional**: During this time, the sponsor can solicit advertisements for the supplement to help defray costs for publication and/or printing. To initiate this process, the sponsor will work the HJH&SW advertising representative Michael Roth at 808-595-4124 or roth-comm@gmail.com.

6. The sponsor or their designee will conduct a final review of each article to ensure adherence to HJH&SW guidelines and AMA style. **Time frame: 2 weeks**

7. For each article, the sponsor will submit the final Word document and Copyright Transfer Agreement to the HJH&SW journal production editor. The journal production editor will send the articles to the copy editor for final journal style review. Copyediting will be 8 hours per edition plus 1 hour per article for additional articles purchased. Any additional hours will be billed at $100 per hour. **Time frame: 2 weeks**

8. The sponsor will submit the final articles to the layout editor for formatting. **Time frame: 1 month**

   Acting in the role of guest editor, the sponsor will include a column introducing the supplement. **IMPORTANT**: All articles submitted for layout should be in their finalized form. Page proofs will be returned to the sponsor for their review and approval, but changes will only be made to fix any errors that were introduced during the layout process. Any editing or changes to the text or figures after the initial copy layout will incur a fee of $50 per page.

9. The sponsor will review the electronic copy from the layout editor and submit any final corrections. **Time frame: 5 working days**

10. The layout editor will make the final corrections and provide a finished electronic copy of the supplement to the sponsoring editors to allow time for printing.

11. The managing editor will work with the sponsor to draft a press release. Sponsors should contact the managing editor at least 30 days prior to the date of publication to plan and script the press release. Sponsors are encouraged to submit 1-2 photos to accompany the press release. Note that obtaining signed photo releases is the responsibility of the sponsor.

12. The supplement will be published online along with the press release. An electronic copy will be sent to our subscribers and circulation lists, and the edition will be forwarded to the National Library of Medicine for indexing and made available for no cost access to the public.

Revised 2/6/20
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In 1941, a journal then called The Hawai‘i Medical Journal was founded by the Hawai‘i Medical Association (HMA). The HMA had been incorporated in 1856 under the Hawaiian monarchy. In 2008, a separate journal called the Hawai‘i Journal of Public Health was established by a collaborative effort between the Hawai‘i State Department of Health and the University of Hawai‘i at Mānoa Office of Public Health Studies. In 2012, these two journals merged to form the Hawai‘i Journal of Medicine & Public Health, and this journal continued to be supported by the Hawai‘i State Department of Health and the John A. Burns School of Medicine.

In 2018, the number of partners providing financial backing for the journal expanded, and to reflect this expansion the name of the journal was changed in 2019 to the Hawai‘i Journal of Health & Social Welfare. The lead academic partners are now the six units of the UH College of Health Sciences and Social Welfare, including the John A. Burns School of Medicine, UH Public Health, the Thompson School of Social Work & Public Health, the Nancy Atmospera-Walch School of Nursing, the UH Cancer Center, and the Daniel K. Inouye College of Pharmacy. Other partners are the Hawai‘i State Department of Health and the UH Office of the Vice Chancellor for Research. The journal is fiscally managed by University Health Partners of Hawai‘i.

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The aim of the Hawai‘i Journal Watch is to highlight recent research of the entities that financially support the HJH&SW. The research articles that are covered in the Hawai‘i Journal Watch are selected by both the HJH&SW and by researchers in the units that support the HJH&SW. The researchers whose articles are covered in the Hawai‘i Journal Watch are given the opportunity to fact check the news brief.

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