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Aim:
The aim of the Hawai‘i Journal of Health & Social Welfare is to advance knowledge about health and social welfare, with a focus on the diverse peoples and unique environments of Hawai‘i and the Pacific region.

History:
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 units of the UH College of Health Sciences and Social Welfare, including the John A. Burns School of Medicine, Thompson School of Social Work & Public Health, the School of Nursing and Dental Hygiene, the UH Cancer Center, and the Daniel K. Inouye College of Pharmacy. Another partner is the Hawai‘i State Department of Health. The journal is fiscally managed by University Health Partners of Hawai‘i.

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Lee L. Guest Editor's Message: Bridging Innovation, Technique, and Outcomes in Modern Orthopaedics. *Hawaii J Health Soc Welf*. 2026;85(6):131. doi: 10.62547/SGRO2478

Guest Editor's Message: Bridging Innovation, Technique, and Outcomes in Modern Orthopaedics

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I extend a warm welcome to all readers of the Hawai‘i Journal of Health and Social Welfare. This supplemental issue features research and review articles authored by faculty and residents from the University of Hawai‘i Division of Orthopaedic Surgery, in collaboration with our colleagues from the Stanford University Department of Orthopaedic Surgery.

This supplement highlights a diverse range of contemporary orthopaedic topics, including innovative imaging and three-dimensional modeling techniques, biomechanical and wound management research, and the evaluation of surgical risk in arthroplasty and trauma. It also features unique case reports addressing rare pathologies and complex fracture management in a rare population, thus underscoring the breadth and evolving nature of modern orthopaedic practice.

Special thanks go out to our authors and reviewers who contributed to this supplemental issue. In addition, personal thanks to our current research resident, Julian Rimm, and prior research residents, Wade Banta and Kenneth Kato, for their tireless work to get this issue completed. Lastly, thank you to Ms. Jamie Castelo for her help and support on behalf of our residency program. So, broaden your exposure to orthopedics and enjoy this issue.

Aloha,

Lorrin Lee

Hasegawa ME, Rimm JB, Ishikawa KM, et al. Common grappling submissions: A descriptive, illustrative and literature review of anatomic structures at risk and pathophysiology. *Hawaii J Health Soc Welf*. 2026;85(6):132-141. doi:10.62547/RNVF9981

Common grappling submissions: A descriptive, illustrative and literature review of anatomic structures at risk and pathophysiology

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Keywords: Martial arts, Brazilian Jiu Jitsu, Mixed Martial Arts, Submissions, Grappling Injuries

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Abstract

Grappling disciplines have immensely grown in popularity. These martial arts and sports, such as Judo, Brazilian Jiu Jitsu, Sambo, and Mixed Martial Arts, utilize techniques and movements to maintain control, subdue, or submit an opponent. Grappling submissions introduce risk of injury through a variety of specific moves, positions, and mechanisms. Yet grappling disciplines remain relatively niche, shrouded with confusing, non-descriptive terminology and jargon. This often results in a poor understanding of injury mechanisms, anatomic regions injured, and pathophysiologic cause of injury. The lack of basic anatomic and physiologic understanding is a potential barrier to optimal care and future research endeavors by clinicians in a burgeoning patient population. As such, this study aims to provide a concise guide to common grappling submissions, with illustrative examples and pathophysiologic mechanisms, description of anatomic structures at risk, and a literature review of injuries, with intention of improving care, and facilitating future investigative efforts by clinicians.

Abbreviations

ACL = anterior cruciate ligament
ATFL = anterior talofibular ligament
CFL = calcaneofibular ligament
IGHL = inferior glenohumeral ligament
LCL = lateral collateral ligament
MCL = medical collateral ligament
PCL = posterior cruciate ligament
POL = posterior oblique ligament

Introduction

Grappling based martial arts and sports, such as Judo, Brazilian Jiu Jitsu, Sambo, and Mixed Martial Arts, utilize techniques and movements to maintain control, position or submissions over an opponent.[1,2] Submission techniques, in particular, pose inherent risk of injury to participants, yet, this population remains understudied.[3-7] Currently, information regarding submission mechanisms and anatomic structures at risk lacks a consolidated form in the literature.[5] As such, the impetus for this study was to formulate a consolidated source of illustrative and descriptive review of common grappling submissions, anatomic structures at risk, and literature review of injury risk with intention of improving the understanding of grappling related injuries among health care professionals.

Submission types

Submissions discussed in this article will include: (1) Chokes/neck cranks, and (2) Joint locks.

The term "chokes" refers to maneuver that mechanistically achieve submission via strangulation of the neck. Strangulation leads to submission via decreasing cerebral blood flow and/or inflicting pain to the neck region. Although the term choke is a mis-representation, this is the colloquially accepted term and will be used to describe these types of submissions in this study. Joint locks apply force at a joint leading to supraphysiologic range of motion. The joint motion past normal physiologic constraints, typically confers immense pain, injury, or loss of function resulting in submission.

The following submissions will include technique descriptions, anatomic structures at risk and a review of current literature pertaining to each submission. This review will predominantly highlight the musculoskeletal structures at risk, but will include additional structures when pertinent. Illustrative and photographic examples of submissions will be shown using a combination of *gi* (the heavy fabric uniform used in traditional Sambo, Judo, or Brazilian Jiu Jitsu) and non-*gi* photographs and illustrations.

Chokes and Neck Cranks

Rear naked choke/Lapel chokes/Neck crank/ Guillotine

A rear naked choke is accomplished when an attacking player is able to mount their opponent's back, and compress both sides of the opponent's neck. This is often achieved with a *Mata Leào* grip, meaning "Lion killer" in Portuguese. This grip involves an attacking athlete placing one arm around the neck of their opponent, grasping their

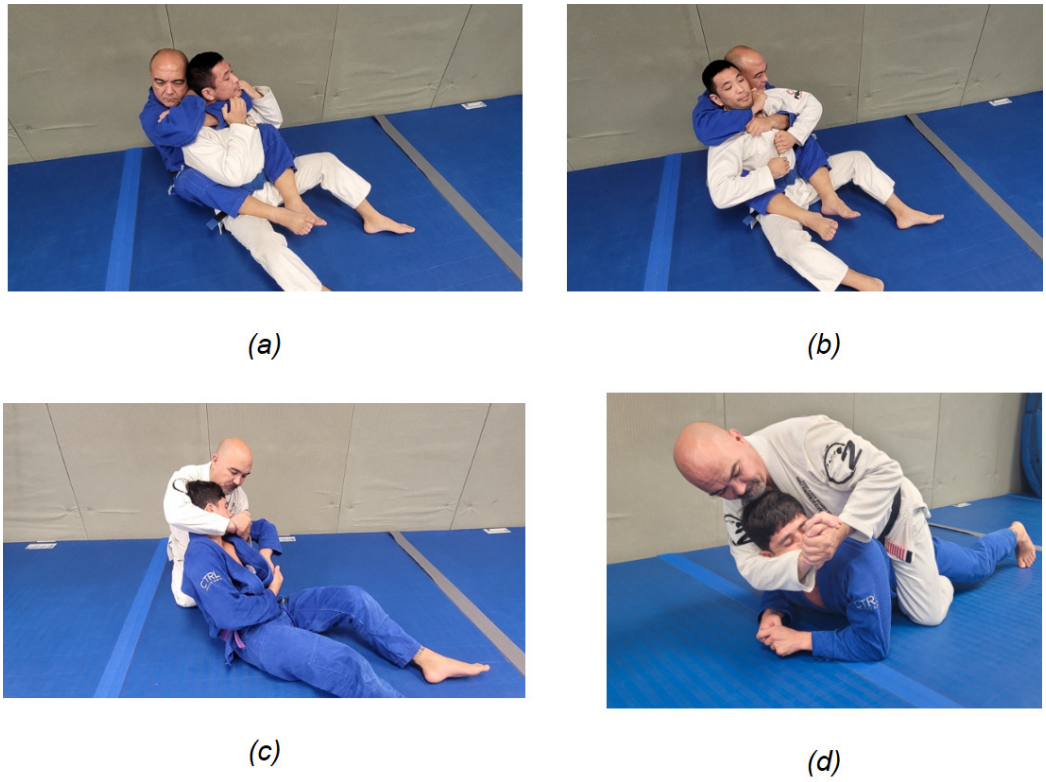

Figure 1. Variations of chokes and neck cranks a) Mata Leào grip b) Lapel choke variation c) Neck crank from back mount variation d) Neck crank from alternate back mounted position

contralateral bicep as its placed behind the opponent's head (**Figure 1a**). Similarly, lapel chokes accomplish compression through utilizing a *gi's* lapel, with a number of variations in grips, to compress an opponent's neck. An example can be seen in **Figure 1b**.

Neck cranks, as opposed to chokes, or strangles, achieve a submission due to pain. It most commonly involves applying a compressing or restricting force with their forearms or wrist against an opponent's neck (**Figure 1c and 1d**). The direction of this force is commonly oblique, creating a twisting or torsional force at the neck and jaw. This results in supraphysiologic motion, and compression, at the jaw or cervical spine eliciting immense pain.

A guillotine submission is accomplished with an attacking athlete wrapping one arm around an opponent's neck, while using the other arm to apply an inferior to superior and anterior to posterior directed compressive forces across the neck (**Figure 2a**). The position of the attacking player can differ, but the mechanisms of eliciting a submission remains the same regardless of position (**Figure 2b**).

Anatomic structures at risk and literature review

Most notably, in a choke hold or neck crack, the neck musculature is exposed to injury. In particular, the sternocleidomastoid will be at risk due to direct compression as well as eccentric or concentric contractional injury as an attacked athlete attempts to alleviate contact pressure. Other prominent muscles also at risk include the trapezius muscle, scalenes, levator scapulae, longissimus capitis, semispinalis capitis, and splenius capitis. Moreover, the trachea, thyroid cartilage, and accompanying ligaments, may be at risk. In addition, the cervical spine may be at risk of fracture, dislocations, sprains. The jaw may also be placed at risk of injury if the attacker's arm position is proximally placed over the jaw rather than the neck. This may expose the zygomatic arch, teeth and mandible, in particular the temporomandibular joint, at risk of injury.

Other structures at risk include carotid arteries, jugular veins, and various nerves. These structures are at risk for injury due to direct compression, traction injuries, or torsional forces resulting in artery dissections, vein injury, or neuropraxias. The incidence and prevalence of vascular injuries resulting from chokes is sparse in the literature, though there are case reports and case series reported.[8] Minor injuries include skin abrasions or lacerations which can occur from the forceful abrasion of the *gi* lapel utilized in the choking mechanism.

Most commonly, injuries involving rear naked chokes, lapel chokes, neck cranks, or guillotines involve muscular strains or minor cervical sprains, and loss of consciousness; however, vascular injuries, such as carotid and vertebral artery dissections, stenosis and ischemic stroke, have been reported.[8-10] Prior literature has suggested the carotid artery may be predisposed to risk from these submissions due to tethering of the vessel with free neck mobility, or a combination of direct compression and hyperextension of the neck.[9] Additionally, some biomechanical studies have suggested the force applied during these chokes may be equivalent to those experiences in a car accident, and as such, suggest participants must exercise control and cau-

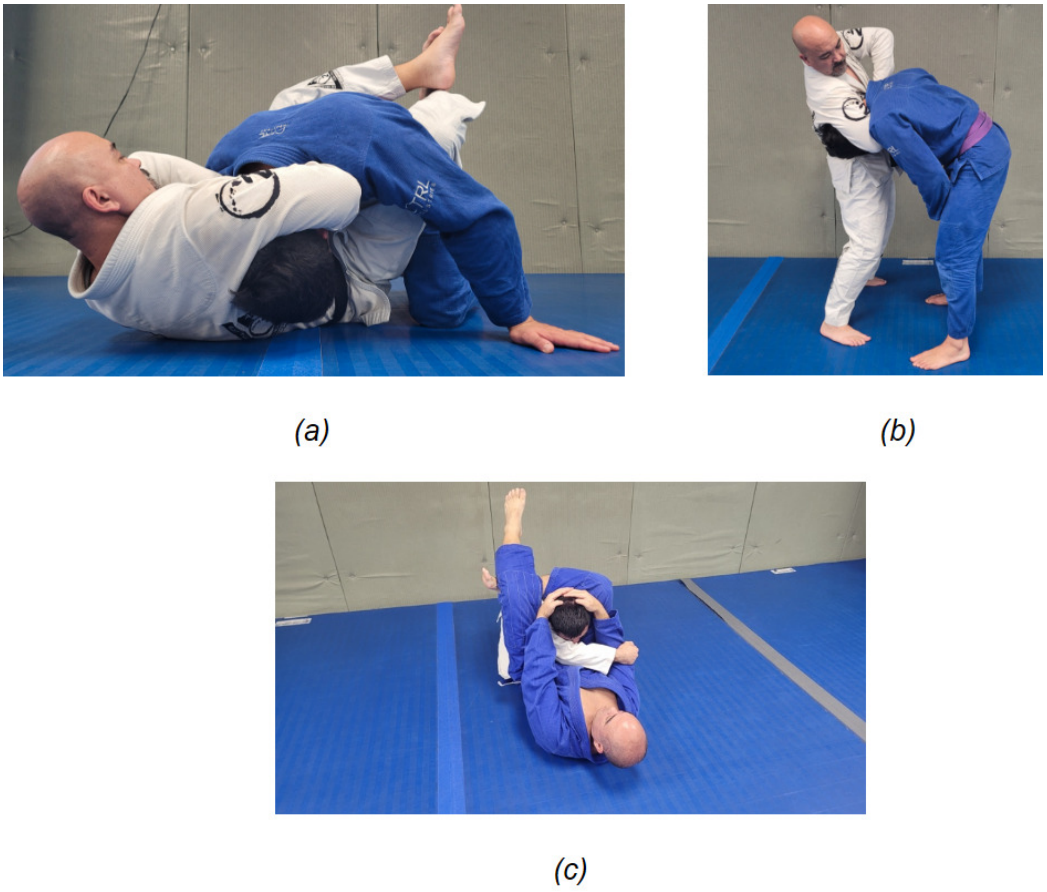

Figure 2. a) Guillotine submission from closed guard position b) Standing guillotine c) Triangle submission

tion when applying these techniques, or should submit early if caught in one.[11,12]

Triangle chokes

Triangle chokes, can be accomplished when either an attacker's legs or arms compress an attacked opponent's arm, in an adducted position, against their neck. Compression is then applied by the attacking athlete (**Figure 2c**). Again, the positions of the athletes can vary, but the mechanism of compressing vascular structures in the opponent's neck against their own arm remains the same.

Anatomic structures at risk and literature review

Much like rear naked chokes, neck cranks, or lapel chokes, the musculature of the neck is at risk of injury during triangle chokes. Additionally, because the submission involves a participant's arm, shoulder joints, tendons, ligaments, and muscles are also at risk. These may include glenohumeral and acromioclavicular joints, with accompanying ligamentous structures at those joints. The deltoid, latissimus, rotator cuff, and serratus may also be at risk of injury. Similarly to rear naked chokes, neck cranks and lapel chokes, an attacked player's neck may be rotated or in hyperextension, placing cervical vertebral articulations at risk of injury. In addition, the attacking opponent may sustain quadriceps, hamstrings, gastrocnemius, or knee ligamentous injury if using their lower extremities to accomplish the submission or the opponent attempts to escape. Neurovascular structures as mentioned in the prior choke section are also at risk of injury, as they may be subjected to similar traction, torsion or compression imparted during the triangle choke.

The triangle submission has been implicated as inciting injury in several studies. Hinz et al noted the triangle submission to be the most prevalent submission technique involving lower extremity injury to an attacking athlete.[13] Scoggin et al described one case of a cervical strain as a result of triangle choke.[5]

Joint locks

Arm bar

An arm bar is a type of joint lock that is accomplished with an attacking athlete maintaining isometric position of the shoulder and forearm with concomitant hyperextension of the elbow. Frequently, an attacker will place both legs over the shoulder, and extend their hips to hyperextend an opponent's elbow, maximizing the length of mechanical lever with distal extremity control (**Figure 3a and 3b**). Variations can occur with regards to position of attacking opponent, leg position, or foot position. However, all variations allow attacking participants to gain control of the shoulder and forearm to apply a force perpendicular to the elbow joint causing hyperextension.

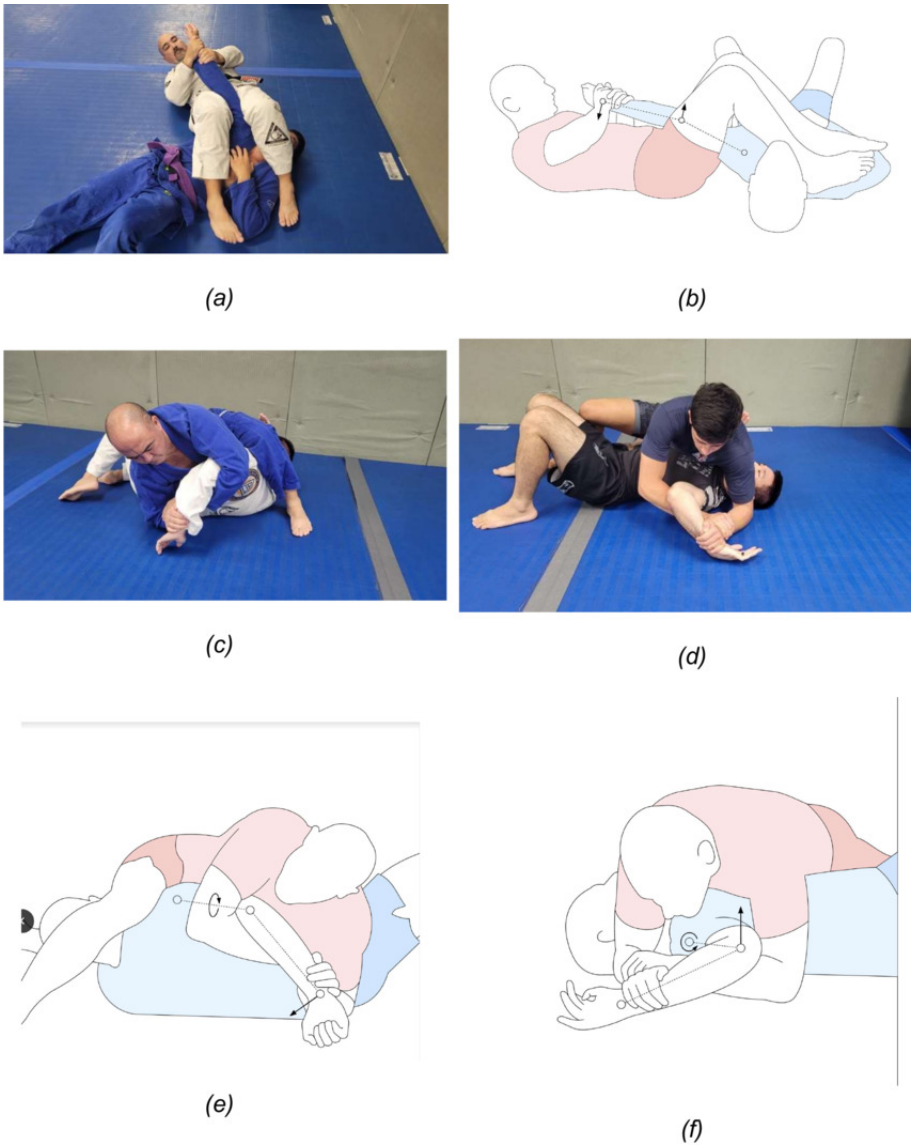

Figure 3. Upper extremity joint locks a) Arm bar submission b) Illustrative example of arm bar submission c) Americana submission d) Kimura submission e) Illustrative example of rotational forces during Americana f) Illustrative example of rotational forces during Kimura. Illustrations created with use of Inkscape. Inkscape Software, version 1.3 (Inkscape Project, Boston, MA).

Anatomic structures at risk and literature review

The elbow joint's osseous, ligamentous, tendinous structures are most at risk. In particularly, the olecranon and olecranon fossa may sustain injury due to elbow hyperextension. Medial and lateral collateral ligament complexes of the elbow are also at risk, dependent on position of the arm. If the forearm is supinated during the attack, the common flexor tendons are at risk, while if the forearm is pronated the origin of the extensor tendons are at risk of injury. The defender will often flex their biceps to combat hyperextension of the elbow, resulting in immense eccentric force at the bicep's distal insertion and possible injury. In addition, there may be anterior subluxation of the shoulder joint once maximal elbow extension is reached, stressing the anterior shoulder capsule, anterior labrum, or potentiating osseous injuries such as a bony Bankart or Hill-Sachs lesions. Also, the combined rotational force from defensive players trying to escape can lead to fracture.

Arm bars have been implicated as a common submissions causing injury.[14-16] Current literature suggests a higher risk of injury to the olecranon and medial structures of the elbow, though injury to lateral and anterior structures are possible.[5,17] Scoggin et al found the elbow was the most commonly injured joint in Brazilian Jiu Jitsu competitions, with arm bar submission being the most common mechanism. The authors also suggested external rotation of the attacked opponent's arm during an arm bar attempt, which imposes a valgus moment on the elbow, may increase risk to the ulnar collateral ligament.[5] These authors also reported distal biceps rupture and LCL injury from arm bars.[5] A study by de Almeida et al reported magnetic resonance imaging of 5 grappling athletes whom all had total or partial rupture of the common flexor tendon and total rupture of the ulnar collateral ligament after arm bar related in-

juries.[17] The current literature indicates most injuries after arm bar are sustained on the medial elbow, but that thorough workup is warranted for concomitant injuries.

Kimura/Americana

Kimuras and Americanas are arm locks involving hyper-internal rotation or hyper-external rotation, respectively, at the shoulder. A Kimura submission, named after legendary Japanese Judoka Masahiko Kimura, involves manipulating the arm in 90 degrees of shoulder abduction, and 90 degrees of elbow flexion, to force glenohumeral hyper-internal rotation (**Figure 3c**). Similarly, an Americana forces glenohumeral hyper-external rotation (**Figure 3d**). As with other submissions, the position of the attacking and attacked opponent may vary, but all require the shoulder in 90 degrees of abduction and 90 degrees of elbow flexion to facilitate either hyper-internal or hyper-external rotation at the shoulder (**Figure 3e and 3f**).

Anatomic structures at risk and literature review

The most immediate structures at risk of injury in these submissions are within the shoulder. For the Kimura, the posterior band of the inferior glenohumeral ligament (IGHL) may be stretched during internal rotation, as well as external shoulder rotators such as supraspinatus, infraspinatus, and teres minor. Additionally, the posterior shoulder capsule may be stretched with increasing internal rotation, while also increasing risk of impinging anterior structures such as the labrum. There also is a theoretical risk of anteromedial humeral head fracture, as the humeral head internally rotates. Whereas in an Americana submission, shoulder injury constellations may mimic that of traumatic anterior shoulder dislocation, as arm abducts and externally rotated. Glenoid labral articular defects due to shearing are also a possible, as are bony Bankart or Hill-Sachs lesions, especially there is a resultant anterior shoulder dislocation. Internal rotators of the humeral head, such as the subscapularis, pectoralis major, anterior portion of the deltoid, and latissimus dorsi, are at risk for injury are placed on stretch during hyper-external rotation. Distal elbow injuries may also occur for both submissions, via manipulation of the elbow. In particular, an Americana places the elbow in similar position as the late-cocking position seen in baseball pitchers, imparting strain on the ulnar collateral ligament of the elbow, and medial elbow structures. The axillary nerve and artery may be at risk with these submissions, particularly if there is a concurrent shoulder dislocation.

There have been several reports concerning injury associated with Kimura submissions. Scoggin et al reported an elbow ulnar collateral ligament injury and acromioclavicular joint injuries attributed to Kimura submissions.[5] Hinz et al found the Kimura was the second most likely submission to be associated with injury, though injuries sustained were not specified.[13] In addition, several authors involved with this study have anecdotally treated patients who sustained humeral shaft spiral fractures as a result of Kimura submissions. To the authors' knowledge, no literature has reported on injuries related to Americana submissions though this is likely due to underreporting, rather than a diminished injury risk.

Knee Bar

A knee bar is a lower extremity joint lock which places the knee in hyperextension. An attacker will extend their hips with a force vector perpendicular to the knee joint, in an anterior to posterior direction, resulting in supraphysiologic knee extension (**Figure 4a**).

Anatomic structures at risk and literature review

Hyperextension of the knee may involve supraphysiologic tension of hamstrings or gastrocnemius. Prior cadaveric studies have examined isolated knee hyperextension and found evidence of injury to the lateral collateral ligament (LCL), popliteus tendon, and popliteofibular ligament, anterior cruciate (ACL) and posterior cruciate ligaments (PCL).[18-20] Though, it is important to understand grappling submissions do not occur with passive motions as done in cadaveric studies. An *in vivo* knee bar will have additional valgus, varus, or torsional forces being applied. A varus directed force may affect lateral structures, such as LCL, lateral meniscus, anterolateral complex of the knee, posterolateral corner, and fabellofibular ligament. If a valgus moment is induced, then medial structures such as the medial collateral ligament (MCL), medial meniscus and its posterior horn, hamstring insertion, posterior oblique ligament (POL), and oblique popliteal ligament are at risk. Likewise posteromedial or posterolateral capsular attachments may also be at risk of injury with hyperextension of the knee. Lastly, there is a theoretical risk for knee dislocation if enough force is applied to the knee during the submission, but this would likely require previous knee injury or ligamentous instability given the multiple static and dynamic stabilizers to the knee. Neurovascular structures such as the popliteal artery, tibial nerve, and common peroneal nerve are at risk of injury, particularly if there is subluxation or dislocation of the knee.

For many grappling academies and grappling organizations, knee bars have been discouraged, banned, or reserved for advanced practitioners. This stems from grapplers' anecdotal understanding of possibly devastating injuries. Even so, the available literature on knee bars is lacking.[21] One case report described an intraarticular patellar dislocation after a knee bar, however the literature denotes this as an exceedingly rare injury.[22] A recent study suggested structures, in descending order of providing resistance to hyperextension, were posteromedial capsule, posterior oblique ligament, posterolateral ligament, fabellofibular ligament, and cruciate ligaments.[23.] MCL and oblique popliteal ligament provided resistance as well, with the same authors noting over 50% of resistance of hyperextension to the posterior capsular structures, whereas approximately 25% was provided by cruciate ligaments.[23] As such, these structures should be evaluated when caring for athletes after knee bar injuries. Additionally, health care professionals should understand when evaluating knee bar

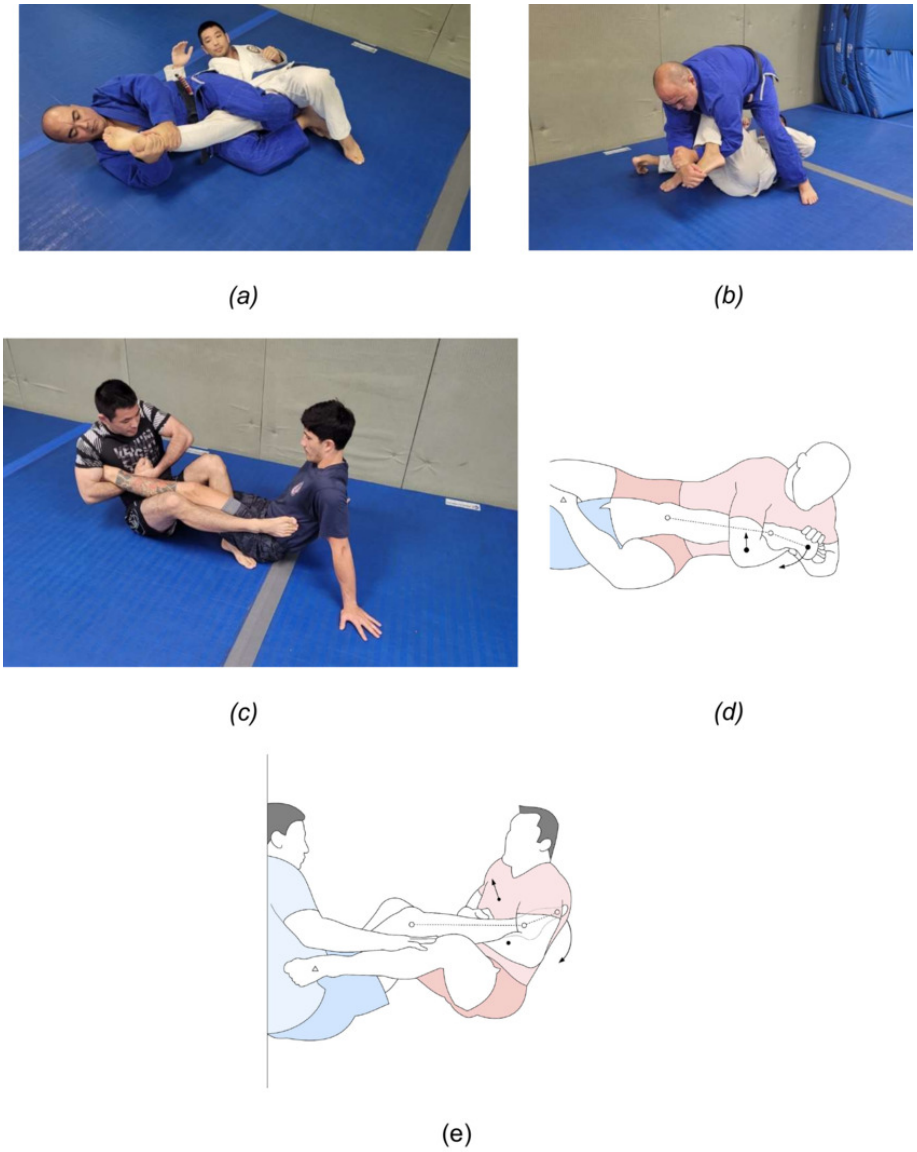

Figure 4. Lower extremity joint locks a) Knee bar submission b) Toe Hold submission c) Straight ankle lock submission d) Illustrative example of force vectors during toe hold submission e) Illustrative example of force vectors during straight ankle lock submission. Illustrations created with use of Inkscape.

related injuries, there is polyaxially motion and force being applied to the extremity. This requires a thorough examination of structures potentially effected by varus, valgus, or torsional forces at time of submission.

Toe hold/Straight ankle lock

A toe hold submission is executed when an attacking opponent is able to plantar flex the tibiotalar joint while inverting and supinating the foot (**Figure 4b**). This is accomplished by creating a fulcrum across the Achilles tendon or medial ankle (**Figure 4d**). Concurrently, a toe hold may result in maximal internal rotation at the knee after maximal arc of foot motion is achieved.

A straight ankle lock is applied when a fulcrum on the Achilles tendon is created, forcing the tibiotalar joint into maximal plantar flexion via a posterior to anteriorly directed force (**Figure 4c and 4e**).

Anatomic structures at risk and literature review

The final position of a toe hold is similar in position as to common ankle sprains. As such, the Anterior Talofibular ligament (ATFL) and Calcaneofibular ligament (CFL) may be at risk of injury, which are also at risk with straight ankle locks. Additionally, there is a theoretical injury risk to the peroneal tendons, in particular the peroneal brevis, as a result of compression of the peroneal brevis within the fibular groove.[24] Risk of osseous injury also exists, particularly with shearing or compressive force with talar motion across the tibiotalar and subtalar joints. Specific to straight ankle lock, recent literature has suggested the tibionavicular ligament and tibiospring ligament, components of the superficial deltoid, begin to tense at 10 degrees and 15 degrees of plantar flexion, increasing in tension as plantar flexion increased.[25] Likewise, the extensor digitorum longus, tibialis anterior, and extensor hallucis longus are at risk of in-

jury as they will be stretched during maximal plantar flexion. The anterior portion of the ankle joint capsule will also be placed on tension during this submission and may be an added source of injury. The Achilles tendon may also be at risk of contusion or compressive injury due to its use as the submissions' fulcrum.

Toe holds and straight ankle locks have been implicated as a major cause of ligamentous ankle injury.[13] Because the main structures at risk are the ATFL and CFL, patients sustaining repetitive lateral ankle injury due to toe holds or straight ankle locks may present with mechanical symptoms and physical examinations suggestive of lateral ankle instability, peroneal tendon instability or complaints of chronic ankle pain, similar to athletes in other sports susceptible to chronic ankle sprains. Likewise, minor injuries such as Achilles contusions have also been reported.[13,26] The dearth of literature implicating straight ankle locks and toe holds is likely due to underreporting rather than a benign risk of injury.

Heel Hook

A heel hook is accomplished by forcing maximum internal or external rotation at the knee joint. This is done by limiting motion at the hip and most commonly manipulating the calcaneal tuberosity to force maximal rotatory motion at the knee. There are 2 heel hook variations, with name designation determined by position of an attacked athlete's leg. If an attacked athlete's knee position is relatively medial to the tibia, fibula and foot-ankle complex, this allows for an "outside" heel hook (**Figure 5a**). If an attacked player's knee is relatively lateral to the tibia, fibula and foot-ankle complex traversing to a more medial position, this will facilitate an "inside" heel hook (**Figure 5b**). An "outside" heel hook will force the knee into maximum internal rotation, while an "inside" heel hook will force maximal external rotation (**Figures 5c and 5d**). The position of the foot also differs, with the final position in an "outside" heel hook a plantarflexed, inverted and supinated position, similar to a toe hold, whereas an "inside" heel hook results in a dorsiflexed and everted foot position. For both submissions, there is variable amounts of knee flexion or extension.

Anatomic structures at risk and literature review

"Outside" heel hooks stress the knee joint in maximal internal rotation. As such, the cruciate ligaments are at risk of injury, and depending on position of the knee may involve medial knee structures. The ACL is at particular risk when the knee is in an extended position at time of internal rotation, whereas the PCL becomes more prone to injury with knee flexion, particularly between 90 and 120 degrees of flexion.[27] Secondary restraints include the posterior oblique ligament, as well as the posteromedial complex, which includes both portions of the MCL, POL, popliteal ligament, and posterior horn of the medial meniscus, all of which are at risk of injury.[27] In addition, foot inversion, supination, and plantar flexion, will place lateral ankle ligaments, such as the ATFL and CFL, at risk. Patellar dislocation may occur as the knee is flexed, externally or internally rotated, and subjected to a valgus force.[28] This could potentiate injury to the patellar tendon, quadriceps tendon, medial patellofemoral ligament injury, and femoral or patellar osteochondral defects.[29]

"Inside" heel hooks will stress the knee in maximal external rotation. Primary restraints at the knee in external rotation are lateral knee structures, including popliteofibular ligament, LCL, popliteal tendon, biceps femoris tendon, fabellofibular ligament and arcuate ligament.[27,30] Secondary restraints to external rotation motion may include the MCL. Additionally, there may be meniscal injury as the medial tibial plateau moves anterolaterally in relation to the femur, resulting in a possible anterior horn medial meniscus injury, as the knee is extended.[31]

In the current literature, heel hooks have been implicated as a source of injury. Baker et al described a complete ACL rupture and MCL injury in a mixed martial artist after an "outside" heel hook submission. Hinz et al found heel hooks to the be the third most common submission to cause injury, with a high incidence of ankle ligamentous injury, though the authors did not differentiate between heel hook types.[13] Heel hook submissions carry an ominous reputation amongst grapplers, with some grappling organizations banning them from competitions.[5,6] Theoretically, there is increased injury risk with "inside" heel hooks, as it capitalizes on the decreased arc of motion in foot dorsiflexion and eversion, as compared to inversion and plantar flexion. The ability to achieve maximum foot and ankle motion arc quicker for "inside" heel hook allows an attacking player to quickly force maximal knee external rotation, leaving the opponent less reactionary time to submit. This contributes to anecdotal beliefs that an "inside" heel hook is more dangerous. Regardless, patients with injuries from heel hooks should undergo a thorough knee exam, as well as close examination of the ankle and foot for both variants of heel hooks.

Conclusion

Grappling injuries are expected to increase, as various grappling disciplines and sports continue to gain popularity. Investigative efforts into these injuries have also increased but overall remain lacking. Grappling related activities are still considered relatively niche, and are shrouded in confusing terminology and jargon, limiting improvements in patient care. While the submissions discussed in this manucript are not comprehensive, it is the authors' hope this review provides a consolidated source of reference to improve basic understanding of grappling submissions anatomic regions at risk, pathophysiology, and current literature review, in an effort to improve care for this burgeoning constellation of sport-related injuries.

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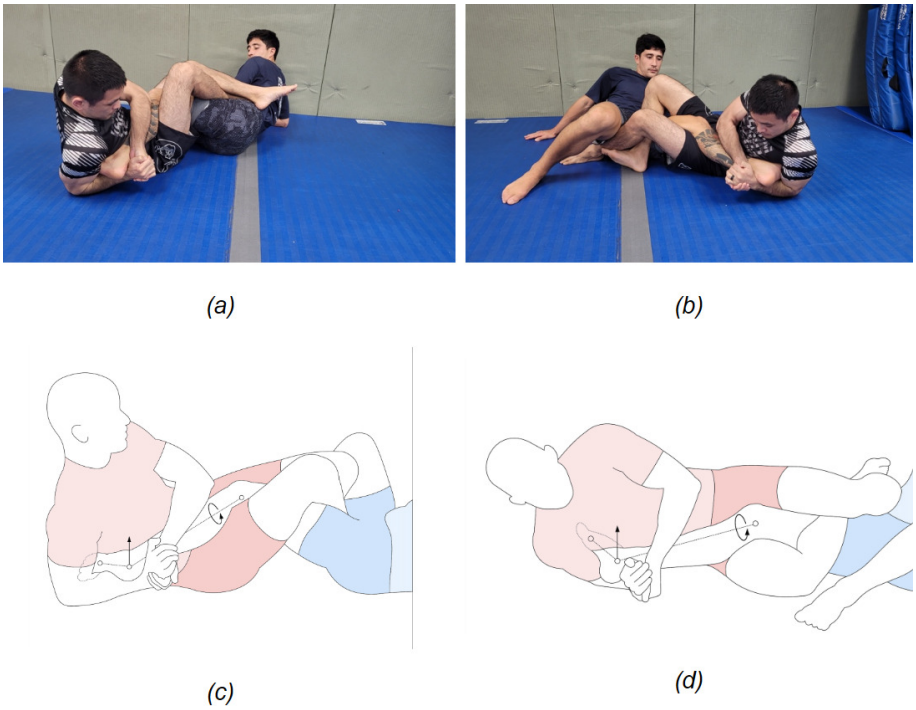

Figure 5. Heel Hooks a) Outside heel hook, notice knee position is medial relative to heel b) Inside heel hook, notice knee position is lateral relative to heel c) Illustrative example of force vectors during outside heel hook d) Illustrative example of force vectors during inside heel hook. Illustrations created with use of Inkscape.

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Horng JC, Nguyen RT, Burnham MM, Tanji CM, Rimm JB, Crawford SN. Correlations of Alpha Angle on Preoperative Imaging with Intraoperative Fluoroscopy for the Evaluation of Cam Deformity: A Cross-Sectional Study. *Hawaii J Health Soc Welf*. 2026;85(6):142-148. doi:10.62547/IJQG3259

Correlations of Alpha Angle on Preoperative Imaging with Intraoperative Fluoroscopy for the Evaluation of Cam Deformity: A Cross-Sectional Study

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Abstract

Reliable preoperative imaging of femoroacetabular impingement is important for effective diagnosis and treatment. While numerous imaging techniques exist, their relative accuracy remains unclear. The purpose of this study was to evaluate the accuracy of preoperative standard hip radiographs and magnetic resonance imaging (MRI) axial and radial views compared to the gold standard of intraoperative fluoroscopy for cam-type femoroacetabular impingement. Data were collected from 93 patients who underwent femoroplasty for cam deformity between 2015 and 2020 by a single orthopedic surgeon. One-way analysis of variance with post-hoc pair-wise evaluation, Pearson correlation coefficients, and Bland-Altman plots were used to evaluate differences and agreement between the imaging modalities. The fluoroscopic alpha angle (62.3°±7°) was significantly different than the radiographic (58.5°±7.0°; *P*=.004) and MRI axial angles (52.0°±8.2°; *P*<.001) but was similar to the MRI radial angle (60.7°±7.9°; *P*=.9). MRI radial angles had the highest correlation with fluoroscopy (r=.876, *P*<.001). The analysis revealed a sensitivity of only 27% for radiographic evaluation and a specificity of 41% with MRI axial evaluation. However, MRI radial evaluation displayed a sensitivity of 87% and specificity of 91% for diagnosis of cam deformity in the study population. These findings suggest the alpha angle derived from radial MRI correlated most strongly with intraoperative fluoroscopy. Radial MRI should continue to be the gold standard for preoperative templating and diagnosis of femoroacetabular impingement in symptomatic patients without obvious deformity on radiographs.

Abbreviations

AP = anterior-posterior
BMI = body mass index
CT = computed tomography
FAI = femoroacetabular impingement
LCEA = lateral center-edge angle
MR = magnetic resonance
MRI = magnetic resonance imaging

Introduction

Femoroacetabular impingement (FAI) is a condition affecting the femoral head and acetabular rim due to irregular bone growth at the hip joint.[1] Of the 2 types of FAI, cam-type FAI is characterized by excessive bone growth at the anterolateral head-neck junction with subsequent loss of sphericity at the femoral head.[2] The abnormal contact between the nonspherical femoral head and the acetabular rim can lead to significant discomfort and limited range of motion.[3] If symptoms persist, a femoroplasty is the definitive treatment to correct the cam deformity.

Prior to the surgery, standard radiographs (anteroposterior, Dunn and/or lateral views), magnetic resonance imaging (MRI) axial, and magnetic resonance (MR) radial sequence imaging are common modalities used to characterize the cam deformity.[2] The alpha angle is typically used to quantify the femoral head-neck concavity and acts as a parameter in determining the need for surgical intervention.[2,4,5] A cam deformity is defined as an alpha angle greater than 55°.[5,6]

The asphericity of the femoral head-neck junction is frequently underestimated by conventional preoperative radiographs, computed tomography (CT), and non-radial sequenced MRI in the author's experience. Consequently, cam deformities are often insufficiently resected and lead to failure of treatment.[2,7] At the authors' institution, musculoskeletal radiologists will typically measure the alpha angle from the axial images on plain MR. While not included in the standard imaging sequence for workup of FAI, MR radial sequence imaging techniques along with static and/or dynamic fluoroscopy have been used to reliably assess cam deformities preoperatively and intraoperatively, respectively.[7,8] However, there is a lack of literature comparing the alpha angle accuracy among the various imaging techniques, so MRI radial sequences have not been included as part of the standard preoperative imaging prior to a femoroplasty.[9] Thus, the optimal preoperative imaging sequence to accurately depict a cam deformity remains unclear. An accurate 3-dimensional (3D) awareness and depiction of the concavity of the femoral head-neck junction is crucial for surgeons to evaluate the cam deformity and ensure adequate resection.[2,6] This is critical, as failure to adequately resect the cam lesion is the primary cause of clinical failure after hip arthroscopy.[10] Furthermore, the alpha angle is often used by medical insurance companies to de-

termine the medical necessity of a femoroplasty (Current Procedural Terminology [CPT] code 29914). However, the alpha angle as a sole measurement can be misleading as to the true nature of the deformity, especially when assessed on non-radial sequences or a non-Dunn type lateral radiograph. The gold standard to determine both the presence and accurate resection of the cam deformity is intraoperative fluoroscopy.[2,11] Therefore, the primary objective of this study is to compare the accuracy of standard radiographs, MR axial imaging, and MR radial sequences to intraoperative fluoroscopy for cam-type FAI.

Methods

Institutional review board exemption was obtained for the study protocol. This cross-sectional study included data collected from a consecutive cohort of patients who underwent arthroscopic femoroplasty between 2015 and 2020 to correct a cam deformity. All surgeries were performed by a single fellowship-trained orthopedic surgeon at a multispecialty tertiary community hospital.

Hip images, age, body mass index (BMI), and other patient demographics were obtained through manual review of patient electronic medical records. Only patients over the age of 18 at the time of surgical intervention who had received standard radiographs, MRI views, and intraoperative fluoroscopy of the hip were included in the final analysis. Individuals with preexisting osteoarthritis of the hip or combined cam-pincer impingement were also included.

Patients presenting with suspected femoroacetabular impingement (FAI) were initially assessed using preoperative imaging series including standard radiographs and MRI views. All imaging was performed by radiologic technologists at the study institution. Standard radiographs of the pelvis taken at the initial evaluation included both anterior-posterior (AP) and Dunn (near 90° of flexion and 20° of abduction with the pelvis in neutral rotation) views with the patient supine. MRI included axial and radial sequence views of the affected hip taken using a 3 Tesla (3T) MRI scanner. Immediately prior to the femoroplasty, all patients were required to undergo intraoperative fluoroscopy including standardized 6-view fluoroscopic views of the hip according to the Larson method,[2,11] considered the gold standard to accurately map the cam lesion.

A single blinded reviewer retrospectively evaluated all preoperative and intraoperative images. The alpha angle was measured using the technique described by Nötzli et al in 2002 to characterize concavity at the anterolateral head-neck junction.[12] An initial line was drawn through the center of the femoral head and neck. A circular template was placed over the femoral head, with a line drawn between the beginning of the protuberance on the femoral neck and the center of the femoral head. The alpha angle is the angle formed by the intersection of these lines. An alpha angle >55° as measured on intraoperative fluoroscopy confirmed the presence of a cam deformity. Alpha angle in standard radiographs was calculated using Dunn views only. Lateral center-edge angle (LCEA) was determined on AP radiographs using Ogata et al's modified method, with LCEA >40° indicating a pincer impingement.[13]

Alpha angle data were then compared between the preoperative imaging techniques and fluoroscopy. A one-way analysis of variance with a post-hoc pair-wise evaluation was performed to evaluate differences in measured angles. Additionally, Pearson correlation coefficients and Bland-Altman plots were used to assess the level of agreeance between preoperative and fluoroscopic findings. Sensitivity and specificity of the preoperative alpha angles were calculated using fluoroscopy and the previously described cut-offs to model the prevalence of disease. Diagnostic accuracy calculations could have been influenced by a high disease prevalence, as all selected patients received intraoperative fluoroscopy and FAI surgery. Descriptive statistics were displayed as mean ± standard deviation alongside range. All statistical analyses were performed using SPSS version 25 (IBM Corporation, Armonk, NY) with $P<.05$ considered statistically significant.

Results

Of the 197 identified patients who received femoroplasty for the treatment of cam deformity, 104 were excluded due to missing images, poor image quality, or no fluoroscopy. A total of 93 patients were included in the final analysis, with a mean age of 33.1±10 years and BMI of 26.8 kg/m^2. In all, 78 (84%) patients had an intraoperative fluoroscopic alpha angle ⩾55°. The mean LCEA was 32.6°±5.6°.

Table 1 compares the alpha angles collected using each imaging modality. The MRI radial angle (60.7°±7.9°) was the only modality similar to the fluoroscopic alpha angle (62.3°±7°, $P=.9$). Both the radiographic angle (58.5°±7.0°; $P=.004$) and MRI axial angle (52.0°±8.2°; $P<.001$) were significantly different from fluoroscopy. The Pearson correlation data between imaging modalities are presented in **Table 2** and **Figure 1**, with the MRI radial angle correlating best to fluoroscopy (r=.876, $P<.001$) followed by the radiographic (r=.400, $P<.001$) and MRI axial (r=.381, $P<.001$) angles. Correlation among radiographic and MRI axial angles was relatively poor, with a correlation coefficient below .400.

Agreement between the imaging modalities is also presented as Bland-Altman plots in **Figure 2**. Radiography (r=.551, $P<.001$) and MRI axial evaluation (r=.446, $P<.001$) had poor agreement with fluoroscopy, both displaying a positive correlation. MRI radial evaluation had the greatest agreement with no observed correlation (r=.003, $P=.97$). Furthermore, MRI radial sequence evaluation most accurately predicted the presence of a cam lesion on fluoroscopy, with a sensitivity of 87% and specificity of 91% (**Table 3**).

Discussion

The principal finding of this study is that MRI radial sequence views provided the most accurate preoperative assessment of the alpha angle in patients receiving arthroscopic femoroplasty to correct a cam deformity. MRI radial

Table 1. Demographic and Radiographic Parameters for Individuals Undergoing Femoroplasty for Cam-type Femoroacetabular Impingement from 2015-2020 (N=93).

	Mean (SD)	(Range)
Age	33.1 (10.0)	(19,59)
BMI	26.8 (4.4)	(17.6,39.1)
CEA	32.6 (5.6)	(19,50)
Radial Alpha Angle	60.7 (7.9)	(42,78)
Axial Alpha Angle	52.0 (8.2)	(36,77)
Radiograph Alpha Angle	58.5 (7.0)	(39,75)
Fluoro Alpha Angle	62.3 (7.0)	(45,76)
Radial – Radiograph[a]	2.1 (8.4)	(-18,18)
Radial – Axial[a]	8.7 (9.7)	(-11,34)
Fluoro – Radiograph[b]	3.7 (7.5)	(-13,23)
Fluoro – Radial[b]	1.6 (3.8)	(-5,11)
Fluoro – Axial[b]	10.2 (8.5)	(-7,36)

BMI = body mass index; CEA = center-edge angle; Radial = radial sequence magnetic resonance imaging; Axial = axial sequence magnetic resonance imaging; Fluoro = fluoroscopy

[a]Radial minus radiograph alpha or axial angle

[b]Fluoroscopic alpha angle minus radiograph, radial or axial angle

alpha angles were the most similar to and had the greatest correlation with intraoperative fluoroscopy. Furthermore, MRI radial sequence had the highest sensitivity and specificity in identifying a cam lesion (alpha angle >55°) prior to the operation. These findings suggest MRI radial sequences should be used in the initial characterization, management, and preoperative planning to ensure accurate assessment and resection of cam deformities. This has significant clinical implications for physicians and their patients as insurance companies rely on alpha angle measurements to approve cam resection procedures.

Radial sequence MR imaging is considered the most reliable tool to evaluate cam deformity, especially in patients with a high clinical suspicion but no obvious radiographic signs.[14-17] As a result, MRI findings have often been compared to other preoperative FAI imaging sequences including radiography and CT. However, the best imaging modality to accurately measure the alpha angle in cam lesions has not been identified. To the authors' knowledge, this is the first study comparing the alpha angle as measured on MRI radial sequence to the known alpha angle on intraoperative fluoroscopy.

Previous studies on the role of radial MRI in FAI management have highlighted its high sensitivity, precise circumferential modeling of the femoral head-neck junction, and ability to visualize surrounding soft tissue without use of ionizing radiation.[3,14-16,18] This study confirms an additional benefit of MRI radial views, which is the close approximation of intraoperative fluoroscopic alpha angles used to evaluate adequate resection of cam deformities. The excellent correlation between the 2 modalities could allow surgeons to template a resection with greater precision compared to MRI axial views or standard radiographs.

Multiple articles have explored standard radiographs as a rapid, lower-cost alternative to radial MRI. While some methods (particularly the Dunn and cross-table lateral views) demonstrate a high sensitivity and good alpha angle correlation with radial MRI, there is an associated risk of underdiagnosis.[3,7,18-21] The Dunn view in the current study severely underestimated the incidence of cam deformity, with a sensitivity of 27%. This finding is lower than previously reported values of 52-96% sensitivity of Dunn view alpha angles in studies using MRI to diagnose cam deformity.[18-20] MRI axial views were sensitive (93%) but had a 59% false positive rate, indicating they may overestimate small cam lesions. Furthermore, positive correlations observed on Bland-Altman plots for radiographs and axial MRI suggest possible skewing of alpha angles when attempting to measure especially large or small lesions. These findings suggest standard radiographs and axial MRI are not reliable for the routine diagnosis of cam deformities.

While this study did not evaluate the accuracy of CT, recent studies comparing 3D-MRI and 3D-CT for dynamic simulation of FAI have reported near-equivalent and highly accurate diagnostic outcomes.[15,17,22,23] Due to the radiation exposure introduced by CT, 3D-MRI may be the more practical option for patients who can safely receive MRI.[22,23] Based on these findings, alpha angle accuracy of 3D-CT and 3D-MRI could be a future topic of study.

Limitations

There were multiple limitations in the current study. First, due to the retrospective nature of this study, the data were collected entirely through chart review. Second, this study lacked a control group, as it only included patients selected for arthroscopic FAI surgery. This contributed to an ex-

Table 2. Pearson Correlation between Alpha Angles of Preoperative and Intraoperative Imaging Techniques in Individuals Undergoing Femoroplasty for Cam-type Femoroacetabular Impingement.

	Radiograph r (*P-value*)	Axial r (*P-value*)	Radial r (*P-value*)
Fluoroscopy	.400 (<.001)	.381 (<.001)	.876 (<.001)
Radiograph		.316 (.002)	.379 (<.001)
Axial			.288 (.005)

Radial = radial sequence magnetic resonance imaging; Axial = axial sequence magnetic resonance imaging

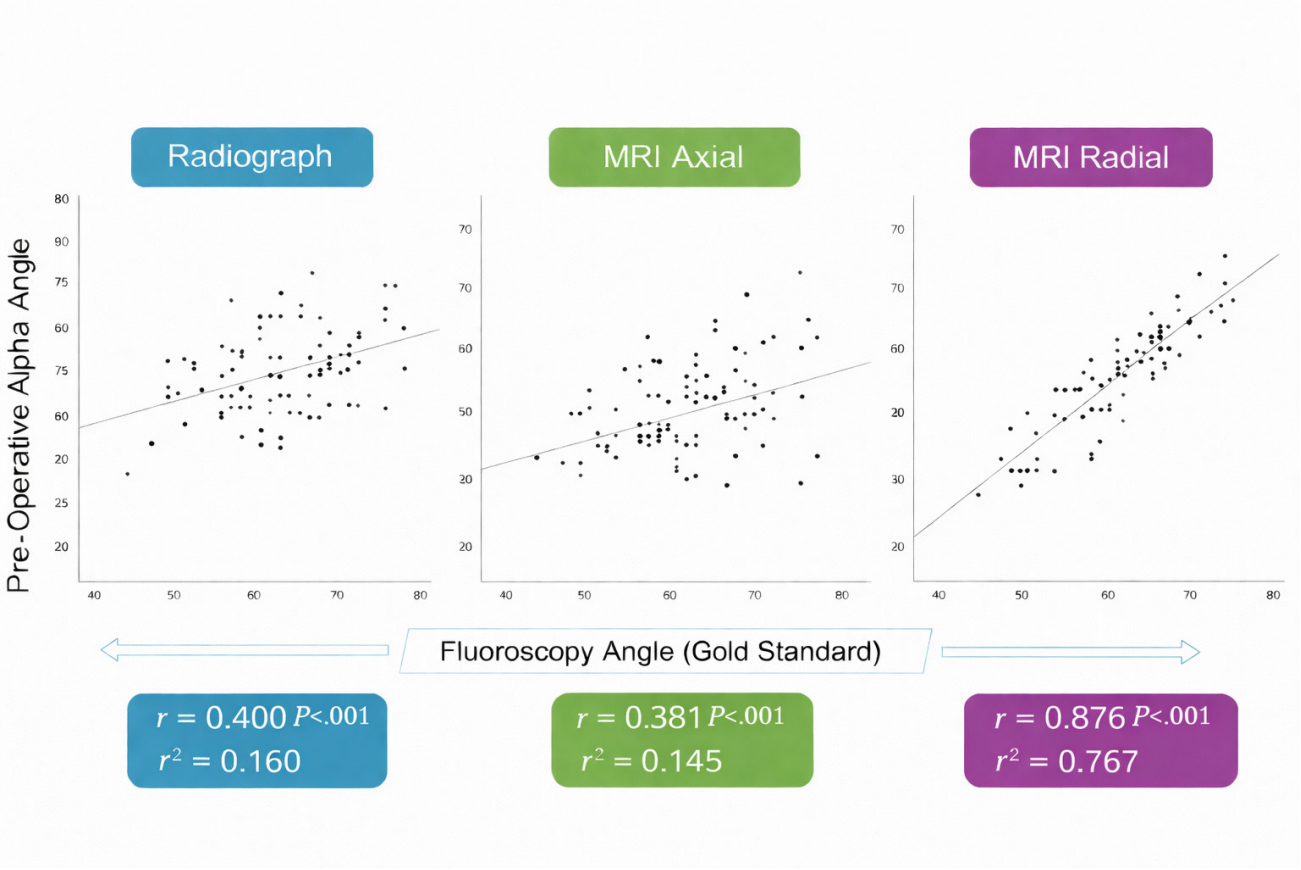

Figure 1. Alpha Angle Assessment Accuracy Comparison of Radiographic, Axial, and Radial Magnetic Resonance Imaging (MRI) to Fluoroscopy Angle

Scatterplot of alpha angles calculated using preoperative imaging modalities (y-axis) and intraoperative fluoroscopic alpha angles (x-axis). Pearson's correlation coefficient (r) for each comparison is included.

tremely high prevalence of disease, which could lead to overestimated sensitivity of the tested imaging modalities. Third, alpha angle as a diagnostic criterion for cam deformity is controversial with shifting recommendations. While a commonly reported cutoff of >55° was selected in this study, recommendations range significantly and are not perfectly diagnostic for cam lesions. Fourth, all radiographic measurements are subject to a degree of error. Fifth, unintentional variation in the positioning of patients for imaging procedures could have had a slight impact on derived measurements. Finally, all procedures were done by a single surgeon at a single institution, which may limit generalizability based on patient selection, demographics, and management protocols.

Conclusion

This study suggests preoperative MRI radial sequence provides a more accurate alpha angle measurement compared to standard radiographs and axial MRI imaging by most closely correlating to the alpha angle derived from intraoperative fluoroscopy. As a result, MRI radial sequencing may be effective in diagnosis and preoperative templating of cam-type FAI deformity.

Conflict of Interest and Disclosures

Dr. Scott N. Crawford reports serving as the founder and president of the Hawai'i Orthopedic Performance Education organization. No other authors identify any conflict of interest or financial disclosures.

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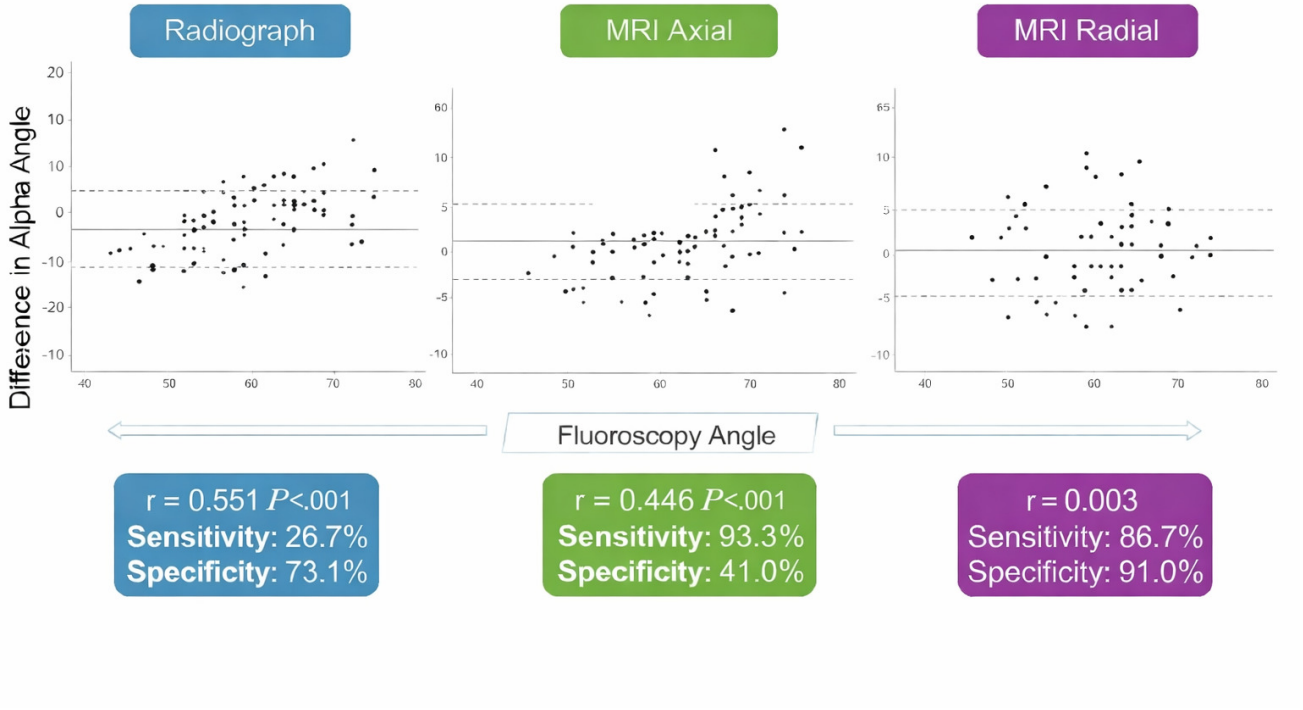

Figure 2. Diagnostic Accuracy of Alpha Angle Measurements

Bland-Altman plots and r-values comparing level of agreement between preoperative imaging modalities and intraoperative fluoroscopy. Sensitivity and specificity for cam deformity is also shown for each preoperative imaging modality. Radial sequence MRI displayed the highest level of agreement with a near-zero correlation. MRI = magnetic resonance imaging.

Table 3. Bland Altman Correlation and Accuracy of Radiographic, Axial, and Radial MRI Measurement Techniques

Bland-Altman correlation				
	Fluoroscopy r (*P-value*)		Sensitivity	Specificity
Radiograph	.551 (<.001)	Radiograph	26.7%	73.1%
Axial	.446 (<.001)	Axial	93.3%	41.0%
Radial	.003 (.974)	Radial	86.7%	91.0%

Radial = radial sequence magnetic resonance imaging; Axial = axial sequence magnetic resonance imaging

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Death after Total Hip Arthroplasty in Patients with Compensated Heart Failure: Retrospective Cohort Study

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Abstract

Total hip arthroplasty (THA) is the preferred treatment for femoral neck fracture when functional longevity is expected, but congestive heart failure (CHF) is a risk factor for mortality. The hypothesis of this study is that mortality risk increases with disease severity, influencing the choice between total and hemiarthroplasty. This study queried the National Surgical Quality Improvement database for patients treated for an acute, closed, intracapsular femoral neck fracture, identifying 4486 THA and 34 282 hemiarthroplasty recipients. Subjects were stratified by preoperative risk factors, New York Heart Association categories of mild, moderate, and severe CHF, and odds of death within 30 days. The 30-day postoperative mortality rates for total and hemiarthroplasty were 2.1% (n = 95) and 5.4% (n = 1857), respectively. The 30-day postoperative mortality of patients undergoing THA with mild CHF was 14.3%, and moderate CHF was 21.4%., and for patients undergoing hemiarthroplasty with mild CHF was 11.4%, moderate CHF was 13.9%, and severe CHF was 18.4%. Mild (adjusted odds ratio [AOR] 1.63, 95% Confidence Interval [CI] 1.24-2.14), moderate (AOR 2.21, CI 1.49-3.30), and severe (AOR 2.89, CI 1.41-5.93) CHF was associated with death within 30 days of hemiarthroplasty. Mild (AOR 5.37, 95% CI 2.16-13.38) and moderate (AOR 12.00, CI 3.42-42.17) CHF was associated with death within 30 days of THA. Patients with CHF had increased mortality after THA for acute femoral neck fracture, suggesting it is not a modifiable risk factor. Hemiarthroplasty is a reasonable choice with CHF given evidence of unfavorable survival.

Abbreviations

AOR = Adjusted Odds Ratio
CHF = congestive heart failure
NICE = National Institute for Health and Care Excellence
NSQIP = National Surgery Quality Improvement Program
THA = total hip arthroplasty

Introduction

In North America, an estimated 140 000 patients annually sustain an acute femoral neck fracture.[1-3] Treatment options include internal fixation and hip arthroplasty depending on patient factors such as age, fracture morphology, functional status, and pre-operative medical comorbidities. Hip arthroplasty allows for swift mobilization while mitigating concern for fixation failure, osteonecrosis, or nonunion among osteoporotic elderly patients when compared to internal fixation.[4-9]

Despite advances in perioperative medical care and surgical technique, the mortality after a femoral neck fracture remains high at 20% within 1 year postoperatively.[10,11] This is partially attributed to the elevated incidence of severe medical comorbidities in this population such as renal disease, pulmonary disease, dementia and congestive heart failure (CHF).[4,11] Given the elevated post-operative mortality rates, hemiarthroplasty remains the overwhelming arthroplasty treatment option in this population owing to equivalent 2-year quality-of-life metrics, lower dislocation rate, less blood loss, initial lower complication rate, and surgical morbidity when compared to total hip arthroplasty (THA).[12-14] THA is indicated for patients with favorable long-term survival given the clinical and functional longevity of THA when compared to hemiarthroplasty after the first 2 years after surgery, and gives the benefit of avoidance of secondary conversion surgery in the subset of patients who experience persistent groin pain after hemiarthroplasty.[4,12,14-17]

Given that several years of post-operative survival are necessary to materialize the benefit of THA when compared to hemiarthroplasty, the National Institute for Health and Care Excellence (NICE) guidelines provide a framework for choosing between these treatment options to maximize appropriate resource utilization and minimize patient morbidity.[18] However, the NICE guidelines are broad and thus patients with seemingly benign but physiologically severe medical comorbidities remain eligible for THA.[18] One such example of this comorbidity type is compensated CHF. CHF can be diagnosed both based on objective measures such as ejection fraction evaluated by echocardiography, and clinical characteristics outlined in the Framingham criteria (including pulmonary edema, cardiomegaly, hepatojugular reflux, jugular venous distention, orthopnea, peripheral edema, and exertional dyspnea, among others).[19] CHF is present in 6-20% of patients undergoing treatment for a hip fracture.[20] Prior studies cite CHF as a risk factor for mortality following arthroplasty for femoral neck fracture.[20] However, these studies do not delineate the effect of compensation with CHF on mortality in this subpopulation. While decompensated CHF is generally treated with hemiarthroplasty, compensated CHF may be asymptomatic and thus

be eligible for THA under the NICE guidelines.[18] This is despite the 3-fold increase in mortality with compensated CHF in the general population.[21] This study sought to determine the effect of heart failure compensation on the 30-day case-specific mortality rate following THA after an acute femoral neck fracture. The authors hypothesized that the impact of CHF on mortality after THA would be dependent on CHF severity.

Methods

A query of the National Surgical Quality Improvement Program (NSQIP) database from 2015-2018 for patients receiving a THA (current procedural terminology [CPT] code: 27130) or hemiarthroplasty (CPT code: 27236 and 27125) for an acute, closed, non-oncologic intracapsular femoral neck fracture (International Classification of Diseases, Tenth Revision [ICD10] code: S72.0xA or ICD9 code: 820.0-2) was performed. Independent analyses were run for the hemiarthroplasty and THA cohorts. Patients were initially stratified based on the presence or absence of pre-operative risk factors and the odds of death within 30-days of a hemiarthroplasty or THA for a femoral neck fracture. CHF was further classified into 3 categories based on the New York Heart Association criteria: mild (diagnosis of heart failure without dyspnea on exertion; compensated CHF), moderate (diagnosis of heart failure with moderate dyspnea on exertion; exertional CHF), and severe (heart failure with dyspnea at rest; decompensated CHF).[21] There were only 3 patients diagnosed with severe CHF so they were excluded from the THA cohort and analysis. Univariate analysis identified significant preoperative risk factors (P<.10) for inclusion in a multivariate logistic regression. Significance in the multivariate logistic regression was defined as P<.003 for hemiarthroplasty and P<.004 for THA after a Bonferroni correction for 16 hemiarthroplasty-associated and 14 THA-associated risk factors related to mortality on the prior univariate analysis.

Continuous variables were reported as mean and standard deviation, with comparisons conducted in univariate analysis via two-sided t-tests or analysis of variance. Categorical variables were reported as number and percent, with comparisons conducted in univariate analysis via chi-square tests. Results from multivariate logistic regression analysis were reported as adjusted odds ratio (AOR) and the 95% confidence interval (CI) not encompassing 1. All statistical computing was performed using Stata Release 15 (StataCorp LLC, College Station, TX).

Results

In the group of patients who received a total hip arthroplasty, the mean BMI was 25.7 kg/m^2, 69.1% were female, and the mean age was 72.3 years (**Table 1**). In the group of patients who received a hemiarthroplasty, the mean BMI was 24.7 kg/m^2, 67.9% were female, and the mean age was 80.3 (**Table 2**).

The 30-day mortality for a patient receiving a THA for femoral neck fracture without CHF was 1.8% (n=80). The presence of mild CHF increased the absolute risk of 30-day mortality to 14.3% (n=9) after THA for femoral neck fracture. The presence of moderate CHF increased the absolute risk to 21.4% (n=6). The 30-day mortality for a patient receiving a hemiarthroplasty for femoral neck fracture without CHF was 5.1% (n=1693). The absolute risk of 30-day mortality increased to 11.4% (n=106) with mild CHF, 13.9% (n=44) with moderate CHF, and 18.4% (n = 14) with severe CHF. A comparison of the mortality rates between patients who underwent total hip arthroplasty for femoral neck fracture with CHF versus patients without CHF, adjusted for BMI, sex, age, partial or total dependence for activities of daily living, COPD, insulin use, hypertension, dialysis dependence, pre-operative blood transfusion, pre-operative albumin level, and pre-operative hematocrit found that any level of CHF significantly increases the risk of 30-day mortality. When compared to the mortality of patients without CHF receiving THA for an acute femoral neck fracture, there was a severity dependent association with CHF (mild: adjusted odds ratio [AOR] 5.4, 95% confidence interval [CI] 2.2 - 13.4; moderate: AOR 12.0, CI 3.4 - 42.2; **Table 3**). THA for an acute femoral neck fracture had a number needed to harm (the number of patients receiving a treatment needed for one patient to experience the adverse outcome) of 8 for mild CHF and 5 for moderate CHF.

A comparison of the mortality rates between patients who underwent hemiarthroplasty after femoral neck fracture with CHF versus patients without CHF, adjusted for BMI, sex, age, partial or total dependence for activities of daily living, COPD, resting or exertional dyspnea, insulin use, tobacco use, hypertension, dialysis dependence, pre-operative blood transfusion, pre-operative albumin level and pre-operative hematocrit found that any level of CHF significantly increases the risk of 30-day mortality. When compared to the mortality of patients without CHF receiving a hemiarthroplasty for an acute femoral neck fracture, there was a severity dependent association with CHF (mild: AOR 1.6, CI 1.2 - 2.1; moderate: AOR 2.2, CI 1.5 - 3.3; severe: AOR 2.9, CI 1.4 - 5.9; **Table 3**). Hemiarthroplasty for an acute femoral neck fracture had a number needed to harm of 16 for mild CHF, 11 for moderate CHF, and 8 for severe CHF.

There was no statistically significant difference in 30-day postoperative mortality rates in patients with mild CHF who received hemiarthroplasty or THA (P=.54), or moderate CHF (P=.27) (**Table 4**).

Discussion

Prior studies have advocated for hemiarthroplasty in patients with an acute femoral neck fractures who also have medical comorbidities such as neurocognitive deficit, dialysis-dependence, and severe cardiopulmonary disease given the elevated postoperative morbidity and mortality risks associated with these preoperative characteristics.[3] Based on existing treatment paradigms, an acute femoral neck fracture in the setting of decompensated CHF is a clear indication for hemiarthroplasty. In comparison, with appropriate medical treatment, compensated CHF patients often

Table 1. Demographic Characteristics of Patients Undergoing Total Hip Arthroplasty for a Displaced Femoral Neck Fracture Stratified by Survival 30-days Post-operatively, National Surgery Quality Improvement Program Database 2015-2018

Variable	Whole Population (n=4486)	Surviving at 30-days (n=4391)	Mortality at 30-days (n=95)	*P*-value
Body Mass Index (kg/m^2)[a]	25.7 ± 5.6	25.7 ± 5.6	23.8 ± 6.4	.001
Sex (female)	3098 (69.1%)	3049 (67.9%)	49 (1.1%)	<.001
Age (years)	72.3 ± 11.2	72.1 ± 11.2	81.5 ± 8.7	<.001
Activities of Daily Living[a]				
Partial Dependence	323 (7.2%)	303 (6.7%)	20 (0.4%)	<.001
Total Dependence	52 (1.2%)	48 (1.1%)	4 (0.1%)	<.001
Chronic Obstructive Lung Disease	367 (8.2%)	349 (7.8%)	18 (0.4%)	.001
Dyspnea				
with Exertion	164 (3.7%)	159 (3.5%)	5 (0.1%)	.55
with Rest	21 (0.5%)	20 (0.4%)	1 (0.0%)	.55
Insulin Use	308 (6.9%)	296 (6.6%)	12 (0.3%)	.050
Tobacco Use	732 (16.3%)	3669 (81.8%)	85 (1.9%)	.159
Congestive Heart Failure				
Mild	63 (1.4%)	54 (1.2%)	9 (0.2%)	<.001
Moderate	28 (0.6%)	22 (0.5%)	6 (0.1%)	<.001
Hypertension	2601 (57.9%)	2537 (56.5%)	64 (1.4%)	.074
Dialysis Dependence	57 (1.3%)	52 (1.2%)	5 (0.1%)	.007
Pre-operative Transfusion	82 (1.8%)	76 (1.7%)	6 (0.1%)	.007
Pre-operative Albumin (g/d)[a]	3.6 ± 0.6	3.6 ± 0.6	3.1 ± 0.6	<.001
Pre-operative Hematocrit (%)	35.9 ± 14.2	35.9 ± 14.2	35.4 ± 14.7	.087

[a]Missing variables: Body mass index analyses excluded 251 patients with missing data; Activities of daily living analyses excluded 19 patients with missing data; Pre-operative albumin analyses excluded 1645 patients with missing data

show no outward clinical signs of their diagnosis.[22] Additionally, since CHF can be diagnosed clinically based on the presence of the criteria outlined in the Framingham study, or through the use of echocardiography to evaluate heart function by measuring ejection fraction, many patients can also be identified in early stages of heart failure when their symptoms are silent due to compensation despite the presence of the disease.[22] Despite the diagnosis of CHF, more advanced diagnostic work-up such as echocardiogram in this population often reveals minimal cardiac disease, and as a result these patients are often evaluated as being "medically optimized" for surgery.[8,18,23] Bohsali et al recently evaluated peri-operative outcomes following arthroplasty for a femoral neck fracture among patients with CHF; however, the study stratified severity of CHF based upon ejection fraction (preserved or unpreserved) as opposed to New York Heart Association criteria.[24] Though perioperative CHF is often evaluated based on echocardiographic results of ejection fraction, the New York Heart Association classification includes an ordinal scale of clinical status not encompassed with ejection fraction stratification alone making it more applicable to surgical screening.[25] The New York Heart Association classification of CHF severity is an independent predictor of CHF outcomes regardless of ejection fraction.[24-26] Prior studies also aggregated CHF into a single diagnosis despite the vast differences in the outcomes of compensated versus decompensated heart failure.[20,21,27] The decision-making algorithm for hemiarthroplasty versus THA is complex and the NICE guidelines are one method of guiding the surgeon to the most appropriate treatment option.[16] Data from studies investigating the long-term outcome of THA and hemiarthroplasty surgeries suggests the quality-of-life outcomes are equivalent between hemiarthroplasty and THA even up to 4-years after surgery.[28] Thus, a hemiarthroplasty may perform acceptably well for the lifetime of the compensated CHF patient. Additionally, if necessary, staged conversion to a THA is a well-tolerated procedure with excellent long-term outcomes.[29]

These findings indicate that there is a significantly increased risk of perioperative mortality after THA in patients with CHF of any severity. This effect included a dose response association, but even in mild CHF, the absolute risk was relatively large at an 8-fold increase when compared to patients without CHF (14.3% compared to 1.8%). The number needed to harm in this scenario was also low at 8. This effect can be reasonably considered to be clinically significant when weighing the risks and benefits of THA in this population.

Table 2. Demographic Characteristics for Patients Undergoing Hip Hemiarthroplasty for Displaced Femoral Neck Fracture Stratified by Survival 30-days Post-Operatively, National Surgery Quality Improvement Program Database 2015-2018

Variable	Whole Population (n=34282)	Surviving at 30-days (n=32425)	Mortality at 30-days (n=1857)	*P*-value
Body Mass Index (kg/m^2)†	24.7 (+/-5.2)	24.7 (+/-5.2)	23.6 (+/-5.1)	<.001
Female sex	23263 (67.9%)	22231 (64.8%)	1032 (3.0%)	<.001
Age (years)	80.3 (+/-10.1)	80.1 (+/-10.2)	84.6 (+/-7.3)	<.001
Functional Status				
Partial Dependence	6507 (18.9%)	5882 (17.2%)	625 (1.8%)	<.001
Total Dependence	1326 (3.9%)	1136 (3.3%)	190 (0.5%)	<.001
Chronic Obstructive Lung Disease	3619 (10.5%)	3298 (9.6%)	321 (0.9%)	<.001
Dyspnea				
with Exertion	1842 (5.4%)	1690 (4.9%)	152 (0.4%)	<.001
with Rest	304 (0.9%)	264 (0.8%)	40 (0.1%)	<.001
Insulin Use	2359 (6.9%)	2211 (6.4%)	148 (0.4%)	.004
Tobacco Use	3765 (10.9%)	3612 (10.5%)	153 (0.4%)	<.001
Congestive Heart Failure				
Mild	929 (2.7%)	823 (2.4%)	106 (0.3%)	<.001
Moderate	316 (0.9%)	272 (0.8%)	44 (0.1%)	<.001
Severe	76 (0.2%)	62 (0.2%)	14 (0.0%)	<.001
Hypertension	22594 (65.9%)	21306 (62.1%)	1288 (3.8%)	.001
Dialysis Dependence	629 (1.8%)	565 (1.6%)	64 (0.2%)	<.001
Preoperative Transfusion	787 (2.3%)	701 (2.0%)	86 (0.2%)	<.001
Preoperative Albumin (g/d)†	3.5 (+/-0.5)	3.5 (+/-0.5)	3.3(+/-0.6)	<.001
Preoperative Hematocrit (%)	35.6 (+/-11.6)	35.6 (+/-0.1)	34.9 (+/-0.3)	.018

Table 3. Multivariate Adjusted Odds of 30-day Mortality Stratified by Heart Failure Severity and Type of Arthroplasty, National Surgery Quality Improvement Program Database 2015-2018

Stratification	Adjusted Odds Ratio[a]	95% Confidence Interval	*P*-value
Total Hip Arthroplasty			
Mild Heart Failure	5.4	2.2-13.4	<.001
Moderate Heart Failure	12.0	3.4-42.2	<.001
Hemiarthroplasty			
Mild Heart Failure	1.6	1.2-2.1	<.001
Moderate Heart Failure	2.2	1.5-3.3	<.001
Severe Heart Failure	2.9	1.4-5.9	<.001

[a]Odds ratio adjusted for body mass index, sex, age, functional status, chronic obstructive lung disease, dyspnea, insulin use, tobacco use, hypertension, dialysis dependence, pre-operative transfusion, pre-operative albumin, and pre-operative hematocrit

There was also a similar dose-response association with mortality for patients undergoing hemiarthroplasty with CHF. In comparison to patients who underwent THA, however, the effect was reduced after hemiarthroplasty owing to the higher baseline peri-operative mortality rates in the hemiarthroplasty population. The impact on perioperative mortality after hemiarthroplasty was approximately double for mild or moderate CHF and triple for severe CHF, all of which were less than the 8-fold increase seen with mild CHF in THA patients. Cullen et al found the 1-year post-operative odds of death to be double when comparing those with and without CHF, which approximates the mortality seen in this hemiarthroplasty population.[21] This reflects an expected trend which is corroborated by the findings of this study, since hemiarthroplasty is generally indicated for patients with other severe medical comorbidities, in addition to CHF. When stratifying these populations, the data in this study demonstrates that combining compen-

Table 4. Comparative Statistics for 30-day Post-Operative Mortality Rates With Mild or Moderate CHF in Hemiarthroplasty Versus Total Hip Arthroplasty Patients, National Surgery Quality Improvement Program Database 2015-2018

Stratification	Surviving within 30 days	Dead within 30 days	*P*-value
Mild Heart Failure			
Total Hip Arthroplasty	54 (85.7%)	9 (14.3%)	.54
Hemiarthroplasty	823 (88.6%)	106 (11.4%)	
Moderate Heart Failure			
Total Hip Arthroplasty	22 (78.6%)	6 (21.4%)	.27
Hemiarthroplasty	272 (86.1%)	44 (13.9%)	

sated and decompensated CHF into a single diagnosis underestimates the mortality estimate of mild or moderate heart failure in the femoral neck fracture receiving a THA. The findings of this study did not demonstrate a statistically significant difference in 30-day mortality for THA compared to hemiarthroplasty in patients with CHF, which reflects the clinical implications of CHF on mortality risk. The patient population with CHF is clinically more like the baseline population of hemiarthroplasty patients who are indicated for hemiarthroplasty due to the presence of underlying medical comorbidities.

Compensated CHF is not a modifiable risk factor in the setting of either hemiarthoplasty or THA. Patients with mild CHF have significantly elevated 30-day post-operative mortality. As mentioned above, when compensated CHF is appropriately treated, it is often asymptomatic, and may even show minimal signs of disease with advanced diagnostic testing such as echocardiography.[8,18,22,23] When considering this alongside these findings that suggest that the mortality risk associated with CHF in patients undergoing hip arthroplasty is not modifiable, it appears that surgical teams may be able to rely on functional clinical status when risk stratifying for preoperative planning purposes, without warranting an echocardiogram. This offers the advantage of streamlining the process of pre-operative preparation by relying on clinical history, and preventing operative delays that may be incurred by pursuing additional diagnostic workup.

Limitations

The limitations to this study include the inherent inability to report causality due to the retrospective nature of the analysis. Additionally, the observations, while profound, are limited to 30-day post-operative mortality, and longer follow-up is necessary to further characterize the details of this relationship but suggest that this is the most optimistic view of the relationship between arthroplasty and CHF in the setting of an acute femoral neck facture. The lifetime association between CHF and mortality suggests the associations would increase with longer follow-up.[30] Though NSQIP is widely employed to report arthroplasty outcomes, it is subject to coding and data entry errors. However, inter-observer reliability is reported to be greater than 98%.[31]

Conclusion

Patients with mild, compensated, CHF are often clinically asymptomatic and remain eligible under NICE guidelines to undergo THA following a femoral neck fracture. CHF is an independent risk factor for early postoperative mortality when arthroplasty is used to treat an acute femoral neck fractures with a number needed to harm of 8 in mild CHF patients receiving THA. CHF is a progressive disease, and although this study was limited in analysis to 30-days post-operatively due to the nature of the NSQIP database, the results indicate that even within that relatively short timeline, there was a high risk of mortality which significantly increased odds of death. Hemiarthroplasty and total hip arthroplasty are likely to be functionally equivalent for the expected lifetime of a patient with CHF, while hemiarthroplasty reduces a number of known surgical risks including increased anesthesia time, blood loss, and risk of requiring a blood transfusion.

Hence, the presence of CHF, regardless of compensation, should be considered as an appropriate indication for choosing hemiarthroplasty.

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Creating a "Box View" of Periprosthetic Distal Femur Fractures Using Three-Dimensional Image Processing

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Keywords: Periprosthetic Distal Femur Fracture, Retrograde IMN, Distal femur fracture, Advanced Imaging Distal Femur, Box View, three-dimensional reconstructions

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Abstract

Retrograde intramedullary nailing of periprosthetic distal femur fractures requires an open box femoral component. However, presence of an open box is difficult to determine using standard imaging. The objective of this study is to present a novel three-dimensional (3D) image processing and analysis technique, called the "Box View," which addresses this problem. Twelve patients undergoing revision total knee arthroplasty's pre-operative computed tomography scans were reformatted to subtract the tibia, and a 3D Box View movie was generated. The method of this study included 4 attending surgeons and 6 residents who reviewed radiographs, computed tomography (CT), and Box View images, then interpreted presence of an open box. Inter-observer reliability was assessed with 2-factor analysis of variance (ANOVA) and sensitivity/specificity of the Box View versus radiograph and CT was performed with a Stuart-Maxwell test. The results of this study showed that the Box View was 81% sensitive and 97% specific for identification of an open box, with a positive predictive value of 100% and a negative predictive value of 85%. The Box View's specificity was significantly better than radiographs (53%, *P*=.003) and CT (50%, *P*=.002), and sensitivity (81%) was significantly better than CT (34%, *P*<.001) but not radiographs (77%, *P*=.63). Inter-observer agreement with the Box View was 0.88, radiographs was 0.65 and CT was 0.09. The conclusion was that the Box View is a novel and useful pre-operative planning tool for treatment of distal femur fractures with high sensitivity and specificity, positive and negative predictive value, and inter-observer reliability.

Abbreviations

3D = three-dimensional
ANOVA = analysis of variance
CT = computed tomography
IMN = intramedullary nail
TKA = total knee arthroplasty

Introduction

As the number of total knee arthroplasties (TKAs) performed annually continues to grow, so does the incidence of periprosthetic distal femur fractures. The incidence of supracondylar femur fractures after TKA ranges from 0.3-2.5% and 5-year incidence of all fractures after primary and revision TKA is 0.6% and 1.7%, respectively.[1,2]

The treatment algorithm for these injuries is evolving. Displaced periprosthetic distal femur fractures are almost universally operative injuries, and recent studies have evaluated the risks and benefits of distal locking plate versus retrograde intramedullary nail (IMN) fixation. Benefits of retrograde IMN fixation include immediate weightbearing and range of motion, a high union rate, and a low complication rate.[3-6]

Assessing standard imaging for whether the femoral component of a TKA is compatible with a retrograde IMN is difficult. A cruciate-retaining prosthesis technically does not have an open box but has a cutout in the femoral component between the femoral condyles that allows for retrograde femoral intramedullary nailing through the intercondylar notch. Posterior-stabilized femoral components can contain an open or closed box within the intercondylar notch to accommodate the tibial post. A closed box design precludes placement of a retrograde IMN, but an open box design does not. Conventional radiographs and even cross sectional imaging can be unreliable in determining if the femoral component is an open or closed box design.

Routine pre-operative imaging of displaced periprosthetic distal femur fractures includes full length femur radiographs and dedicated knee radiographs of the injured extremity. Difficulty in manipulating the injured extremity for precise radiographs can limit their diagnostic capability in determining whether a femoral component has an open box. The role of routine cross-sectional imaging, especially computed tomography (CT), during pre-operative planning is less clear but is most valuable when deciding between retrograde IMN and locked plate fixation. CT has clear advantages over plain radiographs in evaluating the amount and quality of distal bone stock available for fixation, but conventional CT similarly fails to determine whether the existing TKA femoral component is both compatible with retrograde intramedullary access (ie, a cruciate-retaining or open box design posterior-stabilized femoral component) and sufficiently anterior for proper placement of retrograde IMN fixation.

The introduction of three-dimensional (3D) reconstruction and ghost view projections has further increased the value to pre-operative CT imaging. 3D-CT of periprosthetic distal femur fractures can be used to produce an informative image of the femoral component, a "Box View."

Methods

With Stanford University institutional review board approval (#10669), 12 patients who had undergone revision total knee arthroplasty and had pre-operative CT scans of the operative knee were identified from an institutional database. Of the 12 patients identified, 9 had a femoral prosthesis amenable to an intramedullary implant (ie, cruciate-retaining or open box design posterior-stabilized) and 3 did not (ie, closed box design posterior-stabilized). All had available access for retrograde IMN determined definitively at the time of revision surgery. Four orthopaedic trauma fellowship-trained attending surgeons and 6 residents reviewed a randomized list of radiographs, axial CT scans, and the Box View for each patient. Data was collected from reviewers by a paper survey where they were asked to view each image and indicate the presence of an "open" box, a "closed" box, or "unsure."

Radiographic Technique

Non-contrast axial CT scans were performed. Raw CT data was transferred to a General Electric Advantage Windows 2.0 workstation (General Electric Healthcare, Chicago, IL) where it was loaded in reformat and segmented. Reformatting was done in the plane of the femoral component box to produce the largest possible cross-sectional view of the box. In developing this protocol, the team took advantage of the fact that the box was perpendicular to the mechanical axis of the femoral component. The segmentation was performed using paint on slices to exclude the tibia (**Figure 1**, red oval). This was done to prevent signal from the tibia and tibial component from obscuring interpretation of the femoral component box. The key image was a transparent volume projection perpendicular to the box (**Figure 1**, green line). This was essentially an *en face* view of the box. At this point a 36-image, 360° rotational movie was then created using a transparent volume rendering setting. The movies were easily interpreted to determine if the implant has a closed box (**Figure 2**, A and B showing standard radiographs, C showing standard axial CT cuts, and D showing the box view) or open box (**Figure 3**, A and B showing standard radiographs, C showing standard axial CT cuts, D showing the box view, and E and F showing post-operative standard radiographs).

Statistics

Inter-observer reliability was assessed for interpretation of plain radiographs, axial CT images, and Box View using 2-factor analysis of variance (ANOVA) without replication. The sensitivity and specificity of the Box View versus plain radiographs and the Box View versus CT were assessed using the Stuart-Maxwell test for marginal homogeneity. Statistical analysis was performed using Stata Release 15 (StataCorp LLC, College Station, TX).

Results

The sensitivity of the Box View was excellent (81%), as was the specificity (97%). The Box View had excellent positive (100%) and negative (85%) predictive values in this non-fractured test population (**Table 1**).

The sensitivity and specificity were compared for the Box View versus plain radiographs as well as for the Box View versus CT using Stuart-Maxwell test for marginal homogeneity (**Table 2**). The Box View's specificity (97%) was significantly better than both plain radiographs (53%,P= .003) and CT (50%, P=.002). The Box View's sensitivity (81%) was significantly better than CT (34%, P<.001) but not plain radiographs (77%, P=.63).

Intra-class correlation showed excellent inter-observer agreement with the Box View (0.88). This differed from the agreement with plain radiographs (0.65) and CT (0.09, **Table 3**).

Discussion

Whether the femoral component of a TKA is amenable to retrograde IMN is often unclear based on plain radiographs and axial CT scan. In geriatric patients, lateral locked plating of supracondylar femur fractures has limitations mainly due to failure rates.[7] There have been conflicting results regarding outcomes of lateral locked plating versus retrograde IMN, with a recent study finding no functional difference between the 2 treatments at 1 year, but others showing potential benefits to IMN fixation for coronal plane deformity and early patients outcomes.[7-9] Combination of lateral locked plating with IMN fixation has shown improved rates of unplanned reoperation and varus collapse.[10] Ultimately, choice of fixation in periprosthetic distal femur fracture is multifactorial and includes an evaluation of available bone stock, the femoral component of the TKA, and surgeon preference, but incorporation of IMN alone or in combination with lateral locked plating is a growing trend when it is feasible. Despite a growing appreciation of the advantages of femoral nailing, there is a lack of efficient diagnostic options for assessing if a fracture is amenable to nail fixation.[11] The Box View technique offers an efficient method for pre-operatively distinguishing fractures potentially amenable to retrograde IMN fixation. The technique produces images which are easily and reliably interpreted. Interobserver agreement demonstrates that the technique is highly reproducible across multiple levels of training. Additionally, the high sensitivity and specificity of the Box View when compared with both standard formatting of CT imaging makes it a valuable technique when CT imaging is used in pre-operative planning for peri-prosthetic distal femur fracture. Although there was not a statistical difference in sensitivity of the Box View compared to plain radiographs, it has a much higher specificity.

This technique has a number of limitations. The focus of this study was on identifying the presence of an open box component, but did not include any evaluation of surgeon ability to use the Box View method to accurately measure the size of the open box aperture, which can also im-

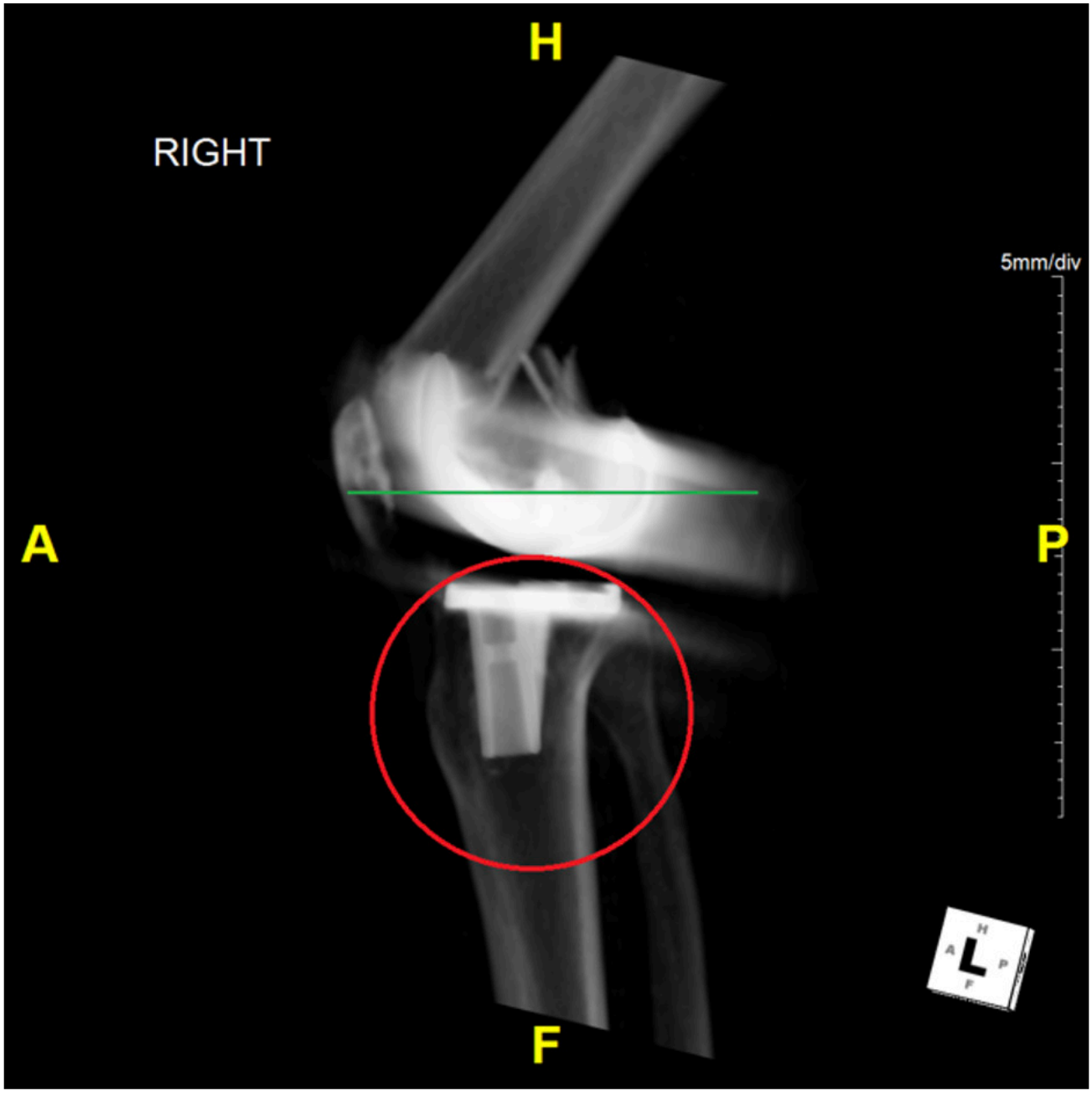

Figure 1. Box View Image Processing.

After segmentation, reformatting, and reconstruction, the volume representing the tibia (red oval) is subtracted. In the second step a ghost view is projected along an axis perpendicular to the green line to give an axial view of the total knee arthroplasty (TKA) femoral component box. A=anterior, P=posterior, H=head, F=foot.

pact the feasibility of utilizing a retrograde IMN.[12] The most accurate way of determining whether a femoral component can accept a retrograde IMN of a given size remains to obtain the operative report from the index TKA surgery and every attempt should be made to obtain this information if possible. However, in cases when the operative report is unavailable within a reasonable timeframe, the Box View can be a useful technique for pre-operative planning. The Box View is an adjunctive technique which requires a radiographic technician familiar with image post-processing, including volumetric subtraction and ghost view projection. It also requires a pre-operative CT. However, even prior to implementation of this technique, non-contrast CT was often part of pre-operative workup to assess intact bone volume and to evaluate the femoral component. Furthermore, multiple attempts to manipulate the unstable fracture to obtain quality orthogonal radiographs can result in both increased radiation to the patient as well as significant patient discomfort. In this setting, the Box View reconstruction technique is fast and effective and imparts minimal additional risk to the patient. Future investigation of the Box View technique should include evaluation of the accuracy of measuring the box aperture for the purpose of evaluating the maximum diameter IMN that can be accommodated. Overall, this Box View has the advantage of facilitating and improving preoperative planning in supracondylar periprosthetic distal femur fractures above a well-fixed TKA.

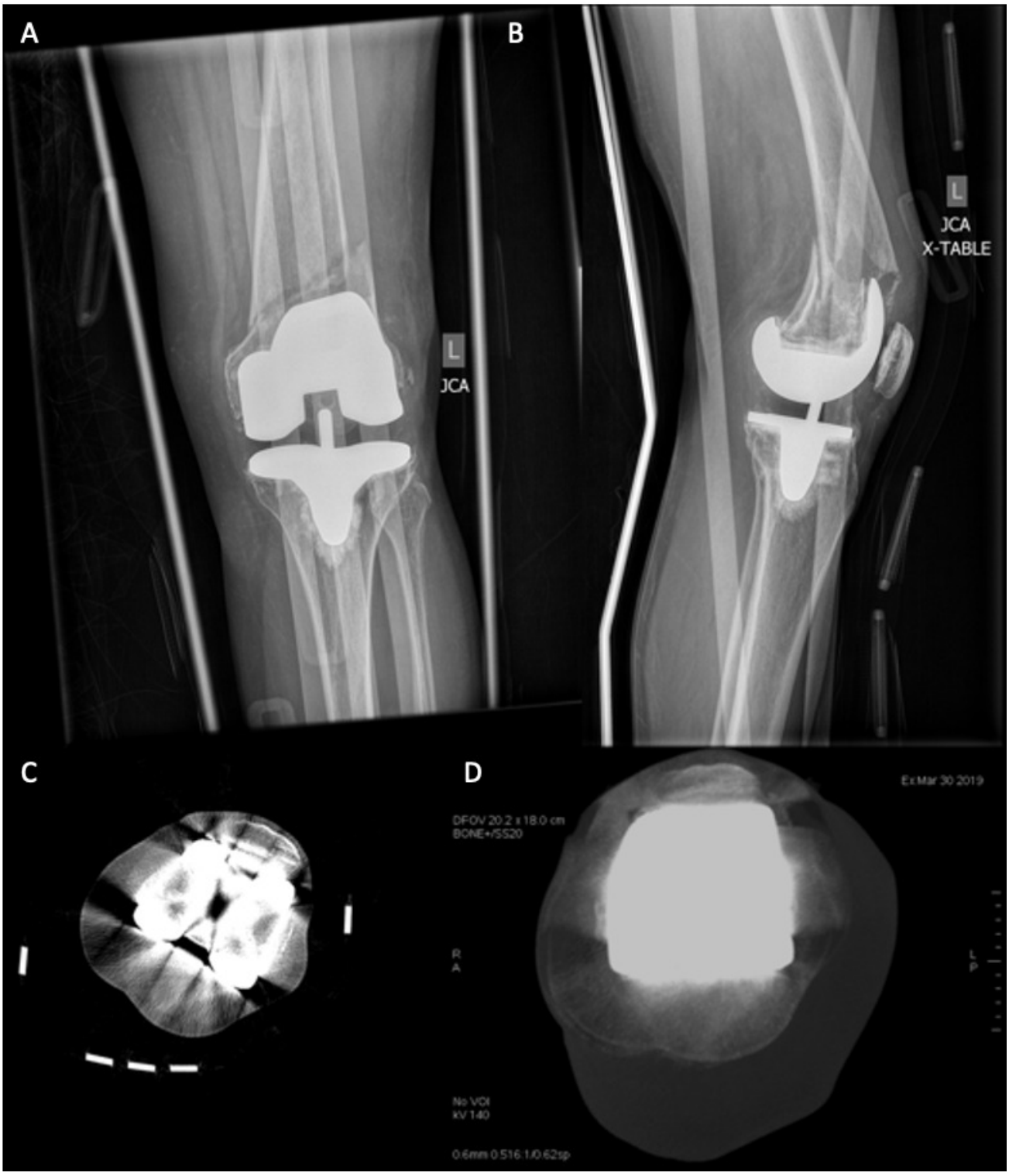

Figure 2. Example of the Unreliability of Conventional Imaging Methods and the Potential Value of the Box View.

A 75-year-old female with a remote history of left knee TKA who sustained a mechanical ground level fall and presented with chief complaint of left knee pain and deformity. A: Anteroposterior knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. B: Lateral knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. C: Axial CT images appear to demonstrate an open box. Intraoperatively a nail could not be passed, and the fracture was treated with a lateral plate. D: Retrospective post-operative Box View clearly demonstrates a closed box.

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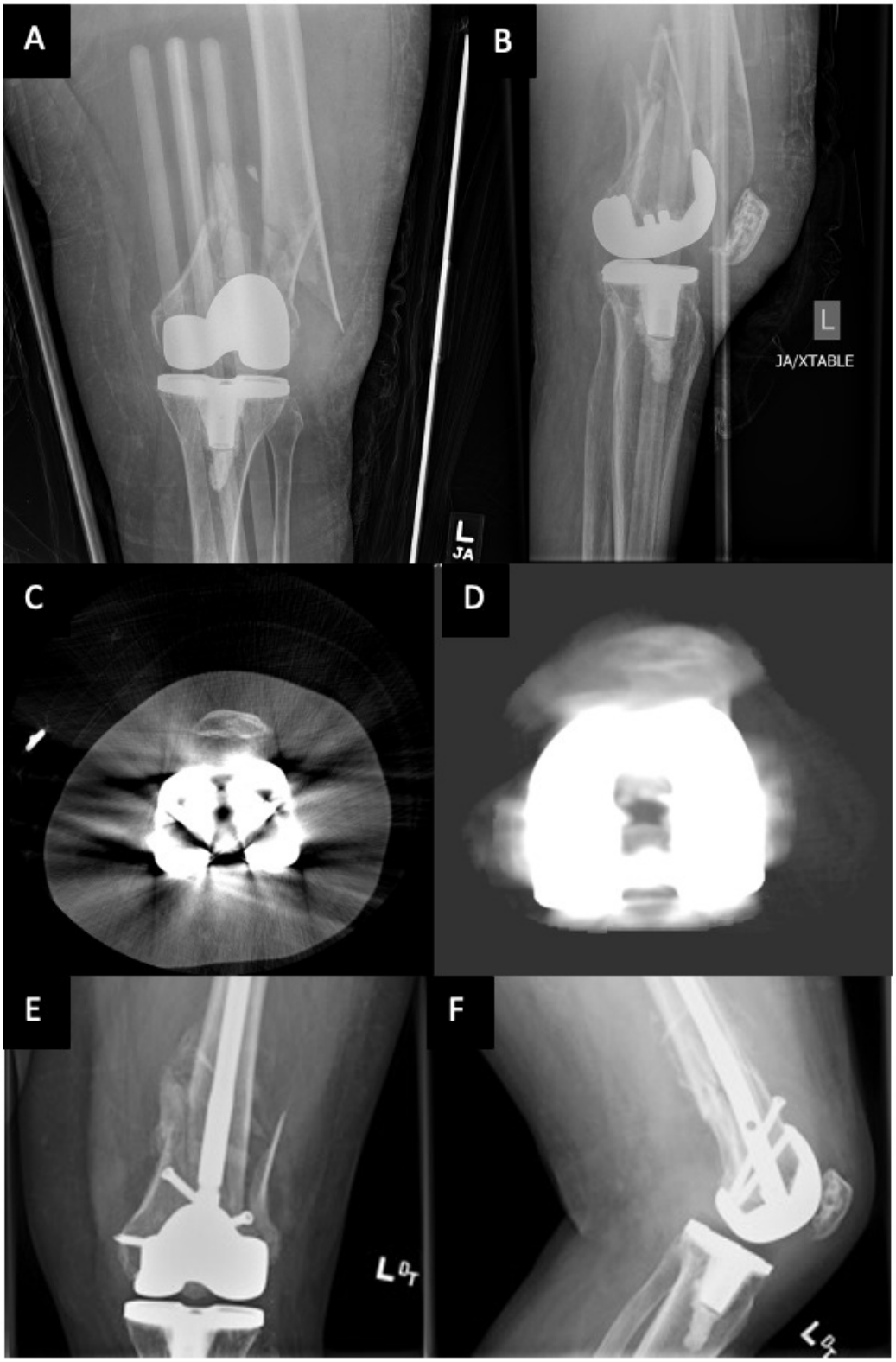

Figure 3. Example of Accurate Identification of an Open Box Using the Box View.

64-year-old female with a one-year history of well-functioning left TKA presenting with left knee pain and inability to bear weight after a mechanical ground level fall. A: Antero-posterior knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. B: Lateral knee radiograph demonstrating a distal femur fracture with a total knee arthroplasty. C: Axial CT image is unclear as to whether the femoral component has a closed or open box. D: Box View clearly demonstrates an open box design amenable to IMN. E: Anteroposterior knee radiograph after intramedullary nailing. F: Lateral knee radiograph after intramedullary nailing.

Table 1. Results for the Interpretation of Plain Radiographs, Computed Tomography (CT) and Box View for the Validation Sample in Pre-operative Identification of Open Box Femoral Components.

	Sensitivity	Specificity	PPV	NPV
Plain radiograph	77	53	95	76
Computed tomography (CT)	34	50	82	56
Box View	81	97	100	85

PPV=Positive predictive value; NPV=Negative predictive value.

Table 2. Comparison of Box View, Plain Radiograph, and Computed Tomography Test Performance in Identification of Open Box Design

	Stuart-Maxwell	df	*P*-value[a]
Box view versus plain radiograph			
Sensitivity	0.92	2	.632
Specificity	11.36		**.003**
Box View versus computed tomography			
Sensitivity	38.47	2	**<.001**
Specificity	12.44	2	**.002**

df=Degrees of freedom
[a]Stuart-Maxwell test for marginal homogeneity

Table 3. Intra-class Correlation Demonstrating the Inter-observer Reliability of Interpretation of Plain Radiographs, Computed Tomography, and Box View in the Validation Sample

	Inter-observer agreement quotient[a]
Plain radiograph	0.65
Computed tomography (CT)	0.09
Box View	0.88

[a]2-factor analysis of variance (ANOVA)

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Hasegawa ME, Livingstone J, Chan SK, Rimm JB, Burnham M, Murray P. An Ex Vivo Study Measuring the Effects of Circumferential and Near-Circumferential Closed Incisional Negative Pressure Wound Therapy Dressings on a Porcine Model. *Hawaii J Health Soc Welf*. 2026;85(6):163-168. doi:10.62547/YMDY4740

An Ex Vivo Study Measuring the Effects of Circumferential and Near-Circumferential Closed Incisional Negative Pressure Wound Therapy Dressings on a Porcine Model

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Keywords: Wound Vac, Negative pressure wound therapy, compartment pressures

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Abstract

To investigate the effects of circumferential and near-circumferential closed incisional negative pressure wound therapy (ciNPWT) dressings on compartment pressures within varying tissue levels using an ex vivo porcine model. A deceased swine model was utilized, with bilateral hind legs disarticulated and prepared for experimentation. ciNPWT dressings were applied at 100%, 75%, 50%, and 25% circumferential coverage, with negative pressures set at -200 mmHg, -125 mmHg, and -25 mmHg. A STIC pressure monitor device measured pressures at tissue depths of 10 mm, 20 mm, and 40 mm. Measurements were repeated 3 times for each configuration, and the averages were calculated. Compartment pressures increased with greater magnitudes of negative pressure and were highest at superficial tissue layers. The pressure differences between superficial and deeper layers were most pronounced in 25%-75% circumferential configurations, suggesting that non-circumferential dressings create a pressure gradient. These findings align with a compressive rather than a "lift-off" force mechanism. This study highlights ciNPWT's compressive effects, particularly on superficial tissues, and suggests that pressure gradients in non-circumferential configurations may enhance fluid dynamics and wound healing. The findings also support the potential role of ciNPWT in inducing mechanotransduction and angiogenesis. Limitations include the use of an ex vivo model and variability in measurement accuracy. Especially in superficial layers, ciNPWT exerts a compressive force with non-circumferential dressings allowing greater pressure gradients. Future in vivo studies are needed to confirm these findings and further explore the therapeutic mechanisms and potential applications of ciNPWT.

Abrreviations

ciNPWT= closed incisional negative pressure wound therapy
ECM=extracellular matrix
NPWT=negative pressure wound therapy

Introduction

Efforts to investigate negative pressure wound therapies effects on wound healing have increased since the 1997 study by Morykwas et al, which showed improved wound perfusion in a swine model utilizing negative pressure wound therapy (NPWT).[1,2] Likewise, improvements in technology have also continued, as exemplified by the advent of closed incisional negative pressure wound therapy (ciNPWT), a variation of NPWT, thus continuing to expand indications and applicability of a NPWT system.[3] Yet, even with accumulating studies examining clinical and surgical use or indications, understanding of physiologic effects and mechanisms remain incompletely understood.[4] Prior authors have postulated that mechanotransduction signaling resultant of microdeformation and macrodeformation from the interaction of soft tissue and NPWT sponge may be responsible.[5-8] In earlier literature, macrodeformation through compression in a circumferential NPWT led some to theorize there may be diminished perfusion distal to NPWT dressings in an extremity.[5] Though, in a recent study by Livingstone et al, the effects of circumferential and near circumferential ciNPWT on an elastic ball model suggested near-circumferential or circumferential NPWT at certain negative pressures may decrease the pressure of the extremity exposed to a NPWT system. Livingstone et al's findings seem to suggest, particularly in a near circumferential configuration, a "lift-off" force occurring rather than compressive force, which could possibly facilitate improved venous and lymphatic drainage from an extremity.[4] Even so, literature concerning NPWT or ciNPWT has yet to reliably or wholly explained its physiologic effects or mechanisms. This study aimed to examine compartment pressures within varying tissue levels at differing degrees of circumferential compression, and magnitudes of negative pressures in an *ex vivo* porcine tissue model. The authors hypothesize there would be higher compartment pressures at more superficial tissue layers, and a linear increase in compartment pressures at larger magnitudes of negative pressure, suggesting a more compressive force being imparted. The authors additionally theorized compartment pressure differences, between superficial and deeper layers, would have the greatest difference at circumferential and near circumferential ciNPWT dressing configurations.

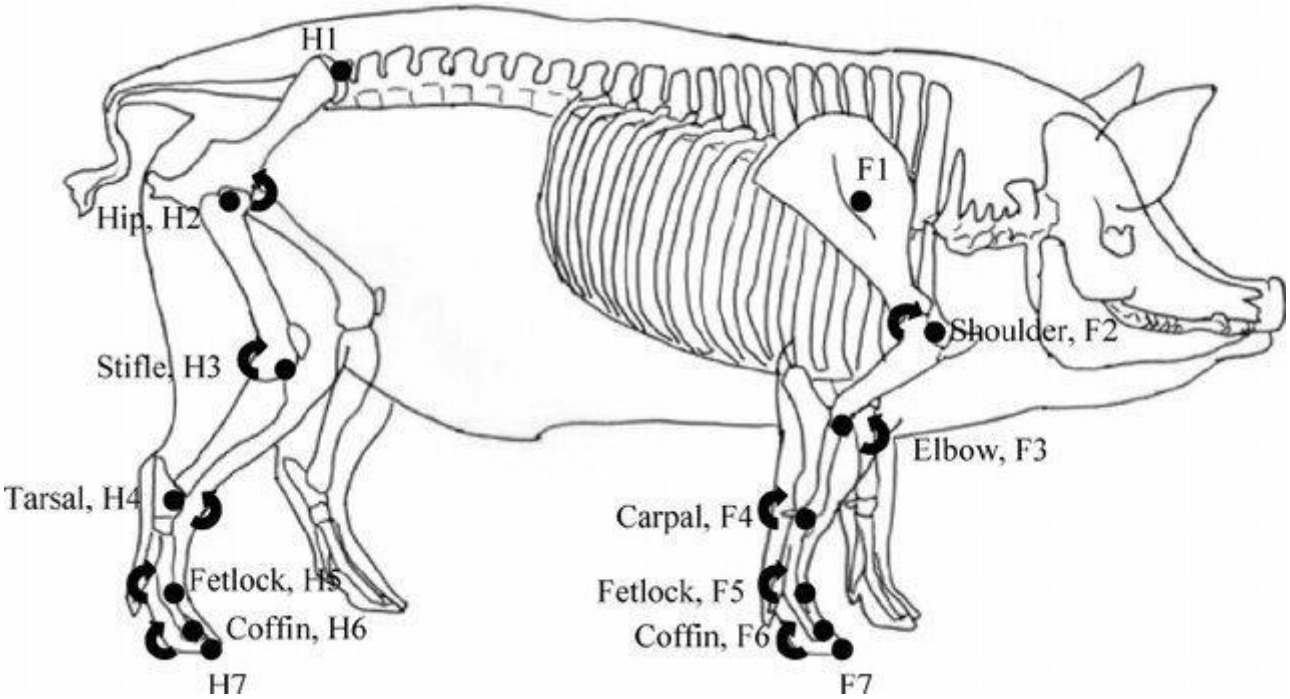

Figure 1. Labeled Joints of a Porcine Specimen[a]

[a]Used with permission from Thorup et al[9]

Methods

Preparation of specimen

A 27-pound deceased whole pig was purchased from a commercial retailer. Bilateral hind legs were disarticulated through the hip joints. Hind legs were then left to thaw until room temperature prior to further manipulation and to ensure compartments were not affected by frozen tissue conditions.

Measurement of tissue levels

One hind leg was chosen for determination of tissue level depth. An incision was made at a point approximately half the distance between the hip joint and stifle joint of the specimen (**Figure 1**). This incision was carried down to the porcine femur bone. There was negligible subcutaneous tissue, and the distance did not allow for adequate penetrance of the compartment measuring needle, therefore the distance from the skin to the most superficial muscular layer was measured and found to be 10 mm. The distance between skin and the intermediate muscular layer was then found to be 20 mm. And then the distance from skin to femur bone was then measured to be 40 mm.

Wound vac application

The negative pressure wound vacuum sponge was placed 100% circumferentially at a point corresponding to the center of the incision made on the contralateral leg. Wound sponge was then placed circumferentially, in a transverse orientation. Adhesive tape was placed over the sponge creating a seal, and the dressing was connected to negative pressure wound vacuum machine. Appropriate seal was confirmed on manufacturer's negative pressure wound vacuum machine (3M science, St. Paul, MN). This process of confirming appropriate seal was repeated for 75% circumferentially wrapped wound vac, 50% or 25%, with dressings in same place and orientation as placed in the 100% circumferentially wrapped configuration. An example of specimen preparation can be seen in **Figure 2**.

Measurement of pressures

A STIC pressure monitor device (C2Dx INC., Schoolcraft, MI), which included a pressure monitor console and accompanying needle, was used to obtain pressures at selected levels. Calibration was accomplished based on manufacturers recommendation. The needle was then introduced at a distance of 50 mm directly adjacent to sponge, at a point corresponding to the center of the incision on the contralateral leg, and directly adjacent to the lily pad suction tubing used to achieve negative pressure. At each tissue level, the compartment measuring needle was equilibrated to ensure accurate measurements according to manufacturer's recommendations. Prior to measurement, the pressures were recorded without any NPWT and found to 0 mmHg. The needle was then inserted at depths of 10 mm, 20 mm, and 40 mm. This process was repeated for all percentages of circumferential wound vacuum compression, and magnitude of negative pressures, including -200 mm Hg, -125 mm Hg, and -25 mm Hg. Compartment pressures were repeated a total of 3 times for each magnitude of negative pressure, tissue level, and degree of circumferential wrapping configurations, and the averages were calculated.

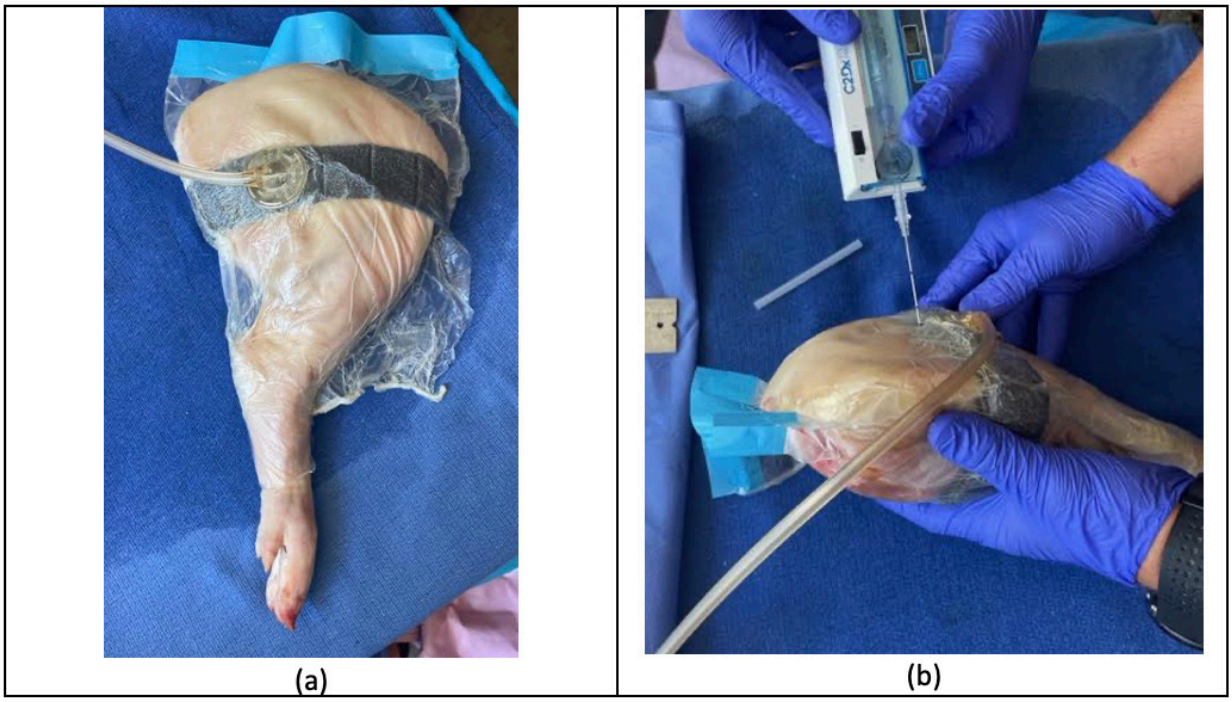

Figure 2. Specimen Preparation and Illustration of Compartment Pressure Measurement

a) Specimen with dressing and negative pressure wound vacuum sponge b) Using compartment pressure device to collect data

The data was recorded in a Microsoft Excel Spreadsheet (Microsoft Corp, Redmond, WA)

Results

The results can be observed in **Table 1** and **Figure 3**. Compartment pressures remained low regardless of negative pressure setting, thus increasing negative pressure value did not translate into meaningful deep tissue compression. Compartment pressures tended to be lower with 100% circumferential dressing configuration. Pressures were at the highest between 25% and 75% circumferential configurations.

Discussion

While NPWT and ciNPWT have become increasingly utilized augments for wound management, the mechanisms of action by which they appear to affect wound healing are not fully elucidated.[1-3] Very few studies in the literature have examined the measurable compartment pressures within tissues subjected to NPWT or ciNPWT.[10] This study, is the first to the authors' knowledge, examining pressures within various tissue levels at varying absolute values of negative pressure and varying percentage of circumferential dressing configurations. The findings in this study seem to suggest a more compressive force, particularly at more superficial layers of tissue, imparted by the ciNPWT and NPWT, rather than a "lift off" phenomenon.[4] There were greater increases in pressures at more superficial layers at greater absolute magnitudes of negative pressures, suggesting greater magnitudes of negative pressure increase the compressive force on underlying tissues. Prior literature has examined the effects of a compressive force's effects on affected tissues, and specifically angiogenesis, though not in a NPWT setting. Ruehle et al found immediate load initiation on nascent microvascular vascular sprout tips inhibited angiogenesis, while delayed compression of extracellular matrix (ECM) increased microvascular formation, and additionally upregulated upstream signaling pathways. Their research suggested not only timing, but mode, and magnitude of a compressive force may affect angiogenesis.[11] This could explain why negative pressure wound therapy has been associated with improved wound healing and increased angiogenesis.[7,12] The mechanism by which a compressive force induces angiogenesis was evaluated by Vaeyens et al, who described a tractional force between ECM and vasculature at the microscopic level facilitated by cytoskeletal components linking the nascent vasculature to the surrounding ECM, inducing budding angiogenesis.[12] A pressure gradient created by ciNPWT or NPWT, as seen in this study, in theory could provoke an angiogenic response by inducing mechanical stimuli facilitated by the ECM and its cytoskeletal connections to nascent vasculature, as understood by works from Vaeyens et al and Ruehle et al.[11, 12] This concept of a pressure gradient was also discussed in a study by Murphey et al examining penetrance of negative pressure in a NPWT model, in which the authors also postulated a potential pressure gradient created under the dressings, and subsequent fluid movement due to these pressure differences.[10] The resultant fluid dynamics and pressure gradient could additionally be enhancing edema clearance, which has been linked with improved wound healing.[13-15] Based on these findings, it is theoretical that NPWT, in part, may be inducing mechanical stimuli both directly to nascent or budding vasculature and indirectly by inducing a

Table 1. Compartment Pressures Measured at 10 mm, 20 mm, and 40 mm Depth Using Varying Negative Pressures and Dressing Configurations

Dressing Type	Pressure Setting (mmHg)	Pressure (mmHg) at 10 mm	Pressure (mmHg) at 20 mm	Pressure (mmHg) at 40 mm
100% Circumferential NPWT	-200	4.2	3.5	0.5
	-125	3.3	4.2	2.2
	-25	3.2	3.8	1.2
75% Circumferential NPWT	-200	7.0	7.0	7.0
	-125	10.0	5.0	1.0
	-25	7.0	2.0	1.0
50% Circumferential NPWT	-200	5.0	4.0	3.0
	-125	4.0	3.0	3.0
	-25	6.0	5.0	3.0
25% Circumferential NPWT	-200	8.0	3.0	0
	-125	4.0	1.0	1.0
	-25	4.0	1.0	0

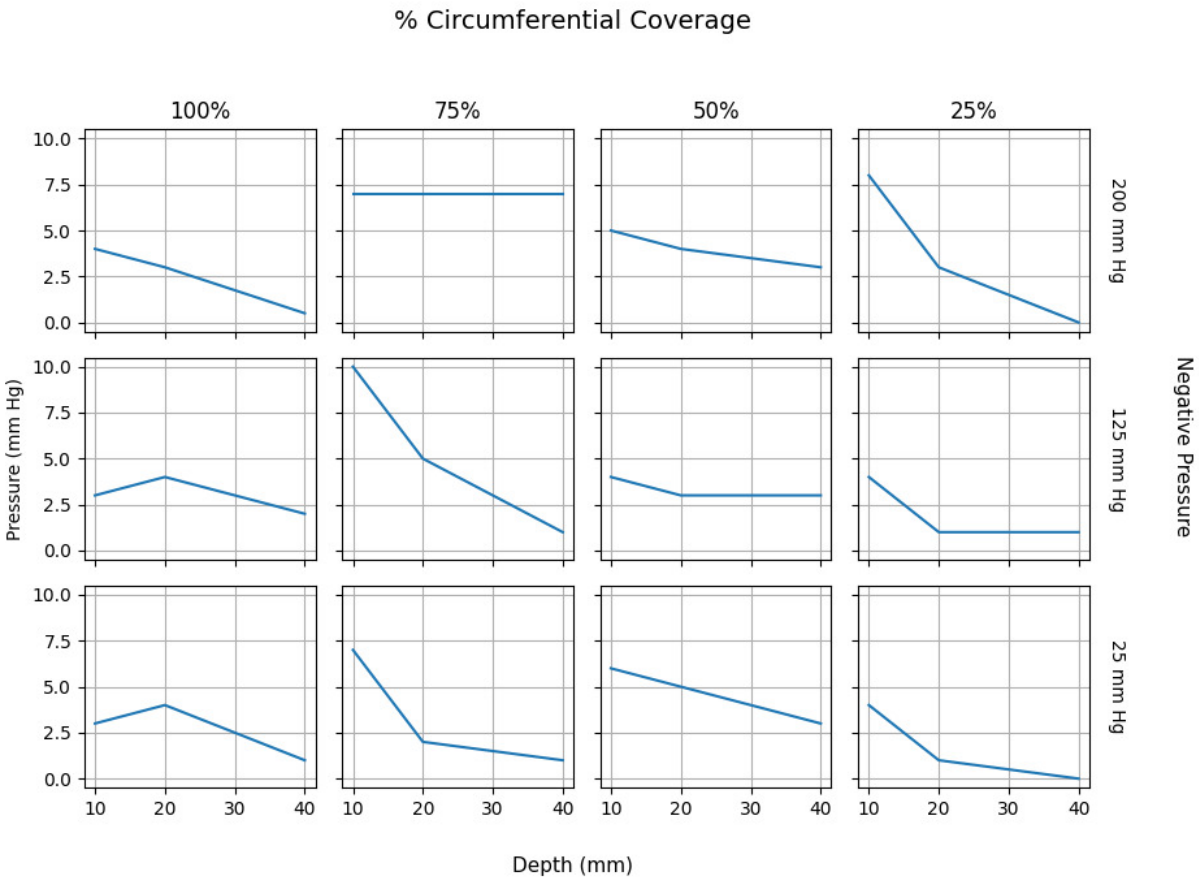

Figure 3. Compartment Pressure Measurements on Circumferential and Near-Circumferential Closed Incisional Negative Pressure Wound Therapy Dressings

mechanical stimuli within interstitial fluid and extracellular matrix, as well as augmenting fluid dynamics to enhance angiogenesis and wound healing. Based on the findings of this study, whatever downstream effects NPWT or ciNPWT may be inducing appear to be via a compressive force imparted from the NPWT or ciNPWT dressings, rather than an externally produced negative pressure in the underlying tissues.

Another novel aspect of this study was examining the effects of different dressing configurations. Prior work by Livingstone et al also examined differing degrees of circumferential dressing coverage. In their elastic ball model, they

noted the greatest effects on pressure were seen in configurations between 20%-90% of circumferential coverage, with the greatest effect at a 66% of circumferential coverage.[4] In this study, the greatest differences in pressures were observed in the 25%-75% of circumferential configurations. The authors believe this may due to non-circumferential configurations allowing tissue and fluid shifts into the portion of the body not in contact with wound vacuum dressings. These "far side" of the models were not subject to a compressive force in a circumferentially dressed configurations, thus allowing for a greater gradient to occur with consistently higher tissue pressures seen at tissue levels closer to the sponge dressing in the non-circumferential configurations. In a full circumferential dressing configuration, any point along the sponge would have the effect of its compressive force mitigated by a corresponding opposing vector from a point directly 180 degrees from it along the sponge dressing. This could explain why higher pressure gradients were observed in non-circumferential dressing configurations, as there was a "far side" portion of the model without sponge dressing which could deform or change shape.

There are limitations to this study. First, a deceased swine model does not have the same compartment pressures of an in vivo model. An in vivo model, when subjected to compressive forces, would likely exhibit different changes due to increased compartment pressures at baseline within tissue compartments. Additionally, the swine model used was a disarticulated hind leg. The disarticulation theoretically could affect the intracompartmental pressures being measured. As such, to isolate the effects of NPWT with as much clinical approximation possible, in vivo whole intact models should be utilized. Another possible limitation is the method of measuring compartment pressures. Though the CD2x STIC instrument was used as recommended by manufacturer instructional guide, equilibration is achieved by introducing "less than 3/10 cc of saline " into a compartment. It is unknown how introducing 1/10 cc versus 2/10 cc may have affected any measurable difference in pressure with the chosen deceased swine model. It must also be noted the degree of accuracy for the CD2x STIC device is +/- 3.4 mmHg, which with the reported compartment pressure levels could affect the observed differences between varying tissue levels, magnitudes of negative pressure and degrees of circumferential dressing configurations. It is also unknown if there may be a greater effect at other varying negative pressure values than the -200 mmHg, -125 mmHg, -25 mmHg used in this study. These values were chosen to approximate values at a higher magnitude of negative pressure, a middle value, and a lower magnitude of negative pressure. And while prior studies have commented on the effects of NPWT dressing material and shape altering its effects on force transmission, this study was not designed to isolate or examine effects of differing sponge material designs or patterns.[7,16]

In conclusion, this study found compartment pressures measured at varying tissue levels and magnitudes of negative pressure showed a positive increase in compartment pressure which appeared to be inversely correlated with distance from the skin. This study also suggested non-circumferential dressing configurations allowed for a pressure gradient to form along the tissue layers. Future studies should include an in vivo model to further elucidate if these findings are replicated in an in vivo model. Likewise, additional studies further elucidating if the forces transmitted during NPWT reach a critical level to induce mechanotransduction and subsequent angiogenesis via mechanisms reported in prior literature. The implications of such a finding may suggest NPWT, and ciNPWT, could have a role in tissue healing beyond just wounds or incisions, if it is able to impart mechanical changes at tissue levels around deeper structures. While the findings in this study are novel, further work is needed to continue establishing NPWT and ciNPWT's mechanism of action, and elucidate their full therapeutic possibilities.

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Chan S, Horng J, Hasegawa ME, et al. A Metal-Associated Epithelioid Angiosarcoma: A Case Report and Literature Review. *Hawaii J Health Soc Welf*. 2026;85(6):169-173. doi:10.62547/MOZH2737

A Metal-Associated Epithelioid Angiosarcoma: A Case Report and Literature Review

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Abstract

Angiosarcoma is a rare, aggressive malignancy that accounts for less than 1% of sarcomas of bone. Epithelioid angiosarcoma, a subtype, is characterized by pleomorphic cells with vascular differentiation and commonly arises in deep soft tissues of the extremities. Angiosarcoma associated with orthopedic implants or retained foreign bodies, such as ballistic debris, is exceedingly rare. Here, the authors present the case of epithelioid angiosarcoma in a 54-year-old male with a history of a prior proximal femur ballistic injury and intramedullary nail fixation who was initially misdiagnosed with chronic osteomyelitis.

Introduction

Angiosarcoma is a rare and aggressive malignancy which accounts for less than 1% of sarcomas of the bone.[1,2] Epithelioid angiosarcoma is a subtype that has also been found in diverse primary sites throughout the body, but most commonly arises from deep soft tissue locations in the extremities.[3-5] Prognosis for angiosarcoma of the bone is overall poor, with median survival rates reported to range from 9-16 months; however, some subsets of patients have more favorable prognosis, with protective factors including stage of cancer upon presentation, age under 50, and surgical treatment.[2,6] Histologically, the epithelioid subtype of angiosarcoma is characterized by large, pleomorphic round cells with prominent nucleoli and high mitotic activity, organizing in sheets and focal areas of vessel formation with irregular anastomoses which can be demonstrated on hematoxylin-eosin staining.[4] Angiosarcoma arising in relation with retained foreign bodies, including orthopedic implants such as intramedullary nails and total joint arthroplasty components, is rare but has been reported in both orthopedic surgical and pathology literature.[5,7,8]

Case

Patient is a 54-year-old male who initially presented to the emergency department with left groin, hip, and thigh pain and orthopedic consultation was requested for concerns of left proximal femur osteomyelitis. Patient reported pain had begun 6 months prior. Work up by various health care professionals attributed his symptoms to adductor muscular strains, osteoarthritis, and trochanteric bursitis. He was prescribed NSAIDs and given a steroid injection to left hip.

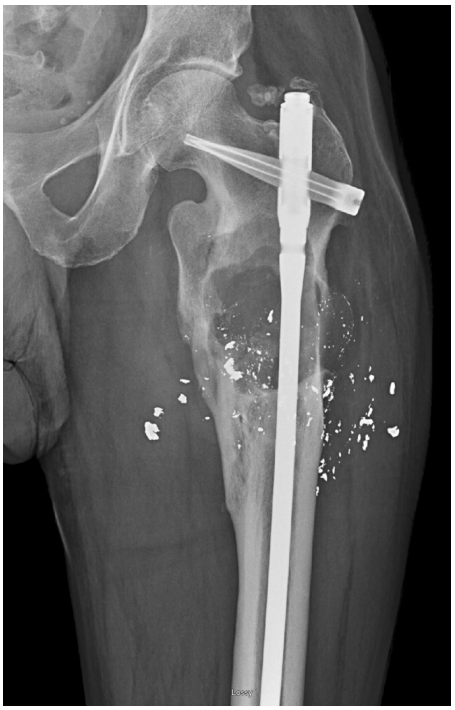

Figure 1. Radiograph of the left femur, demonstrating a cephalomedullary nail *in situ*, bullet fragments, and a remote subtrochanteric femur fracture with lytic changes

There was some relief, but symptoms persisted. He was referred to an orthopaedic clinic where labs demonstrated leukocytosis and elevated inflammatory markers. The patient's pertinent past medical history included a remote open left subtrochanteric femur fracture after ballistic injury, which was sustained approximately 30 years prior and initially treated with a cephalomedullary nail.

At that time of initial assessment, he endorsed subjective fevers and chills. Plain films demonstrated the pre-existing cephalomedullary nail, ballistic debris, as well as an age-indeterminate proximal diaphyseal lytic lesion (**Figure 1**). Nuclear medicine bone scan redemonstrated the lytic lesion, also showing local soft tissue involvement (**Figure 2**). CT guided biopsy was suggestive of acute osteomyelitis. He elected for conservative management with IV antibiotics and was discharged with an appropriate antibiotic plan.

Symptoms initially improved some, but he presented again 1 month later with exacerbation of pain. Magnetic resonance imaging (MRI) was obtained and demonstrated a

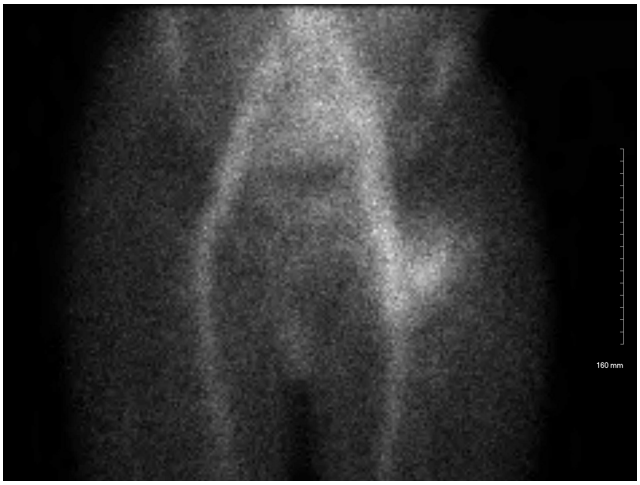

Figure 2. Nuclear medicine bone scan showing increased soft tissue and bone reactivity at the left proximal femur

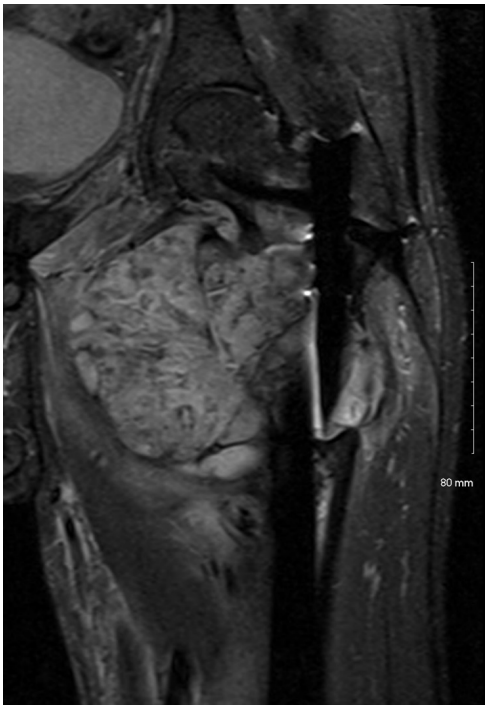

Figure 3a. MRI (fat suppressed) of the left proximal femur, coronal

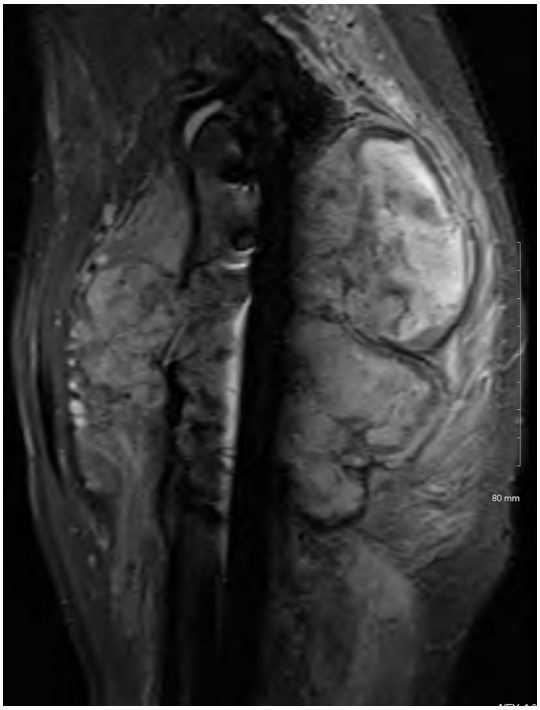

Figure 3b. MRI (fat suppressed) of the left proximal femur, sagittal

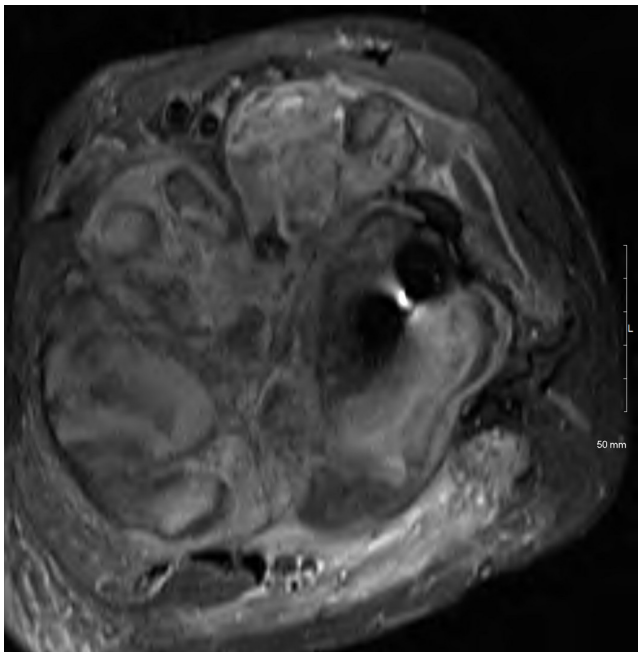

Figure 3c. MRI (fat suppressed) of the left proximal femur, axial

13.4 cm x 140 cm x 13.6 cm lobulated, heterogeneous, destructive mass in the proximal femur with osseous destruction and soft tissue infiltration into the anterior, posterior, and adductor compartments (**Figure 3**). The sciatic nerve was displaced posteriorly but not encased by the mass. Inguinal lymphadenopathy and flow voids within the femoral vascular structures were also noted. Repeat nuclear medicine bone scan redemonstrated abscess and osteomyelitis.

The patient subsequently underwent hardware removal, debridement, intramedullary biopsies, and revision cephalomedullary nail fixation. Gross examination of the intramedullary samples demonstrated aggregates of clotted blood and bone totaling a size of 5.1 cm x 3.8 cm x 0.5 cm. The explanted hardware was unremarkable. Microscopically, the intramedullary biopsies were determined to be a high-grade malignancy with vascular differentiation, consistent with epithelioid angiosarcoma. There was positive immunohistochemical expression of CD31, ERG, cytokeratin AE1/AE3, and cytokeratin 8/18 (**Figure 4**); and nega-

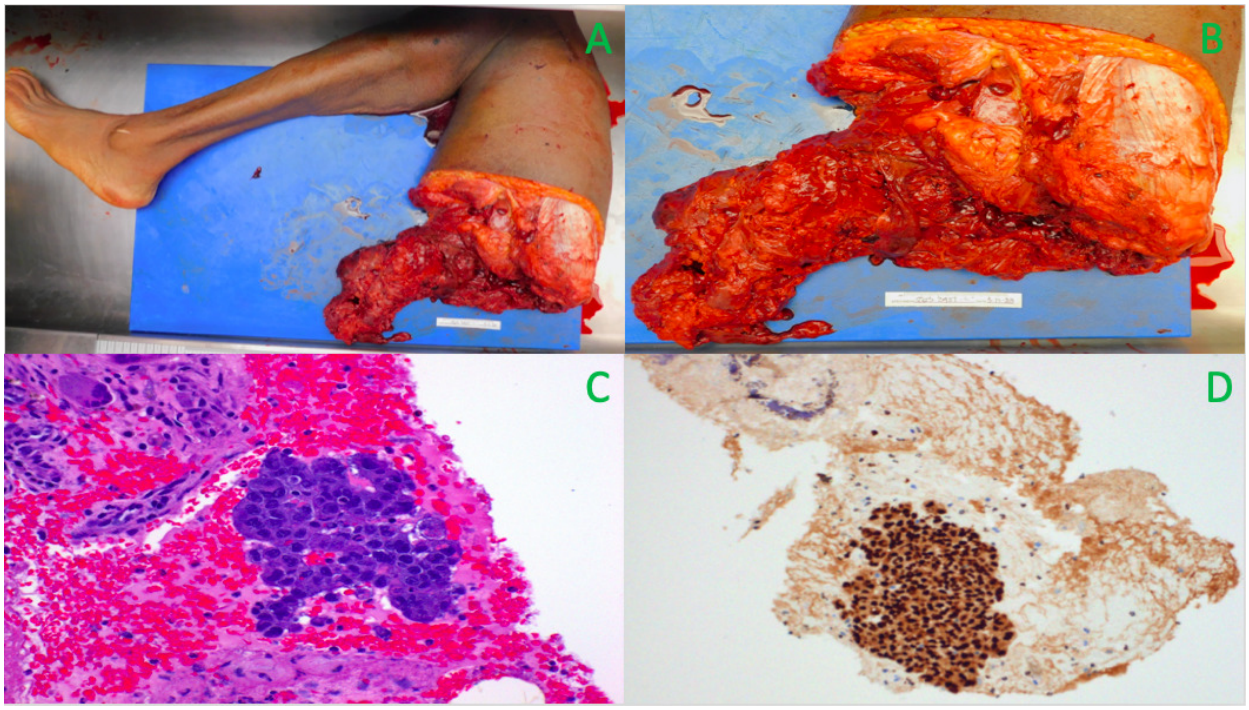

Figure 4. Gross image of left leg with tumor (A&B). Microscopic section of viable tumor cells, Hematoxylin-Eosin stain (C). Tumor cells showing positive immunohistochemical expression for ERG (D).

tive for S100, SOX100, GATA3, NKX3.1, TTF1, PAX8, CDX2, p40, HHV8, and CD34.

Whole body PET/CT scan demonstrated a hypermetabolic lesion to the left proximal thigh. There was no evidence of regional or distant metastatic disease. The tumor was staged as Stage III T2N1M0 epithelioid angiosarcoma. The patient was started on neoadjuvant gemcitabine/docetaxel with intent of limb salvage and completed the course. However, after additional consultation with medical and orthopedic surgical oncology, the limb was deemed unsalvageable and the patient ultimately underwent hip disarticulation

Gross examination of the specimen revealed an irregular gray-white hemorrhagic mass in the proximal thigh with extension into the surrounding soft tissues measuring 18 cm x 9 cm x 7 cm (**Figure 4**). The proximal margin was negative and microscopically there was 99.9% necrosis of the tumor and 0.1% viable tumor, indicating positive treatment effect. Three regional lymph nodes were negative for tumor.

The patient developed post-operative anemia and surgical site hematoma, which was surgically evacuated. Cultures were positive for *Pseudomonas aeruginosa*, vancomycin-resistant *Enterococcus faecium*, *Escherichia coli*, and *Eubacterium limosum*. The patient was started on appropriate antibiotic therapy and underwent serial debridements. The wound eventually healed well with negative cultures.

Discussion

This is a case of ballistic fragment associated epithelioid angiosarcoma in 54-year-old male with a remote history of ballistic left subtrochanteric femur fracture treated with a cephalomedullary device. Metal induced epithelioid angiosarcoma has been described in the literature in association with metal orthopedic implants,[9-16] however, to the authors' knowledge, this is the first report of musculoskeletal epithelioid angiosarcoma associated with retained ballistic fragments.

Per McDonald and Enneking,[9] 3 criteria must be met to establish the diagnosis of metal-associated sarcoma. First, the tumor must be in the direct vicinity of a metallic implant in bone or soft tissue, which excludes lesions that occur in the general region of the implant or a more distant site in the same extremity. Second, the tumor should develop after a latency of around 2 years or more, as a tumor identified within one-year of placement of an implant likely was present before surgery at an unrecognizable stage. Third, there should be no other obvious, well-recognized factor predisposing the development of a secondary malignancy, such as radiation or chronic infection. The most significant factor of the current case that opposes these criteria is the presence of chronic osteomyelitis, which has been implicated in carcinogenesis. As such, metal implant associated sarcoma is less likely implicated in this case based on these criteria. Another confounder to these criteria and potential carcinogenic factor in the current case is the presence of retained ballistic fragments. Though the literature is sparse, there are several cases of musculoskeletal ballistic fragment associated malignancy reported in the literature.[15,16]

Ebrahimzadeh and colleagues described 2 cases in which musculoskeletal malignancies developed near retained war shells over 20 years after initial injury.[17] In the first case, a 44-year-old male developed a low-grade osteosarcoma in the distal femoral metaphysis 22 years after suffering a

gunshot wound with retained ballistics to his thigh. In the second case, a 67-year-old male developed a myxofibrosarcoma in his volar forearm 25 years after suffering a gunshot wound with retained ballistics to his palm and hand. The authors propose that retained ballistics may not be as inert as is historically accepted and a monitoring system should be implemented for patients with known retained ballistics.

Teltzrow et al also report a case of ballistic fragment associated angiosarcoma to the temporal region soft tissues in an 84-year-old man that presented 60 years after the injury.[18] This individual's course was initially complicated by infection and purulent sinus, though the authors did not mention if chronic infection was present at time of resection. The authors postulated that the presence of metal composition may have contributed to carcinogenesis, though chronic inflammation was their leading etiology for carcinogenesis.

The etiologies of carcinogenesis to consider in the current case include primary malignancy, secondary to chronic osteomyelitis, and/or metal implant associated. Akin to the above cases, retained ballistic fragments may also be implicated in carcinogenesis. Though seemingly rare, health care practitioners should be aware of this potential association between retained ballistic fragments and malignancy.

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Hasegawa ME, Delos Reyes CD, Rimm JB, Bickley RJ, Thorne TJ, Toney EA. Operatively Treated Pelvic Ring Fractures in Adult Patient with Osteogenesis Imperfecta after Traumatic Injury: A Case Report. *Hawaii J Health Soc Welf*. 2026;85(6):174-178. doi:10.62547/UCTI7575

Operatively Treated Pelvic Ring Fractures in Adult Patient with Osteogenesis Imperfecta after Traumatic Injury: A Case Report

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Keywords: Osteogensis Imperfecta, orthopedics, orthopedic trauma, pelvic ring

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Abstract

Osteogenesis imperfecta (OI) is a rare heritable disorder of type I collagen that predisposes patients to recurrent fractures and skeletal deformities. Although fracture management in children with OI has been widely described, guidance for adult patients is comparatively limited. This is a report of the case of a 35-year-old man with OI who sustained right-sided sacroiliac diastasis and pubic rami fractures following a high-energy bicycle accident. The injury was treated with percutaneous screw fixation, achieving satisfactory reduction and stable fixation without perioperative complications. The patient advanced to full weight bearing at 12 weeks, and at 2-year follow-up demonstrated near-baseline function with Visual Analog Scale and Majeed Pelvic Scores that closely approximated those reported in non-OI populations. Radiographs showed no evidence of malunion or nonunion, though he continued to experience chronic low back pain. This case suggests that standard fixation strategies may be effective for selected adults with mild OI phenotypes, provided that preoperative planning accounts for the condition's distinctive biomechanical and hemostatic challenges.

Acronyms

OI = Osteogenesis imperfecta
VAS = Visual Analog Scale

Introduction

Osteogenesis imperfecta (OI) is a group of genetic disorders involving mutations of type 1 collagen, a substantial component of bone and connective tissues. Deficiencies in type 1 collagen have been associated with fragility fractures, skeletal deformities, and growth disturbances.[1,2] The genetics and phenotypes of OI have been extensively studied, though literature concerning fracture management in adult patients with OI is comparatively sparse.

Much of the current musculoskeletal literature focuses on pediatric presentations and management, even though up to 25% of lifetime fractures will occur when patients are adults.[3] Despite pharmacologic management, many patients will continue to experience sequalae of their conditions, even with advancements in medications and rehabilitative modalities.[4] Some unique challenges implicated in fracture management of adult patients with OI are altered osseous biomechanics, skeletal deformities, sequelae of chronic bisphosphonate use, low bone mineral density, and predisposition for excessive bleeding.[5,6]

While fractures of the pelvis and acetabulum are typically associated with higher energy mechanisms, those with OI may sustain these fractures after low energy mechanisms. Treatment of adult OI pelvic ring injuries include added challenges, as these patients may have a propensity for excessive bleeding, poor bone quality, and preexisting acetabular or femoral head deformities.[7,8] In a case series by Darmanis and Bircher, the authors reported difficulties with standard implant fixation for acetabular fractures in individuals with OI due to acetabular deformities secondary to disease pathology. Their series required surgical modifications to account for acetabular protrusion, thin quadrilateral plate, and poor screw purchase, and highlighted the need for thorough pre-operative planning.[5]

Though the genetics and medical complexities of OI have been well established, the dearth of literature in fracture management, and in particular pelvic ring fractures was the impetus to report this case. As such, the authors present a case report of an adult patient with OI who sustained pelvic ring fractures after a traumatic mechanism requiring operative management, aiming to contribute to the current literature on optimal practice management for this unique patient population.

Case Study

Institutional Review Board committees at the treating hospitals reviewed this case report and appropriate approval was given for commencement of study. The Visual Analog Scale (VAS) and Majeed Pelvic Score questionnaires were utilized. Appropriate patient education regarding each questionnaire was provided. The questionnaires covered the period 1 month prior to injury and then post-operatively at defined intervals: 2 weeks, 6 weeks, 3 months, 6 months, 1 year, 2 years. Of note, the questionnaires were first given at the 6 week post-operative visit, thus the patient had to recall the 1 month pre-injury and 2-week post-op scores from memory.

Patient responses were collected and analyzed on Microsoft Excel 2020 (Microsoft Corporation, Redmond, WA).

The patient is a 35-year-old male who presented after a bicycle accident. The patient felt immediate pain in his right hip and right hemipelvis and was unable to ambulate, requiring paramedic transport to the local community hospital. Past medical history was pertinent for chronic low

back pain and childhood fractures of his wrist and fingers attributed to a known diagnosis of OI. The patient worked as a farmer and had no functional limitations. The patient could not recall which subtype of OI he had been diagnosed with. After medical stabilization at the community hospital, he was transferred to the Level 1 trauma center in Hawai'i. The patient underwent standard advanced trauma life support and was noted to be hemodynamically stable. Initial imaging revealed pelvic ring fractures, notably diastasis of the right sacroiliac joint and right superior and inferior pubic rami fractures. No additional injuries were identified and the patient was stable. Due to insurance considerations, the patient was transferred to another facility for definitive management.

After evaluation by the accepting orthopaedic team, the patient was diagnosed with right-sided sacroiliac diastasis and right-sided displaced superior and inferior pubic rami fractures. After discussion with the patient concerning treatment options, benefits, risks, and alternatives the patient elected to proceed with surgical management of his pelvic ring injury.

Reduction of the right superior ramus was achieved using a femoral distractor with a Schanz pin placed into the left supra-acetabular corridor and another into the greater trochanter towards the femoral neck. Fixation of the right superior pubic ramus fracture was achieved using the retrograde anterior column screw technique with a 6.5mm x 130mm fully threaded screw. The femoral distractor was removed, and attention was turned to the right sacroiliac diastasis. Reduction was achieved at the sacroiliac joint, with subsequent advancement of a 7.3mm x 110mm iliosacral screw. Appropriate reduction and safe screw placement were confirmed with intra-operative fluoroscopy.

Post-operatively

The patient was discharged on post-operative day 3 and planned for touch down weight bearing on right lower extremity for 3 months post-operatively. The patient was seen at routine follow up with no signs of wound dehiscence throughout the follow-up period. The patient did report right hip pain at his initial 2-week follow-up, with resolution of pain and full active and passive range of motion by his 6-week follow-up. The patient did note acute worsening of his chronic low back pain at his 6-week visit, however the patient attributes this pain to the nature of his work and is well documented prior. The patient was liberated to full weight bearing at approximately 12 weeks post-operatively. At his last follow-up, approximately 2 years post-operatively, the patient reported negligible and occasional right hip pain, as well as his chronic low back pain, though had no functional limitations and had resumed all normal activity.

VAS and Pelvic Majeed Scores

One month prior to injury, the patient felt little to no pain in any portion of his pelvis. On the day of the accident, the patient reported a VAS score of 8 and 9 to his left anterior and posterior hemipelvis respectively, and a score of 10 to both his anterior and posterior right hemipelvis. VAS scores then trended downward at 2 weeks, 6 weeks, 3 months, and 6 months post-injury. At 6 months post-injury, reported VAS began to approximate pre-injury levels, particularly in the anterior and posterior portions of the left pelvis, however scores for the right pelvis remained mild to moderate, reported as a 4 and 3 respectively. By 1 year and 2 years post-injury, the patient's VAS scores were equivalent to that of pre-injury in the left hemipelvis. At 1 year and 2 years post-injury, the right hemipelvis VAS scores remained between 1-3, with the patient reporting scores increasing to 5 while doing physical activities. Summary of VAS scores can be seen in **Table 1**.

Majeed Pelvic Scores were also obtained from patient. The patient reported scores of ⩾ 85 for all portions of the pelvis 1 month prior to injury. Two weeks post-operatively all subscales were poor clinically, with most receiving scores of 0. Thereafter, his scores improved but remained <55 by 3 months post-operatively. At 6 months post-operatively, scores approached pre-injury levels. At 1 year and 2 years post-operatively, scores were comparable to pre-injury scores, namely for the left anterior, left posterior, and right anterior pelvis. The right posterior hemipelvis scores did not show improvement after the 6-months post-operative mark, remaining at a score of 84 until final follow up. Summary of post-operative Majeed Pelvic Scores is presented in **Table 2**.

Discussion

At the study's start, the patient decided to identify his genetic variation of OI through commercial genetic testing (Skeletal Disorders Panel, Invitae, San Francisco, CA). His genetic report identified a *COL1A2* gene variation involving a substitution of an arginine with a serine at codon 948. To the authors' knowledge, there is no current literature on this specific variant.

At final follow-up, the patient reported persistent back pain, which was stated to have been present prior to injury but acutely worsened after injury. Low back pain in individuals with OI is common, with McKiernan et al citing 70% of their respondents whom had OI reporting low back pain causing some functional impairment.[3] At last follow-up, no identifiable pathology had been elucidated to explain the patient's low back pain, though the patient was referred to a spine specialist. This patient's reported persistence of back pain is likely a combination of pre-injury chronic pain and aggravation due to the injury and surgery.

Prior literature suggests that manifestations of OI may affect fracture healing. Some studies have suggested high rates of nonunion in those with OI for both fractures and osteotomies, 24% and 52% respectively.[9,10] A recent animal study found callus size and strength were reduced in OI fracture models, suggesting an increased risk of refracture.[11] Additionally, delayed fracture healing in patients with OI has shown to increase the risk of extended periods of immobilization, muscle atrophy, and hindered bone remodeling.[12] However, the current case demonstrates ap-

Table 1. Visual Analog Scores of a Patient with Right-sided Sacroiliac Diastasis and Pubic Rami Fractures from Pre-injury to 2 Years Post-injury

	1 month prior	Day of accident	2 weeks post injury	6 weeks post injury	3 months post injury	6 months post injury	1 year post injury	2 years post injury
Left anterior	0	8	7	5	4	0	0	0
Left posterior	1	9	8	6	4	2	1	1
Right anterior	0	10	8	8	6	4	2	0
Right posterior	1	10	8	7	5	3	3-normal activity; 5-with exertion	2-normal activity; 5-with exertion

propriate chronology of fracture healing. At the 12-week post-operative visit, radiographs demonstrated minimal residual fracture lines, with no clinical or radiographic evidence of delayed fracture healing, nonunion, or malunion at last follow up. His favorable outcomes may have been the result of his genetic variant and mild phenotype, though his young age, lack of co-morbidities, and appropriate rehabilitation and post-operative activity may also have played a role. Additional genetic work could help elucidate which OI variants are susceptible to worse fracture related outcomes.

There is concern for bleeding diathesis in individuals with OI.[7,8] Fortunately, this patient did not experience any such complications in the perioperative period. This may be due to the percutaneous surgical fixation techniques implemented. His genetic variant also may have not had severe effects on normal physiologic vascular and coagulation functions.

This patients pre-injury and post-operative reported measures are comparable to non-OI patients after pelvic ring fractures. In a study by Liu et al, general population patients who sustained posterior pelvic ring injuries treated by percutaneous sacroiliac screws reported pre-operative VAS scores of 7.13 ± 1.00, which was similar to this patient's pre-operative VAS scores.[13] The post-operative scores in the same study were 5.33 ± 0.78 and 1.33 ± 0.66 at 1 week and 6 months, respectively.[13] The 6 month VAS scores in this case were 2-4, which is slightly higher than the scores reported by Liu et al.[13] Close approximation of patient reported scores between the current patient and non-OI patients was also seen in the Majeed Pelvic Score. A retrospective review by Sharma et al, examined complications and functional outcomes of patients with complex fractures of the anterior pelvic ring treated with internal fixation.[14] The mean 6 months post-operative Majeed Pelvic Scores for non-OI patients was reported as 92.67 ± 5.8.[14] This patient, at the same post-operative interval, reported scores of 95, 86, 81, and 84 for the left anterior, left posterior, right anterior, and right posterior portions of the pelvis, respectively. These findings suggest the patient may have had subjective pain levels and functional abilities similar to that of non-OI patients. The comparable scores between the current patient and a non-OI patient group may suggest patients with mild phenotypes of OI may have comparable outcomes after pelvic ring fixation with those who do not have OI.

Several limitations apply to this study. First, the genetics of OI are heterogenous, which limits the generalizability to other OI patients. Additionally, this patient may have a milder phenotype given his occupational and functional abilities. Likewise, this patient's injuries were sustained because of a higher energy mechanism, which too may hinder generalizability to similar injuries sustained at lower energy mechanisms. This patient also had to provide some intervals of VAS and Majeed Pelvic Scores based on memory, which may introduce recall bias. And as mentioned, the use of a commercial genetic testing company for evaluation of genetic mutations may have incomplete or limited clinical utility.

While limitations in any case study must be recognized, there remains benefit in this study. There are likely many patients either with no or incomplete knowledge of their particular mutation or mutations. OI overall is not a common condition, and patients with OI sustaining pelvic ring injuries is even more rare. This case study contributes to knowledge of a patient population with a dearth of literature on pelvic ring fracture management. In this study, an adult with an apparent mild phenotype of OI presented with traumatic pelvic ring injuries after a high energy mechanism. He was treated with currently accepted, standard of care surgical techniques and fixation, and had short, intermediate, and long-term post-operative follow-ups without complications. His VAS and Majeed Pelvic Scores were similar to those of patients who did not have OI at most post-operative follow-up intervals. At final follow-up, and there was no radiographic evidence of malunion or nonunion, with the patient reporting continued low back pain, which may have been in part due to pre-existing chronic back pain. This patient had no complications at final follow-up and was back to performing recreational and professional activities at near pre-operative levels, suggesting standard pelvic fixation methods may be safe and effective in adult patients with mild OI phenotypes.

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Table 2. Majeed Pelvic Scores by Region of a Patient with Right-sided Sacroiliac Diastasis and Pubic Rami Fractures from Pre-injury to 2 Years Post-injury

Left Anterior							
	1 Month Prior	**2 Weeks Post**	**6 Weeks Post**	**3 Months Post**	**6 Months Post**	**1 Year Post**	**2 Years Post**
Pain	30	0	4	10	25	30	30
Work	20	0	2	6	20	20	20
Sitting	10	3	6	8	10	10	10
Sexual Intercourse	4	0	0	2	4	4	4
Standing (A)	12	6	6	6	12	12	12
Standing (B)	12	0	0	4	12	12	12
Standing (C)	12	2	4	6	12	12	12
Total	100	11	22	42	95	100	100
Left Posterior							
	1 Month Prior	**2 Weeks Post**	**6 Weeks Post**	**3 Months Post**	**Six Months Post**	**1 Year Post**	**2 Years Post**
Pain	25	0	3	7	20	25	25
Work	20	0	2	6	20	20	20
Sitting	10	1	5	6	9	10	10
Sexual Intercourse	4	0	0	2	4	4	4
Standing (A)	12	6	6	6	12	12	12
Standing (B)	12	0	0	2	12	12	12
Standing (C)	12	2	4	6	9	10	10
Total	95	9	20	35	86	93	93
Right Anterior							
	1 Month Prior	**2 Weeks Post**	**6 Weeks Post**	**3 Months Post**	**6 Months Post**	**1 Year Post**	**2 Years Post**
Pain	30	0	2	7	18	25	30
Work	20	0	2	4	20	20	20
Sitting	10	1	6	8	8	10	10
Sexual Intercourse	4	0	0	1	4	4	4
Standing (A)	12	6	6	6	12	12	12
Standing (B)	12	0	0	2	10	12	12
Standing (C)	12	2	4	6	9	12	12
Total	100	9	20	34	81	95	100
Right Posterior							
	1 Month Prior	**2 Weeks Post**	**6 Weeks Post**	**3 Months Post**	**6 Months Post**	**1 Year Post**	**2 Years Post**
Pain	25	0	2	6	20	20	20
Work	20	0	2	6	20	20	20
Sitting	10	1	5	6	9	8	8
Sexual Intercourse	4	0	0	2	4	4	4
Standing (A)	12	6	6	6	12	12	12
Standing (B)	12	0	0	2	10	10	10
Standing (C)	12	2	4	6	9	10	10
Total	95	9	19	34	84	84	84

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