November 2019, Volume 78, No. 11, Supplement 2, ISSN 2641-5216

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Guest Editor’s Message: An Orthopedic Surgery Sampler

Robert E. Atkinson MD

I extend a warm welcome to all readers of the HJHSW. This supplemental issue contains research and review articles authored by the University of Hawaii’s orthopedic surgery faculty and residents. It is a broad sampler of our orthopedic specialty and includes topics on pediatric orthopedics, sports medicine, hand and upper extremity syndromes, total joint arthroplasty, and orthopedic infections.

The book “Range,” by David Epstein encourages us to explore topics outside our narrow field(s) of expertise in order to be more collaborative and imaginative in medicine, business and science in general. I hope this issue broadens your exposure to our dynamic and varied surgical specialty.

My special thanks go out to our authors and reviewers, as well as to our research residents, Drs. Ian Hasegawa and Victoria Scala. Special kudos to Dr. Byron Izuka, who is a tireless champion of the need for clinical orthopedic research. My personal thanks to Mr. Gary Belcher and Ms. Jamie Castelo for their help and hard work on behalf of our residency program. So, broaden your exposure to orthopedics and enjoy this issue.

Aloha, Rob Atkinson
**Cutibacterium acnes** (formerly *Propionibacterium acnes*) and Shoulder Surgery

Marlee J. Elston BA; John P. Dupaix MD; Maria I. Opanova MBBS; and Robert E. Atkinson MD

**Abstract**

Infection is a rare but serious complication of shoulder arthroplasty. The most prevalent cause of patient infections is *Cutibacterium acnes* (formerly *Propionibacterium acnes*), a commensal skin bacterial species. Its presentation is often non-specific and can occur long after shoulder arthroplasty, leading to delay in diagnosis. This bacterium is difficult to culture, typically taking 14 to 17 days for a positive culture and often does not exhibit abnormal results on a standard laboratory workup for infection (eg, ESR, CRP, and synovial WBC count). Male patients are at particularly high-risk due to having a greater number of sebaceous follicles than females. While it is difficult to diagnose, early diagnosis can lead to decreased morbidity, appropriate treatment, and improved clinical outcomes. Current options for treatment include antibiotics, one stage implant exchange, or two stage implant exchange, although success rates of each are not currently well described. A better understanding of the prevention, diagnosis, and treatment of *C. acnes* infection could lead to better patient outcomes from shoulder arthroplasty.

**Keywords**

*Cutibacterium acnes*, *Propionibacterium acnes*, surgical site infection, shoulder surgery

**Introduction**

Infection after shoulder surgery is a rare but potentially catastrophic complication. Patients that develop postoperative wound infections are 60% more likely to spend time in the intensive care unit and experience twice the mortality rate. Synovial joints are at risk for infection given both their relative absence of immune cells and the presence of nutrient-rich synovial fluid. Several species of commensal bacteria are known to cause the majority of shoulder infections. These include *Staphylococcus aureus*, *Staphylococcus epidermidis*, and *Cutibacterium acnes* (formerly *Propionibacterium acnes*).

Recently, it has been noted that the common pathogen in shoulder infection post-arthroplasty is *Cutibacterium acnes*. *C. acnes* infection is also associated with arthroscopy, fracture fixation, injections, cuff repair, and Latarjet procedures. *C. acnes* is a gram-positive, anaerobic bacteria that normally occupies the hair follicles and sebaceous glands and colonizes the shoulder at increased rates compared to the knee and hip. Earlier studies reported a rate of *C. acnes* infection after shoulder arthroplasty presenting as a classical periprosthetic infection of 0%-15% of patients, but these studies recognized that this have been an underestimate of the true rate, as diagnosis of *C. acnes* can be difficult and unreliable. More recent studies, usually with longer durations of culture, have been positive at higher levels for *C. acnes* at the time of revision ranging from 16% to 70%, with the most common estimates around 50%-60%. In one study, the total infection rate was 1.9% with 89% caused by *C. acnes*. Similarly, in a study of deep infection after rotator cuff injury, *C. acnes* was found to be the most prevalent cause of infection, causing 51% of the post-surgical infection cases.

In healthy skin, *C. acnes* plays a commensal role. It outcompetes other bacteria on the skin and colonizes the acidic, anaerobic environment of the sebaceous gland deep in the dermis. Through its digestion of the sebum, it produces free fatty acids which are secreted with the sebum onto the skin. This helps produce an overall acidic pH of the skin, which inhibits pathogenic bacteria such as *Staphylococcus aureus* and *Streptococcus pyogenes*, while favoring other commensal bacteria such as coagulase negative *staphylococcus* and *corynebacteria*.

The prevalence and burden of *C. acnes* has been found to be greater in the axilla and acromion than at the hip or knee. The prevalence and burden of *C. acnes* is also greater at the anterior and posterior acromion than the axilla in men, but not women. In general, men also have a greater prevalence and burden of bacteria than females.

Pathophysiologically, *C. acnes* bacteria feed on lipids and triglycerides producing fatty acids as a byproduct, as well as secrete cytotoxic chemicals and enzymes which can degrade the shoulder capsule. *C. acnes* uses antigens to adhere to cells, biofilms, and surfaces, which can initiate an inflammatory response on the inside of the joint. *C. acnes* forms biofilms within the body, which aids in micro-colony formation, evasion...
of macrophage engulfment, avoidance of phagocytosis. C. acnes may persist within macrophages for up to 8 months in vitro. Over half of C. acnes cultures now carry resistance to more than one antibiotic.  

**Cutibacterium acnes Clinical Characteristics**

C. acnes infection increases the risk of needing revision surgery, morbidity and mortality. The total cost to treat an infected shoulder prosthesis has been estimated at $46,745. Surgical debridement is often not sufficient alone to eliminate C. acnes infection and excess scar tissue from repeated surgery can lead to less functional outcomes. It is important to note that C. acnes infections do not typically elicit typical host inflammatory responses. Classic signs of swelling, erythema, drainage, tenderness, and sinus tract are less common. Rather, common presentations include unexplained pain, stiffness, and component loosening after an initially good outcome and the usual period for acute postoperative infection has passed. C. acnes may not present symptoms for two years or more post operatively. Good recovery of function and pain control followed by increase in pain and stiffness suggest C. acnes, particularly in males. A number of studies have pointed to C. acnes infection as a possible cause of prosthetic loosening. In established C. acnes infections involving a prosthesis, exchange of the prosthesis may yield the best clinical outcome.  

C. acnes may enter the surgical field via surgical incision through the pilosebaceous glands in the deeper layers of the skin. There has been no difference found in bacterial colonization for different types of pre-operative preparation including Chloraprep (2% chlorhexidine gluconate and 70% isopropyl alcohol; Enturia, El Paso, Texas), DuraPrep (0.7% iodophor and 74% isopropyl alcohol; 3M Healthcare), or providone-iodine scrub and paint, (0.75% iodine scrub and 1.0% iodine paint; Tyco Healthcare Group, Mansfield, Massachusetts). Using a rigorous technique, Koh et al. demonstrated that use of 4% chlorhexidine gluconate showers only reduced the skin culture positivity rate to 40%, and even after the Chloraprep had dried the skin positivity rate for C. acnes was 27%. At the end of the case, the skin culture positivity rate rose again to 43%.  

Risk factors for C. acnes infection include male gender and surgery including a prosthesis or for treatment of trauma. Other factors in the development of C. acnes infections include the suitability of the joint for infection, the size of the bacterial inoculum, the patient’s immune response to the bacterium, and the relative proportion of pathogenic strains.  

Early treatment is important in treating C. acnes infection, even though it may not show symptoms for three or more years as it establishes a biofilm which is much more resistant to antibiotic therapy. Unfortunately, there is no established antibiotic regimen for treating C. acnes infection and consultation with an infectious disease specialist is recommended.  

**Cutibacterium acnes Testing**

Serological testing for infection may be unhelpful in laboratory evaluation for C. acnes infection—typical inflammatory markers, such as CRP and ESR, tend to be low or borderline while white blood cell count may be within normal limits. Traditionally, C. acnes was cultured with a tissue swab under anaerobic conditions and held for up to 7 days. It has been noted that this method is insufficient to rule out C. acnes infection, however. Matsen, et al. propose that testing for C. acnes in a failed shoulder should include more than 5 cultures including tissue and explant, sonication of explant, collection of revision specimens prior to antibiotics, sending cultures on both aerobic and anaerobic media, and holding the specimens for 17 days. Intraoperatively, signs of inflammation are not usually seen. In some cases, cloudy fluid, osteolysis, a periprosthetic membrane, and component loosening may be present and are associated with increased likelihood of positive cultures, but absence does not preclude infection. Frozen section has poor sensitivity for infection in cases of C. acnes.  

A new, more sensitive technique involves using PCR. This method utilizes restriction fragment length polymorphisms to create a clinically relevant assay that can detect C. acnes more easily, although controlling for false positives must be carried out carefully. This new method only requires 24 hours and can be carried out in the average pathology laboratory. As a PCR based assay, it can detect as few as ten C. acnes cells when it was tested in an artificial tissue system.  

**Controversy: Cutibacterium acnes and Arthritis**

There are a number of controversies remaining in this field, including some questioning if C. acnes is present intraarticularly prior to surgery and if C. acnes may be responsible for some cases of arthritis. However, when carefully controlled for contamination, a cause and effect relationship between P. acnes and osteoarthritis was not supported in a separate study. Further study has found the bacteria only in skin tissue and not in the deeper tissues such as the rotator cuff and glenohumeral cartilage. This suggests the bacterium is a contaminant from the skin during surgery. Whether the data support a link between C. acnes and arthritis is still an area that requires more investigation.  

**Recent Developments and Future Directions**

A number of strategies have been proposed as potential techniques to minimize infection and manage these infections. It has been suggested that a second change of gloves for the surgeon and re-draping, use of a skin barrier, along with hair...
removal by electric clippers or depilatories, could reduce C. acnes infection.20, 25 Another preventative method being utilized is the application of vancomycin powder during shoulder arthroplasty to prevent C. acnes infection.25 This was found to be highly cost effective. Another technique under development is the disruption of the C. acnes biofilm by using calcium sulfate cement beads loaded with tobramycin, vancomycin, or a combination of the two to deliver high local concentrations of antibiotic; so far testing has only been in vitro.3 This was noted to be effective in eliminating both planktonic organisms and biofilms. Point-of-care testing could lead to improved outcomes for patients by informing decisions while still in the operating room. Changes in interleukin-6 (IL-6) levels, leukocyte esterase, and alpha-defensin are being investigated for correlation to C. acnes infection, although sensitivity and specificity have been lower.41-45 More recently, topical benzoyl peroxide has been investigated as a preventative agent for C. acnes.46-48 Presurgical treatment with topical benzoyl peroxide was found to be more effective than chlorhexidine gluconate in decreasing the skin burden of C. acnes, but was unable to completely eradicate it in any study.

Conflicts of Interest
None of the authors identify any conflicts of interest.

References
Carpal Tunnel Syndrome: An Update for the Primary Care Physician

Anne R. Wright MD and Robert E. Atkinson MD

Abstract

Carpal tunnel syndrome costs the United States billions of dollars each year. The majority of patients are industrial workers, females, and the elderly who first present to their primary care physicians. Therefore, it is essential that the primary care physician understand this syndrome in order to diagnose and direct treatment. Here we present a review of the anatomy, pathophysiology, diagnosis, and current treatment of carpal tunnel syndrome that is relevant for the treating primary care physician. In addition, we discuss the role of the primary care physician in the diagnosis, management, and treatment of carpal tunnel syndrome. The aim of this review is to improve the integrated care of those patients suffering from carpal tunnel syndrome.

Keywords

Carpal Tunnel Syndrome, Peripheral Nerve Entrapment Syndrome

Abbreviations

CTS: Carpal Tunnel Syndrome
PCP: Primary Care Physician
TCL: Transverse Carpal Ligament

Introduction

Carpal tunnel syndrome (CTS) is the most common peripheral nerve entrapment syndrome. It is defined as a compression of the median nerve at the level of the wrist joint associated with decreased function of the nerve at that level.\(^1\),\(^2\) It can be either acute or chronic, with chronic being much more common.\(^1\),\(^3\) Likewise, CTS is the most expensive upper extremity musculoskeletal disorder in the United States, with costs exceeding $2 billion annually.\(^4\) According to Dale, et al, CTS in the United States has an incidence of 5.8% and a prevalence of 7 to 19%, with higher numbers seen in industrial workers, females, and the elderly.\(^5\),\(^6\) As such, many patients with signs and symptoms of CTS will present initially to their primary care physician (PCP) who must in turn understand the syndrome in order to identify it and guide proper treatment.

Anatomy and Pathophysiology

The floor of the carpal tunnel is formed by the carpal bones, while the roof of the carpal tunnel is formed by the flexor retinaculum; which includes the transverse carpal ligament (TCL). There are ten structures running through the carpal tunnel: flexor pollicis longus, four tendons of flexor digitorum superficialis, four tendons of flexor digitorum profundus, and the median nerve (Figure 1).

The median nerve lies just below the TCL and is the most superficial structure in the tunnel. The recurrent motor branch of the median nerve most commonly divides from the median nerve proximal to the flexor retinaculum and innervates the muscles of the thenar muscles (abductor pollicis, the superficial head of flexor pollicis brevis, and the opponens muscle). Less commonly the recurrent motor branch divides in a subligamentous or transligamentous pattern. The median nerve continues through the carpal tunnel into the palm where it divides into digital nerves that provide sensation to the thumb, index, middle, and radial half of the ring finger.

The carpal tunnel is open both proximally and distally, but despite this it maintains a distinct tissue fluid pressure level due to its fibrous borders. The pressure in the carpal tunnel of a healthy individual ranges from 2.5 to 13 mmHg.\(^6\),\(^7\) A decrease in the cross-sectional area of the carpal tunnel can lead to an elevation in pressure that becomes critical above 20 to 30 mmHg.\(^6\),\(^8\) At this point epineural blood flow and axoplasmic flow is impeded, and nerve dysfunction, edema, and scarring can result.\(^9\)

The most common symptoms of carpal tunnel syndrome are numbness, pain, and/or paresthesia in the thumb, index, middle, and radial half of the ring finger that is worst at night. Wrist flexion and extension increase pressure in the carpal canal, and wrist flexion during sleep may worsen symptoms such that patients awake with burning and numbness to the hand. Patients with moderate to severe disease can present with atrophy of the thenar muscles and, variably, decreased pinch and grip strength. They may also have pain that migrates proximally.
Risk Factors

Chronic Carpal Tunnel Syndrome

The majority of CTS cases are chronic and idiopathic; however, several risk factors have been identified. These include female gender (peak age 45 to 54 years), increasing age, obesity, thyroid disease, diabetes, pregnancy, renal failure, alcoholism, primary amyloidosis, and drug toxicity. Less commonly, space-occupying lesions in the carpal tunnel may lead to compression of the median nerve. These include a persistent median artery, infection, ganglion cyst, tumor, or scar tissue. Rheumatoid arthritis is also a risk factor as it may lead to an increase in carpal tunnel pressure secondary to pannus formation or synovitis. Additionally, cervical degenerative disc disease may complicate the clinical picture due to overlapping symptoms or mimicking symptoms of CTS.

Carpal Tunnel Syndrome and Work

CTS is common in working age adults. The literature does show an association between CTS and the use of vibratory tools, increased hand force, repetitive wrist motion, and extreme flexion/extension of the wrist. Work activities that patients often associate with the onset of CTS is excessive keyboarding and mouse use. However, to date there has been no evidence to support this association. Thomsen et al performed a systematic review of the literature and concluded that there is insufficient evidence that computer work (keyboarding and mouse use) causes CTS. Additionally, they reviewed several papers looking at positions and forces exerted by computer users and concluded that carpal tunnel pressure increases with keyboarding and mouse use, but the pressure was still below potential harmful levels. Patients with CTS can be counseled, therefore, that use of a keyboard and mouse at work is unlikely to be the cause of their symptoms, but it is possible that these activities may aggravate them.

Acute Carpal Tunnel Syndrome

The clinician must be able to differentiate chronic CTS from acute CTS, as release of the carpal tunnel becomes urgent in the latter. The acute forms of CTS can be divided into traumatic and atraumatic. Traumatic CTS often results from wrist and carpal bone trauma resulting from direct compression or indirect compression of the nerve via hematoma and/or soft tissue swelling. Less commonly, the nerve may be directly injured (ie, transected) in a traumatic event. The uncommon atraumatic causes of acute CTS include septic arthritis, pseudogout, topaceous gout, soft tissue infections, calcifying tendinitis, tumoral calcinosis, and pigmented villonodular synovitis.

Diagnosis

In 2007, the American Academy of Orthopedic Surgery (AAOS) released guidelines for diagnosing CTS. The following is a review of those guidelines in addition to our own recommendations.

History

The diagnosis of CTS should always begin with a history. The clinician should ask about duration of symptoms, severity and character of symptoms, location of symptoms, radiation (eg, Do symptoms radiate from the shoulder?), progression of symptoms (better, worse, stable?), patient’s lifestyle/activities, and any comorbidities. Table 1 describes classic features that may be obtained in a patient with CTS and may have clinical significance.

<table>
<thead>
<tr>
<th>Clinical Question</th>
<th>Classic Presentation of CTS</th>
<th>Clinical Significance</th>
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<tbody>
<tr>
<td>Duration</td>
<td>Variable</td>
<td>Unclear whether duration of symptoms correlates with amount of nerve injury. This should be correlated with physical exam and diagnostic findings.</td>
</tr>
<tr>
<td>Location/Radiation</td>
<td>Along the median nerve distribution</td>
<td>Location and/or radiation of symptoms outside of this distribution may prompt the physician to consider diagnosis other than CTS. If there are symptoms within the median nerve distribution in addition to other distributions (eg, The ulnar nerve distribution) the physician may consider other diagnosis (ie, proximal nerve compression syndrome) that mimics CTS.</td>
</tr>
<tr>
<td>Association Symptoms</td>
<td>Decreased strength with pinching or grip</td>
<td>Due to atrophy of the thenar muscles</td>
</tr>
<tr>
<td>Timing of Symptoms</td>
<td>Increased symptoms at night when sleeping</td>
<td>It is common for patients to sleep with their elbows and wrist fully flexed, leading to an increase pressure in the carpal canal. Therefore, it is common for patients to report increased symptoms at night or when first waking up.</td>
</tr>
<tr>
<td>Lifestyle Activities</td>
<td>Activities that fully extend the wrist (driving, holding a telephone) or fully flex the wrist. Also, occupational hazards such as use of vibratory tools.</td>
<td>See Risk Factors in text.</td>
</tr>
<tr>
<td>Comorbidities</td>
<td>Obesity, Diabetes</td>
<td>See Risk Factors in text.</td>
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Physical Exam

The physical exam should note the patient’s age, BMI, body habitus, range of motion of the wrist and hand, any deformities, swelling, atrophy, and skin trophic changes. In addition, pinch and grip strength can be measured if the proper equipment is available. A sensory and motor exam should be performed, along with provocative tests (described below). Table 2 describes classic features that may be observed in a patient with CTS.

<table>
<thead>
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<th>Table 2. Physical Exam in Carpal Tunnel Syndrome</th>
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<tr>
<td><strong>Physical Exam</strong></td>
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<tr>
<td>Patient characteristics</td>
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<tr>
<td>Visual Findings</td>
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<tr>
<td>Sensory Exam</td>
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<tr>
<td>Motor Exam</td>
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Electrodiagnostic Studies

Electrodiagnostic studies include electromyography (EMG) and nerve conduction studies. Nerve conduction studies measure the strength and speed of impulses propagated down the length of a peripheral nerve. These studies measure the action potentials of both sensory and motor fibers. From these recordings, the amplitude of the waveform is measured, indicating the strength of the impulse via the number of axons successfully activated (unit is microvolts). Also measured is the latency, which reflects the speed of transmission through the nerve, also known as the nerve conduction velocity (units milliseconds). The EMG portion of the electrodiagnostic study involves a needle-recording of electrical activity and can indicate denervation or reinnervation in the setting of nerve injury. With regards to CTS, nerve conduction studies with a distal motor latency of greater than 4.5 ms and a sensory latency greater than 3.5 ms is considered abnormal. Further, the EMG may show evidence of nerve injury (increased insertional activity, positive sharp waves, fibrillations at rest, decreased motor recruitment, and complex repetitive discharges).

The AAOS guidelines state that the physician may obtain electrodiagnostic tests to differentiate among diagnoses. However, they do not suggest using these tests as the primary diagnostic tool as electrodiagnostic studies have well recognized limitations. For instance, nerve conduction studies are limited to the evaluation of large myelinated nerves, and the results reflect the function of the best fibers rather than the worst. Also, electrodiagnostic tests are sensitive, but not specific (90%-94% sensitive, 50%-60% specific), which may lead to an erroneous diagnosis of "asymptomatic CTS". Finally, there is limited evidence correlating electrodiagnostic tests findings alone with functional recovery or reemployment after carpal tunnel release (CTR), which limits the diagnostic use of these studies. Electrodiagnostic testing cannot replace the clinical exam when making a diagnosis; however, in combination with the clinical exam these tests can be confirmatory. The AAOS guidelines recommend that physicians obtain electrodiagnostic tests if clinical and/or provocative tests are positive and surgical management is being considered.

Ultrasonography

There has been recent interest in the use of ultrasonography in the diagnosis of carpal tunnel syndrome, stemming from a desire to decrease discomfort to the patient (associated with electrodiagnostic studies) and the increased use of ultrasound in general. Proponents of ultrasound argue that an increased cross-sectional area of the median nerve at the distal wrist crease will correlate with a diagnosis of CTS. Recently, Ting et al demonstrated a positive correlation between these ultrasound measurements and electrodiagnostic studies in patients with a diagnosis of CTS. Also, Wessel et al demonstrated a correlation between severity of CTS and both a thickening of the TCL and increased cross-sectional area of the median nerve. Although these findings are encouraging, there is not enough evidence to date to recommend ultrasound in the formal diagnosis of CTS.

<table>
<thead>
<tr>
<th>Table 3. Provocative Testing for Carpal Tunnel Syndrome</th>
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<tr>
<td><strong>Provocative Test</strong></td>
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<tr>
<td>Phalen Test (Figure 2)</td>
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<tr>
<td>Reverse Phalen Test (Figure 3)</td>
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<tr>
<td>Tinel Sign</td>
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<tr>
<td>Median Nerve Compression Test (Figure 4)</td>
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</table>
Figure 2. Phalen Test. Dorsum of hands placed together so that maximum wrist flexion is achieved. This is held for 60 seconds.

Figure 3. Reverse Phalen Test. Palms of hands placed together so that maximum wrist extension is achieved. This is held for 60 seconds.

Figure 4. Median Nerve Compression Test. With patient’s wrist at neutral, the examiner places moderate pressure over the carpal tunnel for 30 seconds.

Treatment

Once CTS is suspected or established, the patient should be referred to an orthopedic surgeon, ideally one that specializes in Hand and Upper Extremity. Primary care physicians can counsel their patients that treatment may include conservative management versus surgical management depending on the severity of disease.

Splints

Splinting is often recommended for patients with mild symptoms of CTS. The patient is placed into a wrist splint that maintains the wrist at neutral. The primary care physician can place any patient, regardless of suspected severity of disease, into a wrist splint as preliminary treatment. It may be particularly pertinent to initiate wrist splints if the patient cannot be seen immediately by the orthopedic surgeon.

When counseling the patient, it can be stressed that the wrist splint may alleviate some symptoms but may not cure CTS in every patient. Kaplan et al found five factors to be important in determining the success of nonoperative treatment. These include: (1) age over 50 years, (2) duration greater than 10 years, (3) constant paresthesia, (4) stenosing flexor tenosynovitis, (5)
positive Phalen’s test in less than 30 seconds. They found that conservative management was successful in up to 83.3% of patients if two or less factors were present. However, if three factors were present then success rates were less than 7%; and if four or five factors were present then the success rate was 0%.9,19

Injections

Corticosteroid injections may be recommended for patients with mild to moderate CTS. These injections have shown to provide effective relief of symptoms, but the effects are usually temporary.20,21 It has also been found that injections are more effective in men and patients older than 40 years.8 Aside from its use in treatment, alleviation of symptoms after a corticosteroid injection can confirm the diagnosis and likely success of carpal tunnel surgery. We recommend these injections be done by an orthopedic surgeon or provider that is performing them on a regular basis as misplaced injections can result in unresolved symptoms, earlier recurrence of symptoms and nerve damage with accidental intra-neural injection.

Surgical

Studies have shown superior outcomes with CTR as compared to splinting or injections.22 Conservative treatment is often exhausted before CTR is recommended, unless symptoms are severe (eg, thenar atrophy) on initial presentation. The surgery involves releasing the TCL longitudinally to relieve pressure within the carpal tunnel and decompress the median nerve. This can be done either with an open approach, a mini-open approach, or endoscopically. There is debate regarding the optimal approach and patient factors. Surgeon’s experience will often play a role in choosing the surgical technique. Patients can be counseled that long-term outcomes are similar regardless-of approach.

Summary

CTS is the most common compressive neuropathy. Conservative care is warranted in mild cases or in cases with recent onset of symptoms. Surgical treatment is effective for moderate to severe cases of CTS and will involve release of the TCL in order to relieve pressure within the carpal tunnel. Patient communication regarding expectations and outcomes is paramount, and many times will start with the primary care physician.

Conflicts of Interest

None of the authors identify any conflicts of interest.

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Implementing Regional Nerve Blocks in Hip Fracture Programs: A Review of Regional Nerve Blocks, Protocols in the Literature, and the Current Protocol at The Queen’s Medical Center in Honolulu, HI

Victoria A. Scala MD; Lorrin S.K. Lee MD; and Robert E. Atkinson MD

Abstract

Hip fractures are a common cause of acute pain in elderly patients. However, pain may be undertreated due medical comorbidities. Strong evidence supports the use of regional nerve blocks to reduce preoperative pain after hip fracture. Despite recommendations for their use, regional nerve blocks may not be in widespread practice in the United States. To help promote the addition of regional nerve blocks into hip fracture protocols, this paper will provide an overview of two commonly used regional nerve blocks for hip fracture (fascia iliaca compartment block and femoral nerve block), review the regional nerve block protocols presented in 12 studies, and present the detailed protocol currently in use at The Queen’s Medical Center in Honolulu, HI.

Keywords

Hip fracture, Femoral Nerve Block, Fascia Iliaca Compartment Block, Regional Anesthesia, Continuous Block, Opioid Sparing

Abbreviations

FICB = fascia iliaca compartment block
FNB = femoral nerve block
QMC = The Queen’s Medical Center, Honolulu, HI

Introduction

Each year over 300,000 people aged 65 and older are hospitalized for hip fractures in the United States. Providing effective analgesia for these patients is complicated by advanced age and concomitant comorbidities. Inadequately treated pain has several repercussions for geriatric patients with hip fractures. Delirium is a common complication of hip fractures, affecting approximately 13%-61% of patients, and undertreated pain significantly increases the risk of perioperative delirium in cognitively intact patients. Increased post-operative pain is also associated with significantly longer lengths of stay, delayed ambulation, missed or shortened physical therapy sessions, and impaired locomotion at 6 months following injury. According to a national database in 2014, the average length of stay for a femoral neck fracture in Hawai’i was 7.1 days costing an average of $48,911. In this current climate of increasing health care costs, improving perioperative pain control could be an important step toward reducing these numbers.

The American Academy of Orthopaedic Surgeons (AAOS) clinical practice guidelines on management of hip fractures in the elderly provide a strong recommendation for regional analgesia to improve preoperative pain control. A Cochrane review demonstrated high-quality evidence that regional blockade reduces pain on movement within 30 minutes of block placement and moderate-quality evidence for decreased time to first mobilization after surgery. Despite the potential benefits of these procedures and national guidelines recommending their use, studies in the United Kingdom and Australia have demonstrated regional nerve blocks are not being used on a regular basis. To help promote implementation of regional nerve blocks for proximal femur fractures, this paper will give an overview of common regional nerve blocks for hip fractures, protocols presented in the literature, as well as present the protocol currently used at The Queen’s Medical Center (QMC) in Honolulu, HI.

Type of Block

The primary regional nerve blocks presented in the literature for proximal femur fractures include femoral nerve blocks (FNB) and fascia iliaca compartment blocks (FICB). The main nerves innervating the hip joint are the femoral, obturator, superior gluteal, and nerve to quadratus femoris and inferior gemellus. Of note, these described blocks do not anesthetize the posterior hip joint.

Femoral Nerve Block

Key landmarks for the femoral nerve block include the inguinal ligament, inguinal crease, and femoral artery. The needle is inserted at the femoral crease both below the inguinal crease and 1-2 cm lateral to the pulse of the femoral artery (Figure 1). The needle tip must be positioned below the fascia iliaca to obtain a complete femoral nerve block. In the “3-in-1” technique described by Winnie, et al, digital pressure can be applied distal to the injection site to promote spread of the anesthetic cranially and laterally to block the femoral, obturator, and lateral femoral cutaneous nerves. Placement of the femoral nerve block can be assisted by ultrasound, nerve stimulation, or elicited paresthesias, per the proceduralist’s choice.

Fascia Iliaca Compartment Block

The fascia iliaca compartment is a potential space delineated by the fascia iliaca anteriorly (Figure 2), the outer aspect of the
iliacus muscle posteriorly, the vertebral column and upper part of sacrum medially, and the inner lip of the iliac crest laterally and rostrally. This compartment contains the lateral femoral cutaneous nerve, femoral nerve, and obturator nerve. The goal insertion point is 1 cm caudal to the point dividing the lateral third and middle third of the line connecting the anterior superior iliac spine to the pubic tubercle. The injection site is several centimeters lateral to the femoral artery. Proceduralist may use either ultrasound guidance or the loss of resistance technique, where two “pops” are felt as the needle passes through the fascia lata then fascia iliaca. One study demonstrated increased efficacy of sensory blockade with ultrasound guidance compared to the loss of resistance technique.

**Method of Delivery**

These blocks can be delivered as either a single shot or a continuous infusion catheter. The anatomic technique for continuous infusion catheter is like that for a single shot. Once the needle is in the correct position for either block, a catheter can be inserted 2-4 cm beyond the tip of the needle. After a negative aspiration test, a bolus dose of local anesthetic is injected followed by either a continuous infusion and/or intermittent boluses of local anesthetic via an infusion pump. Infusion pumps can either be electronic or nonelectronic. Of nonelectronic mechanisms, only elastomeric pumps have been studied in depth for continuous regional anesthesia.
Protocols
Several protocols for regional nerve blocks for hip fractures have been presented in the literature. Table 1 summarizes important logistic variables for regional block protocols including the type and duration of block, anesthetic utilized (and pump if applicable for continuous blocks), proceduralist, and location of where block was placed. These protocols highlight how different specialties and different levels of medical experience have all been utilized to perform regional nerve blocks.

Practicality for goals of hip fracture protocols must be taken into consideration. For example, one study\(^\text{15}\) set time goals for eligible patients to receive a FNB that took working hours into account – either within 45 minutes of arrival at the hospital during work hours (7:00 - 19:00) or within 4 hours during off hours (19:00 – 7:00). All medically cleared patients then underwent surgery within 24 hours of arrival to the facility. Only one study\(^\text{24}\) noted the duration of the block procedure, which was less than 15 minutes for insertion and securing the femoral nerve catheter for a continuous femoral nerve block performed by an attending anesthesiologist.

Two studies\(^\text{16,22}\) outlined a training program for performing their regional block of interest. Both protocols included a lecture session followed by supervised placement on a patient. Neither study commented on the number of supervised attempts required before competency was achieved. Although another study\(^\text{21}\) did not outline the training program for junior registrars learning to perform FICB, the authors noted that the learning curve was “relatively easy” as the efficacy of the block did not correlate to the number previously performed by the junior registrar. Two other studies\(^\text{17,18}\) noted that physicians in training could successfully perform their studied block with minimal instruction. However, resident physicians were not used as the proceduralists in these studies and the method of instruction was not elucidated.

The studies\(^\text{12,15–18,20–22}\) for single-shot nerve blocks all demonstrated efficacy as pre-operative analgesia for hip fractures. The duration of a single bolus of bupivacaine 0.5% 20 mL for FNB is only 22 hours (range 15-32),\(^\text{26}\) which limits its application for post-operative analgesia. Either repeated single injections\(^\text{19}\) or continuous block catheters provide the advantage of both pre- and post-operative analgesia.

QMC Protocol

Once the patient is determined by the orthopaedic consult to have an eligible hip fracture (acetabular fractures excluded), anesthesia is consulted for possible block placement. Both surgical and non-surgical patients are eligible. The goal is to have the patient evaluated and blocked by the anesthesiologist within two hours of consultation. CRNAs may relieve the MD during ongoing cases to facilitate block placement. Patients are deemed eligible for block placement by anesthesia if preoperative risk stratification is completed, conditions present on admission are documented, and if they pass the “4 Nos then Go”:

- Does the patient have an active cardiac condition (evolving MI, decompensated CHF, etc.)?
- Does the patient have a significant coagulopathy?
- Does the patient have an active stroke?
- Does the patient have a condition requiring ICU level of care (sepsis, severe metabolic derangement, respiratory failure)?

If the answer is “No” to all four questions, the patient is eligible for a block and optimized for fast track to the OR. The anesthesiologist books the block placement with the OR. The patient is admitted to the hospital by the appropriate service and then transferred to the pre-op area during normal business hours or the post-anesthesia care unit (PACU) after-hours for block placement. These areas were chosen for block placement as all applicable anesthesia equipment including ultrasound machines, infusion pumps, and medications are readily available, and staff have the appropriate training for procedural documentation and toxicity monitoring. Either pre-op nurses assist during normal business hours or operative nurses assist after-hours. For surgical patients, the block placement is covered under the standard surgical consent form at QMC and a separate written consent is not required.

The anesthesiologist confers with the orthopaedic surgeon to ensure any invasive procedure is in alignment with the surgical preparation and plan for the patient. All patients are provided with multimodal analgesia while limiting narcotics and avoiding sedatives when possible. The anesthesiologist may then decide to place a single shot nerve block of 20-30 mL 0.2% ropivacaine based on weight, place a continuous nerve block with local anesthetic delivered via ON-Q pain pump (Kimberly Clark, Roswell, GA), or decline block placement and use only multimodal analgesia. The type of nerve block used (FNB versus FICB) and method of placement is at the discretion of the anesthesiologist, however most place a FICB (either single shot or continuous infusion) under ultrasound guidance. If the catheter tip conflicts with the surgical incision site, a bolus may be given prior to catheter tip removal in the OR. A new catheter may be placed post-op if needed. Post-operatively, the anesthesiologist (or one of their partners) evaluates the patient within 12 hours postoperatively. The patient’s first mobilization postop is with the physical therapist, who then provides feedback to the anesthesiologist regarding mobility. The infusion rate can be adjusted by the anesthesiologist if femoral weakness is an issue. If a catheter infusion is used, it is recommended to keep in place between 12-72 hours post placement. Appropriate DVT prophylaxis may be used postoperatively with catheter in place. The catheter is removed the day before discharge either by the anesthesiologist or RN.
<table>
<thead>
<tr>
<th>Study</th>
<th>Country</th>
<th>Type of Block</th>
<th>Duration</th>
<th>Technique</th>
<th>Proceduralist</th>
<th>Anesthetic Pump (if applicable)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foss, et al.</td>
<td>Denmark</td>
<td>FICB</td>
<td>Single</td>
<td>Loss of resistance</td>
<td>Junior anesthesiologists with less than two years of training</td>
<td>1% mepivacaine with 1:200,000 epinephrine 40 mL</td>
<td>Emergency department (ED)</td>
</tr>
<tr>
<td>Li, et al.</td>
<td>US</td>
<td>FNB</td>
<td>Single</td>
<td>Ultrasound guidance</td>
<td>Anesthesiologist</td>
<td>0.5% ropivacaine 30 mL</td>
<td>Not specified</td>
</tr>
<tr>
<td>Fletcher, et al.</td>
<td>UK</td>
<td>FNB</td>
<td>Single</td>
<td>Elicited paresthesias</td>
<td>ED staff – two consultants, four middle-grade physicians, seven senior house officers</td>
<td>0.5% bupivacaine 20 mL</td>
<td>ED</td>
</tr>
<tr>
<td>Monzon, et al.</td>
<td>Argentina</td>
<td>FICB</td>
<td>Single</td>
<td>Loss of resistance</td>
<td>Four ED attending physicians</td>
<td>0.25% bupivacaine at 0.3 mL/kg</td>
<td>ED</td>
</tr>
<tr>
<td>Haddad, et al.</td>
<td>UK</td>
<td>FNB</td>
<td>Single</td>
<td>Elicited paresthesias</td>
<td>Senior author– orthopedic surgeon</td>
<td>0.25% bupivacaine at 0.3 mL/kg</td>
<td>Not specified</td>
</tr>
<tr>
<td>Mouzopoulos, et al.</td>
<td>Greece</td>
<td>FICB</td>
<td>Multiple single – administered preop and daily every 24h until delirium occurrence or discharge</td>
<td>Loss of resistance</td>
<td>Orthopaedic surgeons</td>
<td>0.25 mg dose of 0.3 mL/kg bupivacaine</td>
<td>Not specified</td>
</tr>
<tr>
<td>Yun, et al.</td>
<td>Korea</td>
<td>FICB</td>
<td>Single</td>
<td>Loss of resistance</td>
<td>Senior author – experienced anesthesiologist</td>
<td>3.75 mg/mL ropivacaine 30 mL</td>
<td>Anesthesia induction room</td>
</tr>
<tr>
<td>Hegh, et al.</td>
<td>Denmark</td>
<td>FICB</td>
<td>Single</td>
<td>Loss of resistance</td>
<td>Junior registrars</td>
<td>2.5 mg/mL bupivacaine 30 mL and 2% lidocaine 10 mL (quantity halved if patient weighed &lt;50 kg)</td>
<td>ED</td>
</tr>
<tr>
<td>Haines, et al.</td>
<td>US</td>
<td>FICB</td>
<td>Single</td>
<td>Ultrasound</td>
<td>ED physicians</td>
<td>0.25% bupivacaine 30 mL</td>
<td>ED</td>
</tr>
<tr>
<td>Nie, et al.</td>
<td>China</td>
<td>FICB</td>
<td>Continuous</td>
<td>Loss of resistance</td>
<td>Anesthesiologist</td>
<td>Initial weight-based bolus of 0.5% ropivacaine (20 mL for &lt;50 kg, 25 mL for 50 kg to 70 kg, 30 mL for &gt;70 kg), followed by 0.25% ropivacaine infused at 0.1 mL/kg/h for 48 hours Electronic pump (Apon, Apon Ltd, China)</td>
<td>Intraop</td>
</tr>
<tr>
<td>Szucs, et al.</td>
<td>Ireland</td>
<td>FNB</td>
<td>Continuous</td>
<td>Nerve stimulation</td>
<td>Senior author – experienced anesthesiologist</td>
<td>Initial bolus of 10 mL of 2% lidocaine and 10 mL of 0.5% bupivacaine over 2-3 minutes followed by 0.25% bupivacaine infused at 4 mL per hour for 72 hours Elastomeric pump (Ace-Medical, AutoFuser, Seoul, South Korea)</td>
<td>ED</td>
</tr>
<tr>
<td>Luger, et al.</td>
<td>Austria</td>
<td>FNB</td>
<td>Continuous</td>
<td>Ultrasound</td>
<td>Attending anesthesiologists</td>
<td>Initial bolus of 30 mL 0.25% bupivacaine followed by 0.125% bupivacaine infused at 6 mL/h; if sensory block was inadequate, an additional 10 mL bolus of 0.125% bupivacaine administered Pump not specified</td>
<td>Not specified</td>
</tr>
</tbody>
</table>
Discussion

Further research into continuous regional nerve blocks is warranted. The influence of femoral weakness on postoperative mobility with continuous regional nerve blocks was not assessed in the cited studies. Furthermore, the risk of infection stemming from the in-dwelling catheter is not fully understood. One study FNB 48 hours after insertion and showed that 57% had positive bacterial colonization, with *Staphylococcus epidermidis* as the most common organism. A different study, however, cultured all catheter tips from continuous FICB and no positive cultures nor signs of infection were observed. There was no long-term follow-up in either study to see if bacterial colonization of catheters correlated with development of surgical site infections. The economic impact of continuous nerve blocks also merits further evaluation.

Careful consideration of available resources, including available staff and equipment, can help lead to the successful addition of regional nerve blocks in hip fracture protocols. A regional nerve block program may not require investment in expensive equipment depending on the technique used. Two studies explicitly chose to not use peripheral nerve stimulators to confirm block placements as the equipment was expensive, we tested the efficacy of using fascia iliaca blocks (FICB or frequently “misplaced” and “time-consuming to use.” Different specialties and levels of experience can be trained to successfully perform these procedures. Regional nerve blocks for hip fractures can be a quick and safe procedure to improve analgesia and patient satisfaction. Hopefully this overview of regional nerve block protocols in the literature and the detailed presentation of the protocol in use at QMC will help spearhead more widespread use of these valuable procedures.

Conflicts of Interest

None of the authors identify any conflicts of interest.

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References


Curveballs in Youth Pitchers: A Review of the Current Literature

Trent M. Tamate MD and Alexander C. Garber MD, PhD

Abstract

As the number of young people playing baseball has increased, so have the number of injuries. Throwing arm shoulder and elbow injuries are most common, and lead to both short and long-term consequences. Recent efforts have been made to identify risk factors for injury with corresponding regulations created to protect youth pitchers. Unlike rules enforcing pitch counts, prohibitions against curveballs are based on minimal objective evidence.

Keywords

curveball; shoulder; elbow; Little League; youth; throwing; pitcher

Abbreviations

OCD = osteochondritis dissecans
UCL = ulnar collateral ligament

Background

The number of youth athletes participating in baseball has continued to increase over the years. Little League Baseball alone is comprised of almost 200,000 teams. While this interest should be viewed positively, it has brought about a concomitant rise in injuries of the throwing arm. In two prospective cohort studies by Lyman, et al, about half of all participants developed shoulder or elbow pain at some point during the study period, with pain present in 15% of all pitching appearances. The problem is exacerbated by year-round play, participation in multiple leagues, and one-sport specialization with an increase in training intensity.

Throwing arm pain can hold significant consequences for youth athletes. A survey of 203 baseball players, ages 8-18 years-old, revealed that the majority experienced arm pain or fatigue throughout the season. 74% experienced arm pain with throwing, 80% had arm pain the day after throwing, and 83% had arm fatigue during a game or practice at some point in the season. This had a notable psychosocial impact on these young athletes, with 55% experiencing less fun while playing, 31% feeling that their parents/coaches were frustrated with their play, and 46% feeling pressured to play despite having pain. Left unchecked, these problems can progress. Shoulder/ elbow injuries necessitating surgery or retirement from baseball were noted to occur with an incidence of 5% in a study of 481 youth pitchers followed for up to 10 years. Given the rising occurrence of throwing arm pain and injuries in young baseball players, there has been an attempt to identify modifiable risk factors to improve prevention.

Overall volume of pitches thrown has consistently been shown to be a risk factor for the development of arm pain and injury. In a systematic review by Grantham, et al, greater number of pitches was identified as a significant risk factor in all included epidemiological studies. Pitching more than 100 innings in a year carried 3.5 times higher odds of serious arm injury in comparison to throwing less than that mark in the Fleisig, et al, 10 year follow-up study. Other consistent risk factors include: pitching with a higher velocity, bigger (taller, heavier) athletes, and pitching while fatigued. These findings have led to the institution of pitch count limitations and other recommendations by organizations such as Little League Baseball and USA Baseball.

Pitch type, specifically curveballs, remains one of the most controversial potential risk factors for arm pain/injury. The idea that throwing curveballs can be detrimental to a young pitcher’s arm has long been accepted by the baseball and sports medicine communities. However, both the American Sports Medicine Institute and Pitch Smart, a collaboration between USA Baseball and MLB, acknowledge that existing research does not support this widely held belief. Despite the lack of evidence, both organizations continue to recommend that pitchers refrain from learning to throw curveballs until they reach maturity. This itself is an arbitrary threshold that has been described as anywhere from 13-14 years old to when boys start shaving.

Anatomy and Biomechanics of the Throwing Motion

Throwing is a motion that takes the shoulder from extreme external rotation and abduction to internal rotation and adduction. Variation exists regarding the exact phases of throwing, but in general, it is composed of wind-up, stride, arm cocking, acceleration, deceleration, and follow-through.

With respect to arm pathology, the focus has mainly been on the late cocking/early acceleration phases of throwing. At this point in the throwing motion, the shoulder is in its maximum position of external rotation and abduction, with the elbow in...
The supraspinatus and posterior rotator cuff muscles are at peak activation. A significant anteriorly directed force is concentrated at the shoulder. Acceleration results in rapid shoulder internal rotation and adduction coupled with elbow extension (Figure 1). The subscapularis exhibits high activity and creates a strong internal rotation torque. In youth, the combination of an open proximal humeral physis with increased laxity of the joint capsule and ligaments leads to the development of unique changes at the shoulder versus adults. Arm acceleration also places large valgus stresses on the medial elbow. The anterior bundle of the UCL is the primary static stabilizer of valgus stress at the elbow. The flexor-pronator mass also provides dynamic valgus stability. Varus torque at the elbow acts to oppose valgus opening, placing tension on the medial structures and compression at the radiocapitellar and posteromedial ulnohumeral articulations.

**Injuries to the Shoulder and Elbow in Overhead Throwers**

The majority of shoulder and elbow injuries sustained by young overhead athletes result from chronic overuse. The aptly named Little League Shoulder represents a proximal humeral epiphysiolysis often brought on by a recent increase in throwing regimen. Other shoulder pathology includes rotator cuff tendinopathies, instability, and impingement of the posterior rotator cuff due to maximum external rotation coupled with an internal rotation torque. At the elbow, UCL injuries have garnered much attention within the baseball community despite its relatively uncommon occurrence in young athletes. Other conditions affecting the elbow include osteochondritis dissecans (OCD) of the lateral compartment, posteromedial compression secondary to valgus extension overload, and Little League Elbow, an umbrella term for medial epicondyle apophysitis, avulsions and accelerated growth with delayed physeal closure.

Although nonoperative management with rest, followed by a gradual return to throwing with modification of mechanics, stretching and strengthening often results in good outcomes, the potential for long-term complications exists. The proximal humeral physis is responsible for 80% of longitudinal growth in the upper extremity. Increased stresses may result in premature closure of the physis with subsequent limb length discrepancy or angular deformity, as well as physeal fractures. Injury progression at the elbow may necessitate surgical intervention, especially as athletes get older. In addition to the physical consequences, the persistence/recurrence of symptoms may limit the ability of young athletes to compete in overhead sports, or even cause them to stop playing altogether. Heyworth, et al, noted that about 1/4th of youth baseball players in their study were instructed to change positions as a part of the treatment of Little League Shoulder. An in-depth review of the evaluation and management of these injuries is beyond the scope of this article.

**Figure 1.** A and B, Side and Front Views Demonstrating Extreme External Rotation Seen During the Late Cocking Phase. C and D, Side and Front Views Demonstrating Sudden Shoulder Internal Rotation and Elbow Extension During Arm Acceleration.
Biomechanical Comparisons Between Fastballs and Curveballs

Understanding the unique stresses that each phase of throwing places on the shoulder and elbow is critical to evaluating the relative effects of throwing the curveball.

The fastball is thrown with consistently higher velocities than the curveball.\(^5\) Therefore, a proportionally smaller amount of force is required to generate the lower velocities seen when throwing curveballs. This would place less stress on the shoulder and elbow, and in theory, be less harmful to the throwing arm. Several published studies substantiate this line of thinking. Grantham, et al, reviewed 10 biomechanical studies and found no differences in proximal force or torque at the shoulder or elbow when comparing curveballs to fastballs.\(^8\) In one of the few biomechanical studies involving youth pitchers, Dun, et al, utilized 3D motion analysis to measure kinetic, kinematic and temporal parameters for fastballs, curveballs, and change-ups. They found increased proximal forces at the shoulder and elbow, as well as increased varus torque at the elbow and internal rotation torque at the shoulder when throwing fastballs.\(^18\)

Nissen, et al, collected kinematic data on 33 pitchers with an average age of 16.6 years-old. They found that, compared to other pitches, fastballs produced increased internal rotation velocity at the shoulder, increased varus moment and increased extension velocity at the elbow.\(^20\) Findings also included an increase in radial-to-ulnar wrist deviation of 3 degrees for the curveball, however this has not been linked to any injury risk.

Curveballs are associated with greater forearm supination (Figure 2).\(^5\)\(^,\)\(^18\)\(^,\)\(^20\) It has been proposed that this particular forearm positioning leads to more injuries at the elbow. However, in a cadaveric study assessing strain with valgus loading on the anterior and posterior bundles of the UCL, only minimal differences were found with changes in forearm rotation.\(^22\) These findings contradict the assertion that the increased forearm supination seen with curveballs elevates the risk of UCL injury.

Biomechanical studies evaluating different pitch types have not demonstrated higher stresses on the throwing arm with curveballs. In fact, the majority of studies concluded that fastballs place the greatest amount of stress on a pitcher’s arm. Indicating that the curveball is less harmful than the first pitch learned by all young throwers.

Epidemiological Studies

Although evidence has been mixed, observational studies to this point have largely been unable to find a significant increase in arm pain/injury associated with throwing curveballs. Grantham, et al, noted that in 3 out of 5 of the epidemiological studies included in their systematic review, no significant difference was found between curveballs and fastballs with regards to arm pain/injury.\(^8\) To further demonstrate the lack of conclusive evidence against curveballs, consecutive studies by Lyman, et al, produced contradictory results. A prospective cohort of 298 pitchers between 9-12 years old were followed for two seasons with phone-administered questionnaires after each game. There was no significant difference in the odds of elbow or shoulder pain between pitchers who threw curveballs and those who did not.\(^2\) In a subsequent study with similar methods, the same group evaluated a cohort of 476 pitchers of slightly older ages (range 9-14 years old, mean of 12 years old). Again, questionnaires were given following each game throughout a single
season. Pitchers who threw curveballs were found to carry an odds ratio of 1.52 ($P=0.04$) versus non-curveball throwers for the development of shoulder pain. The same did not hold true for elbow pain. These conflicting findings in two studies that used similar methods, in similar populations, illustrates the equivocal nature of the research against curveballs.

Olsen, et al, performed a case-control study involving a retrospective cohort of 95 pitchers ages 14-20 years old who had sustained a pitching related injury requiring shoulder or elbow surgery. This group was matched with 45 controls who had no history of shoulder or elbow pain that was either recurrent, lasted > 2 weeks, or caused them to miss game or practice time. Questionnaires evaluating various risk factors were completed. Results showed no difference between cases and controls in both the chronological age and years prior to puberty that pitchers first started throwing breaking pitches. There was also no difference between groups in the frequency of breaking pitches thrown over the past year.

In a large study with extended follow-up, Fleisig, et al, issued annual surveys to 481 pitchers aged 9-14 years old (at study initiation) for up to 10 years or until they retired. Throwing a curveball prior to age 13 was not found to be a significant risk factor for the development of a serious arm injury, defined as one requiring shoulder/elbow surgery or leading to retirement from baseball.

Yang, et al, observed an odds ratio of 1.66 for the occurrence of arm pain in pitchers who threw curveballs. This was seen in a cross-sectional survey evaluating the events of the previous 12 months in 754 pitchers ages 9-18 years old (mean age of 14). There was no significant association between throwing curveballs and complaints of arm fatigue or arm injury, defined as causing a player to miss a game or practice.

Forty-eight percent of youth baseball players were found to have elbow MRI abnormalities in a prospective cohort of 26 participants followed over one season. 1/3rd of these players had new/worsened MRI findings at season’s end. These findings were primarily at the medial aspect, and although over half of pitchers in the study threw curveballs or sliders, these pitches were not found to be associated with MRI abnormalities.

**Discussion**

It is possible the lack of definitive evidence against curveball use in young pitchers is due to the lack of adequately powered studies. Fleisig, et al, who completed one of the largest studies to date, felt that even they may not have had sufficient power to detect a difference in arm injuries in early curveball throwers. 60% of participants in their study threw curveballs.

Studies that have found an association between curveballs and arm pain/injury are typically confounded. Pitchers who learn to throw curveballs, especially at younger ages, tend to be more skilled. These pitchers are often bigger athletes, who throw faster. Furthermore, pitchers of this caliber throw more often, accruing large pitch volumes. All of these factors are independently associated with an increased risk of arm pain/injury.

Restrictions against curveballs in youth baseball rest on a paucity of scientific evidence, supported primarily by expert opinion. Current evidence remains limited, especially given the observational nature of the available studies. Obviously, causation cannot be determined. Recall and selection bias remain an issue, although the studies by Lyman, et al, attempted to reduce this by administering questionnaires after each game. Long-term data is limited, as most studies (with the exception of Fleisig, et al, who had up to 10-year follow-up) only collected data for 1-2 seasons.

Ideally, a study comparing pre-pubertal pitchers from leagues that allow curveballs versus leagues that do not would offer the best opportunity to isolate the effects of breaking pitches. This would theoretically allow for matching by age, height/weight, as well as other typical confounding variables. Long-term follow-up would be desired to determine any lasting negative outcomes from early curveball use.

**Conclusion**

Longstanding taboos against teaching curveballs to pitchers before puberty remains ingrained in youth baseball. This is despite a deficiency of convincing evidence in both biomechanical and epidemiological research showing increased harm. Larger studies with improved control of confounding variables may eventually reveal curveballs to be the dangerous pitch that many believe it to be. However, at present, the sports medicine community has no good evidence to recommend against its use.
None of the authors identify a conflict of interest.

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References
Management of Slipped Capital Femoral Epiphysis: The Hawai‘i Experience

John P. Livingstone MD; Mariya I. Opanova MD; Robert C. Durkin MD; and William Burkhalter MD

Abstract

Slipped capital femoral epiphysis (SCFE) is a growing problem amongst children in Hawai‘i as well as throughout the world. With increasing rates of childhood obesity, SCFEs are affecting more patients at younger ages. This makes the treatment of SCFEs critical as many children with SCFEs have significant growth remaining. There are a host of treatment options based on different classification schemes which can make it difficult to determine the appropriate care for a SCFE patient. In our practice, patients are treated based on a combination of angular displacement, stability as defined by Loder, and patient age. The procedures vary from single screw in-situ fixation for a mild deformity to a modified Dunn procedure for a high-grade deformity in the skeletally immature patient. For all our open fixation methods, epiphyseal perfusion is monitored with an 18-gauge needle attached to an arterial monitor and we routinely remove fixation after physeal closure. Excellent outcomes have been noted for the modified Dunn in our practice. This article describes the algorithm used to treat SCFE in Hawai‘i at a tertiary children’s medical center.

Keywords

slipped capital femoral epiphysis, Hawai‘i, pacific island, modified dunn, intertrochanteric osteotomy, screw fixation, gliding, growing, intraoperative monitoring, arterial perfusion, obesity

Abbreviations

AVN = avascular necrosis
SCFE = slipped capital femoral epiphysis
STSB = screw tip to subchondral bone

Introduction

Mechanism

Slipped capital femoral epiphysis (SCFE) is a result of shear forces overwhelming the proximal femoral physis in prepubescent and adolescent children. The epiphysis remains posterior in the acetabulum as the metaphysis shifts anterior and rotates externally. The impact of the shear stress across the physis is amplified with increased body weight and high impact activities. Hip morphology such as acetabular and femoral neck retroversion can contribute to the increased risk of SCFE.1

Signs and Symptoms

Patients with SCFEs often present with either hip and/or knee pain.2 They will typically have an antalgic gait with increased external rotation of the affected leg.2 This can be identified with a positive Drehmann test where the patient externally rotates their affected leg when the hip is flexed. In patients with a SCFE, internal rotation is usually painful or not possible due to impingement.

Incidence

The incidence of SCFE varies among different ethnicities. Pacific Islanders have a 4-5 times higher incidence of SCFE compared to European populations.4 There is also a higher incidence of SCFEs in Samoans.5 With a large population of both Samoans and Pacific Islanders in Hawai‘i, SCFEs are commonplace amongst pediatric orthopedic practices here in Hawai‘i.

Risk Factors

SCFEs have been shown to be associated with childhood obesity as well as low socioeconomic status.6,7 One study from Scotland noted that as childhood obesity rates increased during their study period, there was a 2.5 fold increase in the incidence of SCFEs from 1981 to 2000.8 There is also evidence that endocrine factors such as hypothyroidism, hypogonadism, and hypopituitarism are risk factors for developing a SCFE.9

Complications

The SCFE deformity has significant implications on hip biomechanics. The resulting femoroacetabular impingement leads to accelerated degenerative changes and an increased likelihood of developing osteoarthritis of the affected hip. One of the most severe complications of SCFEs is avascular necrosis (AVN) of the femoral head.10-12

Classification

Temporal Classification

SCFEs can be characterized based on the duration of symptoms. Acute SCFEs are symptomatic for a duration of three weeks or less while chronic SCFEs are symptomatic for greater than three weeks. Acute on chronic SCFEs are defined as an exacerbation of symptoms in a chronic SCFE. This classification has not been shown to have significant prognostic value and is therefore not as applicable in the clinical setting.13
Loder Classification

Loder used symptomatology to define the stability of SCFEs in his paper written in 1998. He defined a SCFE as stable if the patient was able to ambulate with or without crutches. If they were unable to ambulate with or without crutches, it was deemed to be unstable. This definition has been shown to be highly predictive of development of AVN. Their original series had an AVN rate of 47% in the unstable group and 0% in the stable group. More recently the rate of AVN in unstable SCFEs have been shown to be less than originally described but remains significant at 21%.

Degrees of Displacement

Another way to grade the severity of SCFEs is to look at the degree of displacement. Southwick defined the angle of displacement as the measure between the femoral epiphysis and the diaphysis (Figure 1). Mild SCFEs have a Southwick angle < 30 degrees, moderate 30-60 degrees, and severe > 60 degrees. This classification is useful in guiding treatment options and choice of fixation.

The severity of the slip also predicts the natural history of SCFEs with more severe slips resulting in higher rates of osteoarthritis and poor patient outcome scores. There is an emphasis on restoring normal hip biomechanics in unstable SCFEs to prevent femoroacetabular impingement and degenerative joint changes.

In Situ Screw Fixation

The standard treatment for mild chronic SCFEs is epiphysiodesis with a single screw through the femoral neck and into the epiphysis. This serves to neutralize the shear forces across the physis and prevent further slip. Some recommend that at least 5 threads cross the physis to provide optimal biomechanical stability and prevent slip progression. Screw penetration is a potential complication that can lead to chondrolysis. In order to avoid chondrolysis, a screw tip to subchondral bone (STSB) distance of 2.5-5mm is recommended. In a recent cadaveric study by Heffernan, et al, it was determined that only about 20% of C-arm radiographs were able to accurately determine STSB distance within a 1mm tolerance. They recommend using the known screw pitch of the in-situ screw to estimate the STSB distance to avoid screw penetration. We use the approach-withdraw method to minimize the risk of screw penetration. This involves rotating the leg from an internally rotated position to an externally rotated position while viewing the in-situ screw under fluoroscopy. The STSB distance will decrease and then increase as the leg is rotated thus allowing you to determine the true STSB distance.

The number of screws needed to maintain stability is controversial. Karol, et al, found a 33% increase in stiffness with 2 screws in a bovine model. However, clinical studies suggest a higher rate of complications like pin penetration and osteonecrosis with the use of multiple screws.

In the setting of an acute unstable SCFE with a Southwick angle < 30 degrees, our standard treatment is urgent fixation (Figure 2a). Due to the inherently unstable nature of these SCFEs, we prefer to use 2 fully threaded screws. We routinely remove all SCFE screws after physeal closure and this is easily accomplished with the fully threaded screws. We also do a needle decompression of the capsule and monitor perfusion with an 18-gauge needle fluoroscopically guided into the epiphysis and attached to an arterial line monitor.

Implant Selection

Although epiphysiodesis is optimal in children close to bone maturity, it may be less desirable in younger patients with significant bone growth remaining. Arresting the femoral capital growth can result in a short femoral neck, coxa vara, and relative trochanteric overgrowth. These deformities can disturb regular hip biomechanics and potentially result in pain and gait imbalance.

Figure 1. Photo demonstrating the Southwick angle of a left SCFE.
With these complications in mind, attention has turned to implants which preserve femoral neck growth. Studies looking at such implants have demonstrated that preserving the femoral capital physis allows for improved remodeling of the SCFE deformity. Preserving growth has become increasingly more relevant as younger children are developing SCFEs at an earlier age. One study in Scotland noted a correlation between the increased rate of SCFEs at an earlier age with an increase in childhood obesity rates.

The Synthes SCFE screw is a partially threaded screw with a shaft diameter equal to the threads to facilitate removal (Figure 3). One disadvantage to this screw is that the screw must be left proud in order to allow for growth. This may be symptomatic as the iliotibial band can rub against the head of the screw, especially in younger patients where the screw needs to be left even more proud to facilitate additional growth.

Another growth facilitating SCFE screw is the Pega Medical free gliding screw. This screw has a telescoping design which allows for continued growth without being prominent (Figure 4). The Pega screw relies on a compression force across the physis to prevent slip progression. One potential concern with that is the amount of compression may not be enough to prevent further deformity. In a biomechanical animal model study by Upasani, et al., they found that an even distribution of threads 40%-60% in a 16mm partially threaded screw across the physis gave optimal biomechanical stability. If too many of the threads were in the physis the construct failed with the screw plowing in the neck. The growth implants currently available are designed to have the threads fully inserted in the epiphysis with none crossing the physis. This may reduce the load to failure. A biomechanical study comparing the Pega and the Synthes SCFE screws with a standard fully threaded screw found them to both be as effective as the standard fully threaded screw. Currently there is very little clinical information in terms of long-term outcomes or hardware complications, so more studies are needed before it becomes standard of practice. We are currently incorporating this screw into our practice for select patients that are generally less than eleven years of age (Figure 2b).

**Intertrochanteric Flexion Osteotomy**

In a moderate SCFE deformity (30-60 degrees) the metaphysis of the femoral neck begins to impinge on the anterior acetabulum and external rotation cannot accommodate for the deformity in flexion. This leads to significant acetabular and labral damage and accelerates degenerative changes in the hip joint. Moderate deformities also lead to limited hip flexion and abduction, increased trunk sway, reduced step distance and velocity, and decreased strength at the hip and knee.

In our practice, a stable moderate SCFE is treated with an in-situ screw fixation urgently on initial presentation to prevent slip progression (Figure 2b). We address the remaining deformity...
with an intertrochanteric flexion osteotomy. The osteotomy is fixed with a ninety-degree blade plate. Extra care is taken to avoid a z-deformity of the femur to allow for a total hip arthroplasty in the future if it is required. The intertrochanteric osteotomy anteverts the femoral head relative to the shaft and prevents further impingement by moving the metaphyseal femur away from the anterior acetabulum. The osteotomy also allows for correction of the rotational deformity and restores the articular-to-trochanteric distance thus improving extensor strength and hip mechanics. This procedure can also be used in patients with mild SCFE and residual impingement not amenable to arthroscopic treatment alone. Several retrospective groups have studied the outcome of the intertrochanteric flexion osteotomy and have demonstrated improved functional scores and less radiographic osteoarthritis compared to untreated deformities.34,35 There is limited evidence regarding the impact of intertrochanteric osteotomies on total hip arthroplasty. One study by Haverkamp, et al, found that there was no difference in 10- or 15-year survival rates of total hip arthroplasties amongst patients with intertrochanteric osteotomies compared to patients without a previous osteotomy.36

### Modified Dunn Procedure

We treat severe chronic stable SCFEs as well as moderate or severe unstable SCFEs with a modified Dunn procedure since an intertrochanteric osteotomy is insufficient for deformity correction (Figure 2a, 2b). The procedure is performed by surgically dislocating the hip by a trochanteric flip approach as described by Ganz. The epiphysis is mobilized on its vascular pedicle of the ascending cervical vessels and is then reduced with two or three 3.0mm K-wires. We remove the posterior femoral neck callus to aid in the reduction of the epiphysis and we remove the physeal cartilage in the femoral head fragment to improve epiphysiodesis. Epiphyseal perfusion is monitored with an 18-gauge spinal needle attached to an arterial line monitor. Measurements are taken before reduction, after reduction, and continuously during capsular closure to ensure adequate perfusion throughout the procedure. There is some controversy regarding the use of the modified Dunn on a stable SCFE with a severe deformity.37 We have had success with this operation on severe stable SCFEs and believe that the benefits of preventing impingement and further degenerative joint disease outweigh the potential risks. The rates of avascular necrosis after the Modified Dunn procedure vary widely with reports between 2%-26%,38,39 This suggests that both the technical considerations of surgery and patient selection are key to achieving excellent results.
Conclusion

SCFEs are a growing problem amongst children in Hawai‘i as well as throughout the world. The algorithm implemented at the tertiary children’s medical center in Hawai‘i takes certain variables into account to assist with clinical decision making. Excellent outcomes have been noted thus far with utilization of this algorithm in Hawai‘i.

Conflict of Interest

None of the authors identify any conflicts of interest.

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References

Hip Offset and Leg Length Equalization in Direct Anterior Approach Total Hip Arthroplasty without Preoperative Templating

Ian Hasegawa MD; Anne R. Wright MD; Samanth N. Andrews PhD; Emily Unebasami BS; and Cass K. Nakasone MD

Abstract

The standard practice of preoperative templating may be less important for direct anterior approach (DAA) total hip arthroplasty (THA) with intraoperative fluoroscopy (IF). However, this has yet to be tested. The purpose of this retrospective review was to report the hip offset (HO) and leg length (LL) equalization accuracy following 304 consecutively performed DAA THA with IF and no preoperative templating. A supplemental fluoroscopic gridding tool was used to assess hip symmetry. Operative and fluoroscopic times were also documented to assess for surgical efficiency. The mean HO and LL difference was 3.5 ± 2.6 mm (range: 0.0-9.3) and 2.9 ± 2.2 mm (range: 0.0-9.9), respectively. Hip offset and LL equalization within 10 mm was achieved in all patients. The mean operative time for unilateral THA was 72.2 ± 12.0 minutes, and the mean fluoroscopy time per hip was 10.5 ± 4.5 seconds. These results suggest that for surgeons with adequate experience performing DAA THA with IF, preoperative templating may not be necessary to reliably and efficiently achieve clinically acceptable HO and LL.

Keywords

Total Hip Arthroplasty; Direct Anterior Approach; Preoperative Templating; Hip Offset; Leg Length

Abbreviations

AP = anteroposterior
DAA = direct anterior approach
HO = hip offset
IF = intraoperative fluoroscopy
LL = leg length
THA = total hip arthroplasty

Introduction

Preoperative templating has been considered a necessary exercise to ensure the proper execution of total hip arthroplasty (THA).1-5 The primary objective of preoperative templating is to guide surgical decisions, such as determining the implant size and position required to produce symmetric hip offset (HO) and leg length (LL). This in turn may increase surgical efficiency, ensure that the proper implants and materials needed are available, and reduce the potential for intraoperative complications. Despite these benefits, there are limitations associated with preoperative templating, including those associated with errors in human measurement, suboptimally positioned pelvic radiographs, and magnification errors.3,6 Even digital templating has been associated with a high degree of predictive inaccuracy as rates as low as 36%-38% have been reported.1-3,7,9

Significant HO and LL discrepancies after THA have been associated with poor patient outcomes, persistent pain, gait impairment, nerve palsies, instability, and risk for early failure.10-14 Compared to posterior and lateral approaches, direct anterior approach (DAA) THA has been associated with greater HO and LL equalization accuracy.15,16 In contrast, the predictive accuracy of preoperative templating has not been shown to be any more effective between anterior and posterior approaches.8 This suggests that the improved accuracy in HO and LL equalization associated with DAA THA may be unrelated to the benefits of preoperative templating. For example, DAA THA facilitates the use of intraoperative fluoroscopy (IF), which can be used to evaluate implant size and position, and consequently HO and LL.

For surgeons performing DAA THA with intraoperative fluoroscopy (IF), the time consuming process of preoperative templating may be less important. This has not been studied previously. Therefore, the purpose of this retrospective review was to report the accuracy of HO and LL equalization following a consecutive series of DAA THAs performed with IF and no preoperative templating.

Methods

This institutional review board approved, retrospective review included a consecutive cohort of unselected patients undergoing primary unilateral or single-stage bilateral THA via the DAA between January 2016 and May 2018. This included patients with standard indications for THA as well as those with pre-existing contralateral hip replacement. Revision THA and cases performed for displaced femoral neck fractures were excluded. Additionally, one patient was excluded for review due to a peri-prosthetic femur fracture of a previously placed contralateral THA that required open reduction and internal fixation. This resulted in an abnormally shortened limb and that could not serve as a target for equalization. The final analysis included an unselected cohort of 245 patients.

A single, fellowship-trained orthopedic surgeon performed all THAs via the DAA utilizing a specialized fracture table (Hana, Mizuho OSI, Union City, CA, USA) and methods similar to that described by Matta, et al.17 However, no preoperative templating was performed on any subject. Intraoperative fluoroscopy with OrthoGrid Drone (OrthoGrid Systems Inc., Salt Lake City, UT, USA) was used in each case (Figure 1).
Prior to surgery and at six-weeks postoperatively, all patients completed weight bearing anteroposterior (AP) bilateral hip radiographs, as well as a frog leg lateral radiograph of the operative hip. Intraoperative pelvic images were aimed to match the pelvic tilt demonstrated on preoperative weight bearing radiographs. This was achieved by adjusting the tilt of the fracture table and/or the c-arm. Care was also taken to achieve a rotationally centered pelvic image with symmetric obturator foramen. Standard uncemented implants were used in all cases and are summarized in Table 1.

Primary surgical outcomes included HO and LL differences. Hip offset and LL were measured on both preoperative and six-week postoperative weight bearing AP bilateral hip radiographs. Hip offset was determined by measuring the horizontal distance between the longitudinal axis of the femur and the medial edge of the radiographic teardrop (Figure 2). Leg length was determined by measuring the vertical distance from the trans-teardrop reference line to the center point of the lesser trochanter (Figure 2). Discrepancies were then calculated and recorded as the absolute difference between the measured hip and the contralateral side.

Operative and fluoroscopic times were analyzed as secondary surgical outcomes. Surgical time was defined from the opening incision to the end of wound closure and dressing application. For single-stage bilateral THAs, operative time was recorded from the opening incision of the first operative hip to the end of wound closure and dressing application of the second operative hip. This also included an approximately 30-minutes.
period between completion of the first operative hip and start of the contralateral side. This time period was required for sterile preparation and draping of the second operative hip. Intraoperative fluoroscopy was used at four main time points: acetabular reaming, cup impaction, HO and LL assessment and final stem placement. Fluoroscopy times were recorded directly from the c-arm unit. Bilateral THA fluoroscopy times were recorded separately for each hip.

Descriptive statistics for all outcome variables, including mean, standard deviation and ranges, were determined for the enture cohort, as well as uni- and bilateral THA patient groups.

**Results**

Two hundred and forty-five patients (304 hips) underwent DAA THA without preoperative templating. This consisted of 114 males (47%) and 131 females (53%), with a mean age at surgery of 66.0 ± 10.7 years, and a mean body mass index of 27.9 ± 13.6 kg/m² (Table 2).

Postoperatively, the mean HO difference for the entire cohort was 3.5 ± 2.6 mm (range: 0-7.9) and the mean LL difference was 2.9 ± 2.2 mm (range: 0-9.9) (Table 3). The mean postoperative HO difference for unilateral and bilateral THA was 3.7 ± 2.4 mm (range: 0.0-9.3) and 3.0 ± 2.1 mm (range: 0.3-7.9), respectively. The mean postoperative LL difference for unilateral and bilateral THA was 3.1 ± 2.2 mm (range: 0.0-9.9) and 2.3 ± 2.0 mm (range: 0.0-7.3), respectively.

The mean operative time for unilateral THA was 72.2 ± 12.0 minutes and 175.1 ± 16.2 minutes for bilateral THA (Table 4). The mean fluoroscopic time per hip was 10.5 ± 4.5 seconds (Table 4).

**Discussion**

To our knowledge, no previous study has evaluated the accuracy of HO and LL equalization following DAA THA with IF and no preoperative templating. In the current study, HO and LL differences were achieved on average within 4 mm of the contralateral side. Additionally, 100% of HO and LL differences were within 10 mm. Similar HO and LL mean differences and accuracy rates have been reported in the setting of preoperative templating. This suggests that preoperative templating may not be necessary for DAA THA with IF when performed by experienced surgeons.

Direct anterior approach THA facilitates use of IF due to the supine position of the patient. Furthermore, the bed can be tilted so that the patients’ pelvic tilt matches that of preoperative standing radiographs. This likely explains the high HO and LL accuracy rates observed in the current study as well as those reported in others. Previous research has demonstrated lower HO and LL differences after DAA THA compared to those performed via posterior or lateral approaches despite the implementation of preoperative templating on all patients.

In the current study, IF was used with the addition of a commercially available grid system to aid in the visual assessment of hip symmetry. To our knowledge, only one previous study has examined the use of IF with a grid system, and similar results were reported. Gililland, et al, reported HO and LL equalization within 10 mm at rates of 95% and 100%, respectively. These rates were significantly higher compared to those

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**Table 2. Patient Demographics**

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male: 114; Female: 131</th>
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<tbody>
<tr>
<td>Laterality</td>
<td>Unilateral: 186; Bilateral: 59</td>
</tr>
<tr>
<td>Age (years)</td>
<td>62.0 ± 10.7 (28.90)</td>
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<tr>
<td>Height (centimeter)</td>
<td>165.9 ± 11.1 (139,195.6)</td>
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<tr>
<td>Weight (kilogram)</td>
<td>74.6 ± 17.3 (425,139.3)</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>26.9 ± 4.6 (16.7,45.8)</td>
</tr>
</tbody>
</table>

SD = Standard Deviation

**Table 3. Pre- and Postoperative Hip Offset and Leg**

<table>
<thead>
<tr>
<th>Length Differences</th>
<th>Mean ± SD</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Preoperative, Hip Offset (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>4.5 ± 3.7</td>
<td>(0.17,2)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>3.9 ± 3.4</td>
<td>(0.13,9)</td>
</tr>
<tr>
<td>All</td>
<td>4.3 ± 3.6</td>
<td>(0.17,2)</td>
</tr>
<tr>
<td>Preoperative, Leg Length (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>5.5 ± 5.6</td>
<td>(0.36,7)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>4.6 ± 9.4</td>
<td>(0.71,9)</td>
</tr>
<tr>
<td>All</td>
<td>5.3 ± 6.7</td>
<td>(0.71,9)</td>
</tr>
<tr>
<td>Postoperative, Hip Offset (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>3.7 ± 2.4</td>
<td>(0.9,3)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>3.0 ± 2.1</td>
<td>(0.3,7,9)</td>
</tr>
<tr>
<td>All</td>
<td>3.5 ± 2.8</td>
<td>(0.9,3)</td>
</tr>
<tr>
<td>Postoperative, Leg Length (mm)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unilateral</td>
<td>3.1 ± 2.2</td>
<td>(0.9,9)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>2.3 ± 2.0</td>
<td>(0.7,3)</td>
</tr>
<tr>
<td>All</td>
<td>2.9 ± 2.2</td>
<td>(0.9,9)</td>
</tr>
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</table>

SD = Standard Deviation; mm = millimeter

**Table 4. Operative and Fluoroscopic Times**

<table>
<thead>
<tr>
<th>Operative Time (Minutes)</th>
<th>Mean ± SD</th>
<th>Range</th>
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</thead>
<tbody>
<tr>
<td>Unilateral</td>
<td>72.2 ± 12.0</td>
<td>(45.0,127.0)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>175.1 ± 16.2</td>
<td>(141.0,215.0)</td>
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</table>

<table>
<thead>
<tr>
<th>Fluoroscopy Time (Seconds)</th>
<th>Mean ± SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unilateral</td>
<td>10.4 ± 4.5</td>
<td>(5.0,25.0)</td>
</tr>
<tr>
<td>Bilateral</td>
<td>10.8 ± 9.4</td>
<td>(2.0,23.5)</td>
</tr>
</tbody>
</table>

SD = Standard Deviation
performed with IF alone. Although more studies are needed, fluoroscopic grids may represent a tool that can further enhance the intraoperative assessment of hip symmetry.

Computer navigation is often presented as the most accurate method for restoring HO and LL in THA. While HO and LL outcomes after computer navigated DAA THA have not been reported, the results of this study are comparable to those reported after computer navigated THA performed via other approaches. Hip offset equalization has been reported at rates of 85% and 95% when using 10 mm and 6 mm cut-offs, respectively. Leg length equalization rates have also varied, with reports ranging from 90% to 100% when using a 10 mm cut-off, and 80% to 99% with a cut-off of 6 mm or less. In the current study, 10 mm was used as the clinically relevant cut-off for HO and LL differences, with 100% of patients falling within 10 mm. When using a 6 mm cutoff, LL equalization was still achieved in 88.6% of patients in the current study.

Multiple factors may influence surgical efficiency during THA. Operative and fluoroscopy times are two factors that are easily and objectively measured. By predicting the implant size and position needed to restore native HO and LL prior to the start of surgery, one would expect less operative and fluoroscopy time needed to confirm an appropriately sized and placed implant. However, the results of this study do not suggest this. Both operative (72 minutes) and fluoroscopy (10.5 seconds) times in the current study were less than those previously reported. Contemporary studies of unilateral DAA THA using preoperative templating have reported operative times ranging from 83 to 114 minutes, and fluoroscopy times ranging from 11.1 to 18.5 seconds. Varying methodologies for single-stage bilateral DAA THA make it difficult to compare surgical efficiency between studies. However, the mean operative time for bilateral THA in the current study was 175 minutes, which is comparable to the 180 minutes reported by Parcells, et al.

There are several limitations to this study. First, there was no preoperative templating control group to compare and assess for differences in HO and LL equalization. However, the primary goal of this report was to describe the current practice at the study site and to compare the results of this study to those previously published. Second, the addition of a grid system may be a confounding factor to the results of this study as the previously mentioned grid study reported superior HO and LL results with the addition of a grid system compared to IF alone. As such, these results may not be reproducible in settings where IF during DAA THA is utilized without a grid system. However, this also suggests that imaging tools such as fluoroscopic grids may be helpful when preoperative templating is not performed as it may further enhance the intraoperative assessment of hip symmetry. Finally, the results of the current study represent the practice of a single, high volume surgeon with more than ten years of experience in DAA THA with IF. Multiple studies indicate an improvement in surgical outcomes and a reduction in major complications with increasing DAA surgical experience. As such, the authors recognize that these results may not be reproducible in less experienced or low volume surgeons.

It is also important to note that the authors do not believe preoperative templating is unimportant. For surgeons in training or those with limited experience, the exercise of preoperative templating is critical for learning and understanding the surgical goals of THA. It is not a step in the growth of any developing hip surgeon that should be overlooked.

**Conclusion**

The results of this study demonstrate that IF with a commercially available gridding system may provide adequate information to accurately restore HO and LL following DAA THA, even when preoperative templating is not performed. Additionally, the lack of preoperative templating did not appear to negatively impact surgical efficiency in terms of operative and fluoroscopy times. Based on these results, the time consuming practice of preoperative templating may not be necessary to accurately and efficiently achieve symmetric HO and LL for surgeons with adequate experience performing DAA THA with IF.

**Conflict of Interest**

None of the authors identify a conflict of interest.

**Disclosure Statement**

Dr. Cass Nakasone is a paid consultant for Ortho Development Corporation and Zimmer Biomet. No financial support was received for this study.

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Implications of Spinopelvic Mobility on Total Hip Arthroplasty: Review of Current Literature

John D. Attenello MD and Jeffery K. Harpstrite MD

Abstract

Understanding the impact of pathologic spinopelvic mobility on total hip arthroplasty instability requires an appreciation of the dynamic interplay between and the spine, hip and pelvis. This complex interdependent relationship changes with position, pathology and surgical intervention. Spinal pathology may prevent normal dynamic motion leading to spinopelvic stiffness and abnormal pelvic position. Patients at high risk for pathologic spinopelvic motion and subsequent total hip arthroplasty (THA) dislocation should be assessed with a functional imaging series with lateral standing, sitting and AP standing radiographs. Common patterns of stiffness and imbalance as well as proposed surgical treatment algorithms are presented and discussed in this review.

Keywords

Total hip arthroplasty, dislocation, spinopelvic mobility, flatback, adult spinal deformity, acetabular anteversion, pelvic tilt

Abbreviations

AI = Anteinclination
APPT = Anterior plate pelvic tilt
CSI = Combined Sagittal Index
DAA = Direct Anterior Approach
LSZ = Lewinnek Safe Zones
PFA = Pelvic Femoral Angle
PI = Pelvic Incidence
PT = Pelvic Tilt
sPT = spinopelvic tilt
SS = Sacral slope
THA = Total hip arthroplasty

Introduction

The spine, hip and pelvis have a dynamic and interdependent relationship that changes with position, pathology and surgical interventions. Normal motion requires adequate spinopelvic mobility and proper posture. However, spine disease can decrease motion, through degenerative disease or surgical arthrodesis, and cause abnormal spinopelvic posture due to compensatory pelvic rotation to maintain sagittal balance with an energy efficient posture. The lack of proper spinopelvic motion and coordination may jeopardize the functional position of the acetabulum. As a result, there has been a recent increase in interest to characterize spinopelvic motion abnormalities and elucidate their impact on total hip arthroplasty (THA) outcomes. This is particularly relevant in the modern era of advanced medical interventions that prolong expected lifespan. The prevalence of concomitant degenerative hip and spine disease continues to increase with more patients undergoing both lumbar spine fusions (LSF) and THAs. A review of Medicare data found a 293% increase in patients with LSFs undergoing THA over a period of 12 years. The prevalence of degenerative lumbar spine disease in patients undergoing primary THA for hip osteoarthritis was approximately 40%.

The effect of spine disease on THA arthroplasty has largely focused on dislocation risk. Postsurgical hip instability has altogether been shown to be 2%-4% in large multicenter studies. However, contemporary studies focusing on THA in patients with degenerative spine disease or long segment LSFs has shown a dislocation risk of 8%-18%. Perfetti, et al, noted a seven times higher rate of dislocation with a prior spine fusion and several authors have demonstrated a positive association with the number of levels fused and degree of spinal imbalance. Malkani found that LSFs performed within five years prior to THA to be an independent risk factor for THA dislocation and corroborates previously published data. THA patients with concomitant spinal sagittal imbalance that have not yet been treated with a LSF are also at risk for posterior impingement, dislocation and superior edge loading. Furthermore, standing posterior pelvic tilt has been shown to progressively worsen with increasing age and therefore further increases these risks. There is potentially a new set of risks in these patients if corrective spine surgery is performed post THA due to readjustment of posterior pelvic tilt, functional acetabular anteversion, and spinal stiffness.

The impact of spinopelvic imbalance is particularly profound in THA late dislocations. Heckmann, et al, reported that 90% of their late dislocations (defined as > 1 year) had spinopelvic imbalance. However, not all patients with spinopelvic abnormalities will dislocate, as shown by Yukizawa, et al, in their 10 year follow up study on THA patients which found 62% had abnormal spinopelvic motion. One should also consider that loss of spinopelvic balance and mobility is often progressive. The prevalence of spinal stiffness in patients undergoing primary THA was found to increase from 20% to 60% after 10 years, often with progressive loss of sagittal balance and increasing pelvic tilt. Consequently, the risk of hip instability in elderly patients with non-instrumented spine disease continues to increase with age and progression of disease.

To appropriately address these issues, surgeons must understand the dynamic interplay between the spine, pelvis and hip. Lazen nec et al. pioneered the study of the hip and spine relationship in 2004 and has introduced the idea of a “functional” acetabular
component position in the sagittal plane. Several authors have continued to champion this investigation including Lawrence Dorr. In this review we will examine the current literature, define the commonly used nomenclature, describe normal and pathologic spinopelvic motion, propose means to identify high risk patients with options presented to work them up, and provide surgical interventions to consider.

Nomenclature

One of the challenges to understanding the spine, pelvis, and hip interplay has been the use of non-standardized and uncommon nomenclature. However this may change with the formation of the “Hip-Spine Workgroup.” Ike, et al, provided an excellent list of many of the common terms that are used in the literature and defined them. The authors of this review have chosen additional terms that are used and often not fully understood. We provided a list of these terms and their definitions in Table 1. To further complicate the issue, some of the same terminology is defined differently in the spine versus arthroplasty literature.

The term pelvic tilt (PT) used in arthroplasty literature for hip navigation is the rotation of the pelvis in the sagittal plane as measured by the angle formed between the coronal plane and the anterior pelvic plane (APP) which is defined by a line from the anterior superior iliac spine (ASIS) to pubic symphysis. Therefore, we will hereon refer to this term as anterior pelvic plane tilt (APPt). APPt can be either anterior or posterior because it is referenced from the coronal plane (neutral APPt). Posterior APPt occurs when the pelvis tilts backwards such that the S1 endplate becomes more horizontal which can also be thought of as the long axis of the sacrum itself becoming more vertical. Posterior APPt refers to the same motion as pelvic retroversion.

This is particularly confusing for arthroplasty surgeons which typically refer to retroversion in relation to the acetabular cup which is the opposite motion. For example, with posterior pelvic tilt, or pelvic retroversion, the functional position of the acetabular cup becomes more anteverted.

To further add to the confusion, the term pelvic tilt is used in the spine literature as a spinopelvic parameter referring to the position of the sacrum relative to the femoral heads, as defined by the angle between the vertical axis and a line from the femoral head to the midpoint of the S1 endplate. As a result, some authors use the term spinopelvic tilt (sPT) to distinguish between the two definitions of pelvic tilt, but this is not standard. Spinopelvic tilt is also a function of sacral slope (SS) because the sum of sPT and SS is equal to pelvic incidence (PI), which is essentially a constant value that is defined anatomically, but differs for each individual patient. Spinopelvic tilt is inversely related to SS, therefore an increase in sPT corresponds to a decrease in SS and this motion is equivalent to a posterior APPt as used by arthroplasty surgeons.

When considering dynamic spinopelvic motion that changes with position, static versus functional position also needs to be understood. Arthroplasty surgeons focus on placing components into the ideal Lewinnek Safe Zones (LSZ) in the static intraoperative supine or lateral position. There is a lack of consideration for the dynamic postural changes that take place when the patient is standing or sitting. Focus should be placed on the “functional” position of the components that takes into account the functional motion of the pelvis. It should also be noted that abnormal static pelvic tilt will distort perceived component position on AP pelvis imaging. The original LSZ was determined with the use of a jig that positioned the patient such that the APP was parallel to the floor. However, with any pathologic pelvic tilt in the supine or lateral position intraoperatively, radiographic measurements of anteversion and inclination are inaccurate. For each 1° of posterior APPt, functional acetabular anteversion will increase by 0.7°-0.8°. The change in functional acetabular inclination is less significant and nonlinear, depending on the degree of PT. There have been efforts to identify landmarks on AP pelvis imaging to quantify the degree of pelvic tilt, including the symphysis to sacrococcygeal joint distance, or the obturator foramen width to height ratio. In general, greater posterior APPt will appear more as an outlet view whereas greater anterior APPt will appear more as an inlet view on conventional AP pelvic imaging. This projection consideration excludes component placement with the use of computer navigation technology because it references the APP at 0°.

| Table 1. Additional Commonly Used Terms |
|-------------------------------|-------------------------------------------------|
| Term                          | Definition                                      |
| Combined sagittal index (CSI) | Angle of the acetabular cup in the sagittal plane that is the sum of the ante-inclination and the pelvic-femoral angle. |
| Hypermobility                 | Normal variation of spinopelvic motion defined as excessive dynamic motion when transitioning from standing to sitting. Defined as > 30 degrees SS |
| Pelvic retroversion           | Posterior rotation of the pelvis in the sagittal plane, equivalent to posterior anterior plane pelvic tilt. |
| Anterior Plane Pelvic Tilt (APPt): | Term for pelvic tilt used in arthroplasty literature referring to the rotation of the pelvis in the sagittal plane as measured by the angle formed between the coronal plane and a line from the anterior superior iliac spine (ASIS) to pubic symphysis. |
| Spinopelvic Tilt (sPT):       | Term for pelvic tilt used in spine literature referring to the position of the sacrum relative to the femoral heads, as defined by the angle between the vertical axis and a line from the femoral head to the midpoint of the S1 endplate. |
| Unbalanced Spine             | Pelvic incidence to Lumbar Lordosis mismatch greater than 10 degrees |

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Normal Spinopelvic Motion

Pelvic tilt is key to understanding spinopelvic kinematics (Figure 1). Normal standing posture consists of slight anterior APPt with a mean sacral slope of 40° and adequate physiologic lumbar lordosis (LL) to achieve sagittal balance. The functional acetabular position covers the femoral heads under the central weight bearing dome and allows slight hip extension for ambulation. As one transitions from standing to sitting, the pelvis tilts posteriorly approximately 20° in order to increase functional acetabular anteversion 15 to 20° to accommodate hip flexion without anterior impingement and subsequent posterior dislocation. With 20° of posterior APPt, the hip needs to only flex 55° to 70° to achieve proper sitting posture.

In terms of spinopelvic kinematics, when the pelvis tilts posteriorly by a mean of 20°, the sacral slope decreases by the same value of 20°.3,33,38 As the SS decreases, the lumbar spine flexes which decreases LL in order to maintain sagittal balance, bringing the trunk and head forward. As the pelvis tilts posteriorly, the acetabular anteversion increases 0.8° for every 1° of posterior APPt.9 However, a more accurate parameter to use is the sagittal parameter of anteinclination (AI) which combines changes in both acetabular anteversion and inclination.9

![Figure 1. Lateral standing (top row) and sitting (bottom row) spinopelvic radiographs showing the three classes of pelvic stiffness. Pelvic tilt (white arrows), sacral tilt (black arrows at L5-S1), and ante-inclination (black arrows measuring the cup angle) measured 9° posterior, 26°, and 39°, respectively, on the standing radiographs and 21° posterior, 12°, and 57° on the sitting radiographs of the patient with a stiff pelvis; 3° posterior, 35°, and 27° on the standing radiographs and 32° posterior, 3°, and 62° on the sitting radiographs of the patient with a normal range of pelvic tilt; and 14° anterior, 56°, and 27° on the standing radiographs and 32° posterior, 14°, and 73° on the sitting radiographs of the patients with a hypermobile pelvis. Permission from Kanawade, V., L.D. Dorr, and Z. Wan, Predictability of Acetabular Component Angular Change with Postural Shift from Standing to Sitting Position. J Bone Joint Surg Am, 2014. 96(12): p. 978-986.](image-url)
When transitioning from standing to supine, the pelvis tilts as well, but anteriorly and to a much lesser degree compared to sitting.\textsuperscript{3,43} The mean pelvic arc of motion has been reported to be $<5^\circ$,\textsuperscript{7} but many authors report significantly larger changes and have strongly recommended the use of standing AP pelvis radiographs to be used as a reference for component positioning.\textsuperscript{10,12,44}

**Abnormal Spinopelvic Motion**

As evident in normal spinopelvic kinematics, AP\textsubscript{p}t, SS, and AI are significant functional parameters that compose the dynamic nature of spinopelvic motion. Abnormal motion occurs due to spinal pathology leading to either sagittal imbalance, stiffness, or both.

Spinal sagittal imbalance occurs as the aging spine becomes progressive more kyphotic due to degenerative disease.\textsuperscript{45,46} In order to regain sagittal balance above the pelvis and maintain an energy efficient and pain-free erect posture,\textsuperscript{47} compensatory mechanisms are employed which include obligatory posterior AP\textsubscript{p}t. The limit of posterior AP\textsubscript{p}t is dependent on individual PI and hip extension reserve.\textsuperscript{53} With posterior AP\textsubscript{p}t while standing, the acetabulum is functionally anteverted so there is a risk for posterior impingement and subsequent anterior dislocation with hip extension.

The other factor to consider is flexibility of the spine (Figure 1). Spine mobility can be limited by degenerative spine disease\textsuperscript{38} or iatrogenic postsurgical long segment lumbosacral fusions, typically $\geq 3$ levels. The normal spine can accommodate a mean posterior AP\textsubscript{p}t of $20^\circ$ ($\Delta$AP\textsubscript{p}t or ΔSS of $20^\circ$) when transitioning from standing to sitting.\textsuperscript{3,38} Spinal stiffness is defined as ΔSS less than $10^\circ$.\textsuperscript{8} Consequently, patients with spinal stiffness cannot increase their functional acetabular anteversion to accommodate hip flexion when transitioning from standing to sitting and therefore risk anterior impingement with subsequent posterior dislocation. It is important to note though that stiffness is not always present in patients with spinal pathology such as sagittal imbalance.

**Classifications**

The challenge presented to the total arthroplasty surgeon is how to optimally position acetabular components to minimize risk for dislocation as well as surface wear and liner fracture.

Several authors have created classification schemes for patients to aid in creating a treatment algorithm to address the issue. Stefl, et al,\textsuperscript{4} described 5 patterns of spinopelvic mobility: fixed anterior tilt (“stuck standing”), fixed posterior tilt (“stuck sitting”), kyphotic, fused, and hypermobile. Stuck standing is a stiff spine that maintains anterior tilt with a SS $>30^\circ$ in both sitting and standing (Figure 2). Stuck sitting is a stiff spine that maintains posterior tilt with a SS $<30^\circ$ in both sitting and standing (Figure 3). Kyphotic is a pattern defined by a sitting SS of $<5^\circ$, but mobility is undefined. Fused spines have ΔSS $<5^\circ$ and hypermobile spines have ΔSS $>30^\circ$ when transitioning from standing to sitting.

Phan, et al.\textsuperscript{11} described 4 combinations patterns of spinal flexibility and balance (balanced defined as sPT $<25^\circ$; PI–LL mismatch $<10^\circ$): Flexible and balanced, rigid and balanced, flexible and unbalanced, and rigid and unbalanced. Flexible and balanced patients have normal spinopelvic mobility. Rigid and balanced are stiff, in a position akin to “stuck standing,” and are therefore at risk for posterior dislocation upon sitting. Flexible and unbalanced include patients with degenerative, postlaminectomy or neuromuscular kyphosis. The posterior tilt of the pelvis while standing places them at risk of posterior impingement and subsequent anterior dislocation. Rigid and unbalanced patients are stiff, in a position akin to “stuck sitting”, and therefore at risk for anterior dislocation when standing. These patients include iatrogenic flat back fusions and ankylosing spondylitis patients.

Luthringer, et al.\textsuperscript{12} proposed 4 categories (1A, 1B, 2A, 2B) very similar to Phan, et al, PI–LL mismatch $>10^\circ$ was termed flatback deformity and stiffness was defined as ΔSS $<10^\circ$ from standing to sitting. 1A had normal alignment and mobility, 1B have normal alignment with stiffness, 2A have flatback deformity with normal mobility, and 2B have flatback deformity with stiffness.

These classifications can be useful as general categories, but the degree of stiffness and sagittal imbalance should be determined on a case by case basis. Additionally, as patients age or undergo surgical procedures, they may transition from one category to another.\textsuperscript{29} Spine disease is progressive and loss of spinopelvic mobility and sagittal balance may be responsible for late dislocations. In contrast, release of hip flexion contractures after THA may actually increase spinopelvic mobility because flexion contractures prevent the pelvis from tilting posteriorly during ambulation.\textsuperscript{9} Sariali, et al, found a post-THA mean increase in ΔSS of $5^\circ$ and $3^\circ$ with sitting and standing, respectively.\textsuperscript{50} Stefli, et al, noted that 54% of patients undergoing THA had normal spinopelvic mobility preoperative, and that this increased to 80% after THA, which the authors attribute to release of hip flexion contractures.\textsuperscript{8}

**Work Up**

Proper preoperative work up of a patient with suspected spinopelvic abnormalities that may influence functional THA component positioning should include proper imaging and a thorough history and physical exam.\textsuperscript{8,9,46} Three views of the pelvis should be obtained to including lateral standing and sitting (90° trunk-thigh angle) and AP standing. Standing AP pelvis much more accurately represents functional pelvic position than supine radiographs.\textsuperscript{12} It is also recommended to center the AP radiograph slightly more cephalad than standard practice.
Figure 3. Standing lateral radiograph showing loss of lumbar lordosis and a posterior position of the pelvis as indicated by a sacral slope (SS) of 14°. The femur is in hyperextension relative to the pelvis as indicated by a pelvic-femoral angle (PFA) of 215°, to compensate for a pelvis that does not tilt posteriorly during sitting. A standing combined sagittal index (CSI) of 249° (34° + 215°) is predictive of posterior impingement.

Figure 3B Sitting lateral radiograph showing relative kyphosis of the spine indicated by a sacral slope of 3°. The sitting combined sagittal index is 188° (47° + 141°), which is within the normal range.

in order to capture more of the lumbar spine which may reveal evidence of prior surgery or other pathologic spine disease. Lateral views should include the L1 vertebrae to evaluate lumbar spine mobility or at least the L3 vertebrae because most of the lumbar motion occurs between L3 to L5.7,12

With the standing and sitting lateral radiographs, one can measure multiple parameters including, Pelvic Femoral Angle (PFA), SS, AI, PI, as well as the change in dynamic parameters. The two most important measurements to determine pathologic pelvic tilt and spinal stiffness are standing AP Pt and ΔAP Pt (or ΔSS) when transitioning from standing to sitting. Standing posterior or anterior AP Pt can be measured in reference to the coronal plane of the body (neutral AP Pt) and serve as a surrogate for spinal imbalance.12 ΔSS (or ΔAP Pt) from standing to sitting will determine stiffness (ΔSS < 10°).

Other useful measurements to obtain from the lateral standing XR include PI, LL and PI-LL mismatch. PI can be precisely measured or simply estimated from the location of the femoral heads relative to S1, where femoral heads that are anterior to S1 or directly below S1 correspond to high and low PI, respectively. Spine surgeons commonly use standing lateral lumbopelvic radiographs to determine sagittal balance by measuring LL and PI. PI and standing LL should be within 10° of one another and a mismatch greater than 10° is considered unbalanced and has been shown to correlate with dislocation risk.37 The deformity is also known as flatback because LL is approaching 0°.

Combined Sagittal Index (CSI) is a newly described parameter for sagittal functional hip motion introduced by Heckmann, et al, that may predict impingement in late THA dislocations in patients with spinopelvic abnormality.33 It is made up of the sum of AI and PFA. In a cohort of 20 patients, the authors demonstrated a correlation between late dislocation and abnormal CSI. Increased standing CSI was predictive for posterior impingement in 8 of 9 patients that dislocated anteriorly, whereas increased sitting CSI was predictive for anterior impingement in 10 of 11 patients that dislocated posteriorly. Following this, Tezuka, et al, proposed a functional sagittal safe zone defined by CSI and challenged the notion that cups placed within the Lewinnek coronal safe zone are also in the ideal sagittal position, or normal functional hip zone.36 The authors demonstrated that 14% of hips within the LSZ were not within the normal functional sagittal safe zone. The poor concordance of LSZ coronal and functional sagittal safe zone persisted even when the LSZ was narrowed to 37°-46° of inclination and 12°-22° of anteversion.51,52 The authors further describe the 3 factors from most to least predictive of abnormal CSI and thus risk for dislocation was increased PFA, stiffness (ASS < 11°) and low PI. The mechanism of impingement is thought to be due to increased femoral motion (high PFA), particularly in the setting of decreased pelvic motion (stiffness and low PI).

Screening all patients for loss of spinopelvic mobility and sagittal imbalance may be ideal but is certainly not practical for a high-volume arthroplasty surgeon. Back pain is very prevalent, particularly in elderly patients with degenerative disease. Therefore screening should be reserved for high risk patients that may benefit from more extensive work up including those with spinal pathology including history of spine surgery particularly long segment lumbosacral fusion, evidence of severe degenerative spinal disease, and kyphotic standing posture, or those with hip pathology including history of hip dislocation, revision THA, and hip flexion contractures.

**Treatment**

Most patients undergoing THA will have normal spinopelvic motion,4 (ΔSS 20°-40° from standing to sitting) and will not have clinically significant sagittal imbalance (standing PT ± 10°).10 Furthermore, Steff, et al, demonstrated that 16% of patients with preoperative spinopelvic abnormality regained normal spinopelvic motion post THA, presumably due to release of hip flexion contractures. As a result, for most patients, placement of the acetabular component in the standard coronal plane LSZ, has demonstrated great results for so many years. Even THA in patients with minor spinopelvic abnormalities have historically stayed safe from dislocation because surgeons tend to target narrow acetabular inclination and anteversion angles of 30°-45° and 15°-20°, respectively.7 It should be recognized though that there is a spectrum of instability including impingement pain without frank dislocation. For the high-risk patients with pathologic spinopelvic mobility, several authors have described classification schemes and provided potential solutions.

Phan, et al, proposed adjusting acetabular anteversion according to 4 patterns of flexibility and sagittal balance.11 In a flexible and balanced spine, standard LSZ anteversion was recommended. In a rigid and balanced spine, there is a loss of dynamic motion so a more anteverted and narrow range of 15-25° of anteversion was recommended. For the flexible and unbalanced spine as well as a rigid and unbalanced spine, the patient may first undergo spinal realignment procedure which would place them into the rigid and balanced pattern. However, if THA is performed first, the authors recommend decreasing cup anteversion for a kyphotic deformity to prevent posterior impingement while standing.

Luthringer, et al,12 proposed conceptually similar recommendations to Phan, et al, but specific to each patient’s standing AP pelvis in order to account for standing pelvic tilt (referred to as functional pelvic plane) and therefore provide a functional acetabular position (Figure 4). For 1A (normal alignment and mobility), standard anteversion was recommended. For 1B (normal alignment with stiffness), 30° of anteversion on the standing AP pelvis is recommended to avoid anterior impingement upon
sitting. For 2A (flatback deformity with normal mobility), 25°-30° of anteversion on standing AP pelvis is recommended. For 2B (flatback deformity with stiffness), 30° of anteversion on the standing AP pelvis is recommended, but the authors note that there is a very narrow safe zone between inadequate anteversion causing anterior impingement when seated and excessive anteversion causing posterior impingement when standing, and therefore recommended dual mobility articulation.

Stefl, et al, proposed adjusting both anteversion and inclination according to 5 patterns of flexibility. Hypermobile is a variant of normal but with a tendency to become excessively antverted when transitioning from standing to sitting so the authors recommend decreasing inclination and anteversion within a more narrow range of 35°-40° and 15°-20°, respectively. A stiff pelvis fixed in either anterior or posterior tilt is unable to functionally antvert its acetabulum upon sitting, therefore the authors recommend increasing inclination and anteversion within a more narrow range of 45°-50° (50° reserved for elderly patients), 20°-25°, and 35°-40° respectively. Kyphotic pattern (sitting SS < 5) will have a very vertical position of their acetabulum when seated. The recommendation for hypermobile kyphotic pattern is to decrease inclination, anteversion, and combined anteversion within a narrower range of 35°-40°, 15°-20°, and 25°-35°, respectively. Stiff and kyphotic patients, similar to the rigid and unbalanced pattern by Phan, et al, present a particular challenge because they require increased functional acetabular anteversion to avoid anterior impingement while sitting, but that places them at risk for dropout dislocation while standing. Therefore, the authors recommend a dual mobility articulation component. The authors also characterized the severity of the sagittal imbalance as either pathologic, dangerous or inconsequential. Pathologic imbalance could not be overcome with an ideal acetabular component placement; dangerous imbalance could be managed with precise acetabular component placement; and inconsequential imbalance was clinically insignificant that it did not require specific acetabular component position.

Sultan, et al,\textsuperscript{19} performed an analysis of 14 studies on outcomes of THA before and after spine surgery to address whether to perform THA before or after spinal deformity correction in patients with concomitant pathology. The authors propose initial evaluation of any hip flexion contractures, which if present, should be addressed with initial THA then reevaluation of spinal pathology. If hip flexion contractures are not present, the

Figure 4. (A) Preoperative standing lateral image of a patient with severe posterior pelvic tilt (APP, yellow). (B) Templated cup position of 40° of inclination and 20° of anteversion relative to the APP (or traditional bony landmarks intraoperatively) leads to functional cup position of 45° of inclination and 38° of anteversion when the patient stands. (C) After accommodating for the patient’s posterior pelvic tilt in the functional (standing) position, placement of the cup in 35° of inclination and 2° of anteversion relative to the APP will lead to a cup position of 40° of functional inclination and 20° of functional anteversion relative to the coronal plane when standing.\textsuperscript{*} Permission from Luthringer TA, Vigdorchik JM. A Preoperative Workup of a “Hip-Spine” Total Hip Arthroplasty Patient: A Simplified Approach to a Complex Problem. J Arthroplasty. 2019.
decision to address the hip or spine first depends on severity of symptoms. The authors then defer the positioning of components according to recommendations by Phan, et al.

The contribution of pathologic spinopelvic motion on THA dislocations is certainly not insignificant, particularly in late dislocations and revisions in elderly patient. However, acute primary THA dislocations are typically not due to spinopelvic abnormalities, rather, they are attributed to decreased leg length or offset, component malposition, or abductor insufficiency. The same may be said for late dislocations. This discrepancy though may partly be due to the fact that most arthroplasty surgeons simply do not evaluate the spine and attribute instability and wear problems on familiar and common complications. For revisions and late dislocations, Heckmann, et al, recommend evaluating for bony impingement at extremes of motion with preoperative imaging. If present, consideration should be made to increase offset or partially remove or even distally advance the greater trochanter.

In some cases, spinopelvic limitations preclude the use of standard components. Tezuka, et al, identified the 3 strongest factors predictive for dislocation, namely stiff pelvic motion, low PI, and excessive femoral flexion (PFA). The authors suggest there is no component “safe zone” for these patients and recommended placement of dual mobility articulation. Further studies would need to be performed to further characterize the range of pathologic stiffness, PI and PFA to narrow down the indications for dual mobility articulation. Vigdorchik and colleagues have presented preliminary data supporting the use of a new risk assessment score to identify patients at high-risk for dislocation and have found promising results with the use of dual mobility constructs leading to a 6-fold decrease in the rate of dislocations in this cohort.

**Discussion**

Spinopelvic mobility can be confusing. Most arthroplasty surgeons focus on the acetabular component positioning according to the static position of the pelvis. However, the functional position should be used instead. This will account for the dynamic interplay between the spine, pelvis, and hip.

THA positioning according to LSZ will be adequate for most people. Patients at high risk should be identified and screened more carefully.

Taken altogether, in order to avoid impingement, the position of the anticipated position should take into consideration:

**Spinopelvic Stiffness**

This will determine the dynamic change in the functional position of acetabulum when transitioning from standing to sitting. Stiffness can be either biologic due to degenerative spine disease or iatrogenic due to multilevel lumbosacral fusion. Stiffness prevents normal dynamic posterior pelvic tilt upon sitting and most commonly therefore increases the risk of anterior impingement.

**Sagittal Balance**

Position of the pelvis while standing. Compensation for a kyphotic spine is posterior pelvic tilt when standing which creates a functionally anteverted cup and thus increases the risk of posterior impingement.

**Pelvic Incidence**

PI will determine the degree of femoral flexion required to sit. The lower the PI, the less the pelvis will tilt so greater femoral flexion is required and thus higher risk for bony impingement and dislocation.

Many dislocations will still occur despite adequate component positioning. It is difficult to predict postoperative positioning. For example, patients with hip osteoarthritis may have hip flexion contractures, which when released by THA, may allow for increased spinopelvic mobility. Furthermore, standing PT has been shown to worsen over time as patients become increasing kyphotic leading to late dislocations. The mathematical relationship between APPt and AA, inclination, AI, and SS may help elucidate the ideal position. Further studies on a functional sagittal safe zone, potentially with the use of CSI parameters, may be more applicable than the coronal LSZ.

Lateral standing and sitting radiographs should be obtained in patients that may be at risk. Late dislocation and revisions need to incorporate routine work up for spinopelvic abnormalities as a potential cause for failure. Hips that fall outside the normal range of CSI may be particularly risk.

Options for treatment are to modify acetabular component positioning accordingly or utilize a dual mobility articulation. Ultimately, a compromise must be reached between attaining adequate hip stability while minimizing superior edge loading, polyethylene wear, liner fracture, and inadequate implant-bone contact for osteointegration. Significant and symptomatic spine disease would warrant spine surgery first, whereas symptomatic hip pathology and or flexion contracture may benefit from a THA first.

It should be noted that the cause of acute as well as late dislocations are certainly multifactorial with a significant soft tissue component including attenuation of the hip capsule due to the surgical approach or subsequent wear debris, imbalance and weakness of surrounding musculature, particularly the abductors, and improper positioning of implants. It is the stance of the senior author, who exclusively performs THA via the direct anterior approach (DAA), that less soft tissue disruption may
mitigate the dislocation risk, which would be particularly important in those with pathologic spinopelvic motion. The DAA also allows for placement of components within a narrow range with the aid of fluoroscopy. A practical and simple modification that can be instituted by surgeons utilizing intraoperative imaging is to match their intraoperative supine AP pelvis with the preoperative standing AP pelvis by tilting the bed up or down. By referencing off a tilted pelvis and placing the components in 40° inclination and 20° antversion, the surgeon should match the functional position of the patient’s pelvis while standing. This adjustment, however, does not account for any dynamic motion limitations due to spinal stiffness.

Conclusion

The dynamic interplay between the spine, pelvis and hip is complex with significant implications on total hip arthroplasty outcomes in cases of pathologic spinopelvic motion. As our appreciation and understanding progresses, we hope to be able to more accurately identify high risk patients, effectively and expeditiously characterize their individual anatomy, and ultimately identify the ideal component position to maximize stability and minimize wear. Currently for primary THA, we recommend the screening for high risk patients to include a history of spinal pathology including spine surgery with long segment lumbosacral fusion, evidence of severe degenerative spinal disease, and kyphotic standing posture, or those with hip pathology including history of hip dislocation, revision THA, and hip flexion contractures. A functional spinopelvic imaging series should be obtained for these patients which includes three views of the pelvis: lateral standing and sitting (90° trunk-thigh angle) and AP standing. Evaluation should begin with identification of the deformity type (stuck standing, stuck sitting or kyphotic) and the degree of stiffness. Our recommendations for management are in line with the classification scheme and treatment algorithm proposed by Luthringer, et al. Use of the DAA with minimal soft tissue disruption may also mitigate instability risk.

Ideal component composition continues to be elusive. Reconsideration of component “safe zones” has begun to stray away from the coronal plane values proposed by Lewinnek. A new focus has been placed on sagittal plane safe zones and with the introduction of the combined sagittal index it may provide more appropriate and accurate safe zones. Future studies are needed to identify and narrow down this proposed sagittal safe zone. However, some cases of pathologic motion are so severe that dual mobility articulation implants may be required, particularly in the revision setting.

Conflict of Interest

None of the authors identify a conflict of interest.

Disclosure Statement

Dr. Harpstrite reports personal fees from DePuy, A Johnson & Johnson Company; personal fees from Orthopedic Development Corporation, and personal fees from Smith & Nephew, outside the submitted work.

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References


Effectiveness of Accelerated Recovery Performance for Post-ACL Reconstruction Rehabilitation

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Abstract
Atrophy and protracted recovery of normal function of the ipsilateral quadriceps femoris muscle following anterior cruciate ligament reconstruction surgery is well documented. The Accelerated Recovery Performance trainer is a type of electrical stimulation device that delivers a high-pulse frequency via a direct current, making it unique from many other devices on the market. The purpose of the present study was to investigate the effects of the direct current (via the Accelerated Recovery Performance trainer protocol) on gains in thigh circumference following anterior cruciate ligament reconstruction. Twenty-five patients were enrolled following isolated anterior cruciate ligament reconstruction and randomly assigned to either an isometric rehabilitation protocol augmented with the Accelerated Recovery Performance trainer protocol (experimental group) or the isometric rehabilitation protocol alone (control group). The two groups participated in sixteen sessions of directed rehabilitation over a two-month time period. Patients were followed with serial thigh circumference measurements at 5, 10, 15, and 20 centimeters above the superior patellar pole. Comparison of the overall mean circumferential gains in thigh circumference of the involved leg demonstrated approximately 3:1 gains in the ARP group over the control group, demonstrating it to be superior to isometric rehabilitation alone with regards to gains in thigh girth. The Accelerated Recovery Performance trner protocol should be considered for post-anterior cruciate ligament reconstruction rehabilitation in order to reverse disuse atrophy of the ipsilateral quadriceps femoris.

Keywords
Electrical Stimulation, Anterior Cruciate Ligament Reconstruction, Quadriceps, Atrophy

Abbreviations
AC: Alternating Current
ACL: Anterior Cruciate Ligament
ARP: Accelerated Recovery Performance
DC: Direct Current
ES: Electrical Stimulation
QF: Quadriceps Femoris

Introduction
Disuse atrophy is a well-established phenomenon that follows disease, trauma or surgery of the affected limb. Atrophy of the ipsilateral quadriceps femoris (QF) muscle and consequent protracted recovery of normal function following anterior cruciate ligament (ACL) reconstruction surgery is well documented in the literature. Arangio, et al, showed in 33 patients a 1.8% decrease in thigh circumference, a 10% decrease in average quadriceps torque, and a 8.6% decrease in quadriceps cross-sectional area by MRI at an average of 49 months post-surgery despite aggressive rehabilitation. Atrophy of QF following ACL reconstruction greatly impedes stability, strength, and recovery because QF serves as the primary stabilizer of the knee joint during translation. Current approaches attempting to address muscle atrophy following ACL reconstruction emphasize early post-operative motion, full passive knee extension, immediate weight bearing, and closed-kinetic-chain exercises. In addition, multiple groups have studied the adjunctive use of electrical stimulation (ES) in post-operative rehabilitation and have suggested that the addition of ES can improve muscle strength and size. Delitto, et al, found that ES provides greater isometric strength gains than voluntary exercise alone. The mechanisms for this observed increase in muscle strength have been attributed to both changes in neural factors and direct muscle hypertrophy. Possible neural factors contributing to QF weakness include attenuation of gamma loop IA afferent fibers. ES has been suggested to modulate action potentials in both intramuscular nerve branches and cutaneous receptors, thus inducing force production directly by activation of motor axons and by direct reflex recruitment of spinal motor neurons. Additionally, Gondin, et al, noted that simultaneous use of ES during volitional isometric exercises served to further improve the efficacy of the rehabilitation program.

The Accelerated Recovery Performance (ARP) Trainer is a type of ES device manufactured in the United States by Accelerated Recovery Performance Program. Similar to most ES devices, ARP’s primary use is for the rehabilitation of musculoskeletal injuries in athletes. ARP’s proprietary ES mode has been proposed to deliver a pulse-delivery frequency higher than most other devices, allowing supra-physiologic stimulation of muscle fibers, capable of producing tetany, if desired. The ability of the ARP protocol to achieve a higher pulse-delivery frequency may be attributed to the fact that it uses a direct current (DC), rather than the alternating current (AC) used by many popular ES devices. Direct current may decrease the pain and burning sensation felt by the subjects, thus allowing for a greater amplitude and frequency. Outcomes for ARP treatment have been based primarily on clinical observations during rehabilitation of ankle sprains, hamstring injuries, and distal radius fractures in elite athletes. The aim of the present study was to investigate...
how augmenting rehabilitation with the ARP trainer affects thigh circumference in patients who underwent ACL reconstructive surgery and demonstrated post-operative QF atrophy.

Methods

Twenty-five patients from a single orthopedic sports medicine group with an isolated ACL injury and subsequent surgical reconstruction (with autograft or allograft) were included in this study and randomly assigned to either the experimental or control protocol group based on birth year. All patients completed a standard 15-week post-operative physical therapy immediately prior to beginning the study and demonstrated atrophy of their QF as compared to the ipsilateral side. The six female and nineteen male patients ranged in age from sixteen to fifty-four years (mean and standard deviation, 30.76 ± 11.74). The experimental group consisted of 9 males and 5 females with a mean age of 29.0 years and an age range of 17-51 years. The control group consisted of 10 males and 1 female with a mean age of 32.9 years and an age range of 16-54 years. Figure 1 outlines the patient recruitment and randomization process. The institutional review board approved the study protocol and all patients gave written informed consent.

Pre-intervention thigh circumference was measured at 5, 10, 15, and 20 centimeters above the superior patellar pole. All data including subsequent serial thigh circumference measurements, ARP trainer intensity, and adverse events was collected on a Case Report Form during the primary visit and at every subsequent session. Each patient received 16 one-hour sessions of individual therapy, based on the following protocol, over the course of 6 weeks. Following completion of all sessions, final thigh circumference measurements were taken at 5, 10, 15, and 20 centimeters above the superior patellar pole. Thigh circumference measurements recorded from both the experimental and control group were analyzed according to t-test for statistical significance; a Mann-Whitney Rank Sum test was utilized alternatively to analyze the data.

Protocol

The patients who received ARP therapy were managed three times a week throughout the entire treatment period with either a “heavy” (sessions #1, 3, 4, 8, 9, 13, 14) or a “light” (sessions #2, 5, 6, 7, 10, 11, 12, 15, 16) session (Table 1). At the beginning of every session, a brief physical exam was done involving inspection of the QF muscle of each leg with specific attention...
paid to the relative difference in size of the vastus medialis and vastus lateralis. Two electrodes were placed: one over the muscle belly of the distal aspect of the vastus medialis, and one over the belly of the rectus femoris [5 – 25 milliamps, 15 – 30 volts, 500 Hz]. Because the ARP trainer can contract the muscle to tetany, the dose of ES was titrated by subjective feedback of the patient at each session. Under no circumstances was the patient subjected to intolerable pain or tetany throughout treatment.

ARP protocol included a combination of steady work (holding position while resisting gravity) and fast pulses (repeated isometric contractions). Background stimulation consisted of a pulse frequency of 10,000 cycles/sec and an intensity of 2 – 5 volts. The patient was instructed to perform each exercise until failure for 3 minutes per exercise. Once failure occurred, we stopped the clock and allowed the patient to briefly recover (<15s), repositioned them, restarted the clock and repeated until 3 minutes of total work was performed.

The patients who were assigned to the control group were also managed three times a week throughout the entire treatment period with either “weighted” (sessions #1, 3, 4, 8, 9, 13, 14) or “physioball” (sessions #2, 5, 6, 7, 10, 11, 12, 15, 16) sessions (Table 2). Females started with 5 lbs of weight and males with 10 lbs. Weights were increased throughout subsequent sessions to encourage strengthening.

After completion of the 16 rehabilitation sessions, outcome measures were collected on both the injured limb and the healthy contralateral limb. Pre and post treatment thigh circumferences served as the primary outcome measures.

Results

Comparison of the overall mean circumferential gains in thigh circumference of the involved leg demonstrated approximately 300 percent greater gains in the ARP cohort over the control cohort. The mean total gain across all data points for the experimental group was 12.293 cm (SD = 2.826), while the control group had a mean gain of 4.009 cm (SD = 2.141). There was a total difference of 8.384 cm, or a difference of 2.07 cm at each measured point, thus the ARP cohort had a gain ratio of 3.06:1 when compared to the control cohort. The mean gain across all measurement data points for both study groups was analyzed using a t-test analysis. Validation of the summary data passed both the normality test (P = .402) and equal variance test (P = .627). T-test analysis resulted in a statistically significant t-value of 8.157 and a P-value of < .001. The 95% confidence interval for the summary data was 6.258 to 10.510. Power of analysis at alpha = 0.05 was 1.000.

### Table 1. Experimental Group “Heavy” and “Light” Day Protocols. Patients Participated in the Heavy Day Protocol for Sessions 1, 3, 4, 8, 9, 13, 14 and Light Day Protocol for Sessions 2, 5, 6, 7, 10, 11, 12, 15, 16. All Sessions were Augmented for Electrical Stimulation Via the ARP Trainer Protocol.

<table>
<thead>
<tr>
<th>Heavy Day Protocol</th>
<th>Isometric Rehabilitation</th>
<th>ARP Trainer Protocol</th>
<th>Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric wall squat</td>
<td>3 min/Steady work</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Isometric lunge (bilaterally)</td>
<td>3 min/Steady work</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Seated isometric leg extension</td>
<td>3 min/Steady work</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>5 min/Background Stimulation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isometric wall squat</td>
<td>3 min/Fast pulse</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Isometric lunge (bilaterally)</td>
<td>3 min/Fast pulse</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Seated isometric leg extension</td>
<td>3 min/Fast pulse</td>
<td>1</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Light Day Protocol</th>
<th>Isometric Rehabilitation</th>
<th>ARP Trainer Protocol</th>
<th>Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isometric wall squat</td>
<td>10 sec fast pulse, followed by 10 sec steady work</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Isometric lunge (bilaterally)</td>
<td>10 sec fast pulse, followed by 10 sec steady work</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Seated isometric leg extension</td>
<td>10 sec fast pulse, followed by 10 sec steady work</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Rest</td>
<td>5 min</td>
<td></td>
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</tbody>
</table>

### Table 2. Control Group “weight” and “physioball” Protocols. Patients participated in the weight protocol for sessions 1, 3, 4, 8, 9, 13, 14 and physioball protocol for sessions 2, 5, 6, 7, 10, 11, 12, 15, 16.

<table>
<thead>
<tr>
<th>Weight Protocol</th>
<th>Isometric Rehabilitation</th>
<th>Repetitions/Extremity</th>
<th>Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dumbbell front squat</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Dumbbell split squat lunge, bilaterally</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Manual resistance hamstring, bilaterally</td>
<td>3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Dumbbell Romanian deadlift, 2 legs</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Dumbbell Romanian deadlift, 1 leg, bilaterally</td>
<td>12</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Physioball Protocol</th>
<th>Isometric Rehabilitation</th>
<th>Repetitions/Extremity</th>
<th>Sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Squat</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Hip twist</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Inchworm</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Leg circles, bilaterally</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Kickbacks</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Single leg lunges, bilaterally</td>
<td>24</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>
The mean gain at 5 cm for the experimental group was 2.864 cm with a standard deviation of 0.719, while the control group had a mean gain of 0.936 cm with a standard deviation of 0.622. The difference between the two means was 1.928, which was statistically significant, t-value 7.056 with a P-value of < .001. The 95% confidence interval was 1.363 to 2.493. Data at 5 cm above the superior patella was validated with the normality test (P = .488).

The mean gain at 10 cm for the experimental group was 2.950 cm with 25th percentile and 75th percentile values of 2.700 cm and 3.600 cm respectively. For the control group, the median gain was 1.000 cm with 25th and 75th percentile values of 0.350 cm and 1.175 cm respectively. The difference between the two mean values was 1.950, which was statistically significant. Data at 10 cm failed the t-test analysis for normality test (P < .050); thus, data analysis proceeded with a Mann-Whitney Rank Sum test. The Mann-Whitney U statistic value was 154.000 and resulted in a statistically significant T value of 66.000 with a P-value of < .001.

The mean gain at 15 cm for the experimental group was 3.143 cm with a standard deviation of 0.903. The control group had a mean gain of 0.99 cm with a standard deviation of 0.607. The difference between the two mean values was 2.152. The t-test analysis resulted in a statistically significant t-value of 6.778 and a P-value of < .001. The 95% confidence interval was 1.495 to 2.809.

At 20 cm above the superior patella, mean gain for the experimental group was 2.914 cm, while the control group had a mean gain of 1.245 cm. The data was statistically significant (P < .001). Figure 2 demonstrates the differences in mean thigh circumference between the ARP and control group at the final follow-up.

The average percent gain in thigh circumference for the ARP and control groups are shown in Figure 3. The average percent gain in thigh circumference for the experimental group was 7.38%, 8.29%, 6.96%, and 5.95% at measurements made at 5 cm, 10 cm, 15 cm, and 20 cm above the superior patella respectively. For the control group, average percent gain in thigh circumference was 2.38%, 2.10%, 2.18%, and 2.50% at 5 cm, 10 cm, 15 cm, and 20 cm above the superior patella respectively.

**Discussion**

Our study demonstrates that an accepted isometric rehabilitation program augmented with the ARP trainer protocol is superior to an isometric rehabilitation protocol alone in correcting disuse atrophy of the QF after ACL reconstruction. Patients using the ARP trainer protocol had a three-times increase in thigh circumference compared to the control group.
Persistent weakness and disuse atrophy of the QF has been a consistent finding after ACL reconstruction. Persistent weakness is associated with patellofemoral pain that prevents the patient from exercising properly. Different physiologic mechanisms have been proposed for this phenomenon and have different implications on the maximum efficacy that can be expected of rehabilitation protocols post-ACL reconstruction. Urbach, et al, supported the theory of central nervous system inhibition after joint damage by the finding of bilateral voluntary activation deficits by twitch interpolation following unilateral injury. Likewise, if weakness is due to voluntary activation failure as further suggested by Terese, et al, rehabilitation protocols that stress voluntary quadriceps exercise alone may not result in a complete recovery of QF muscle strength. Because the activities of gamma motor neurons can influence alpha motor neurons through the gamma loop, a decrease in gamma efferent input caused by loss of joint afferents from the native ACL might also explain QF weakness in ACL lesions.

ES has been used for strengthening especially in cases involving immobilization, contraindication to dynamic exercise, patient inability to exert muscular force, and as an adjunct to traditional voluntary exercise protocols. Several studies used ES to target the proposed central mechanism of inhibition. Dean, et al, showed that development of torque through surface ES was dependent on a central mechanism and proposed that the evoked sensory volley recruited motoneurons in the spinal cord. The study also suggested that post-tetanic potentiation increased neurotransmitter release from sensory axons through repeated stimulation, potentially activating higher threshold motoneurons. Powers et al studied high-frequency ES of human upper limb muscles and showed that ES of the flexor pollicis longus and biceps evoked greater torques than could be attributed to direct activation of the motor axons, further indicating that the central mechanism was responsible for the development of extra torque. These studies demonstrated the efficacy of direct activation and recruitment of centrally inhibited motoneurons.

Studies have also proposed that the effects of ES are mainly due to electroanalgesic properties that facilitate earlier movement, QF contraction, and earlier weight bearing than would otherwise not be tolerated post-ACL reconstruction. Other effects of ES on physiology have been hypothesized to include: increase in muscle fiber size, changes in fiber type composition, and prevention of reduction in myofibrillar adenosine triphosphate. Multiple studies support ES therapy as effective in preventing the degree of atrophy following knee surgery and subsequently increasing post-operative muscle function. In contrast, however, Anderson, et al, showed that ES therapy showed no reduction in volumetric atrophy observed and concluded that it was only effective in minimizing strength decreases due to immobilization. Given the conflicting results, this study decided to take a unique approach to solving the problem of disuse atrophy: Electrical stimulation delivered by the ARP unit was not used to prevent disuse atrophy, but rather, was used to restore thigh girth lost following ACL reconstruction.

It is postulated that exercising the QF muscle at maximum work intensity results in compensatory hypertrophy, allowing the muscle to generate greater force than would be possible without ES therapy. Further, it is thought that the use of ES in conjunction with isometric or isokinetic exercise can increase work intensity and result in increased thigh girth. Yet several studies were unable to correlated ES with an increase in QF circumference. Halback, et al, attributed the lack of apparent hypertrophy in healthy individuals training with ES to a decrease in fat and an increase in muscle. This speculation is shared by Nobbs et al, who suggested that training for a longer period of time (greater than six weeks) would result in significant QF hypertrophy. An increased training time of 8 weeks was used by Gondin, et al, which showed a six percent increase in the anatomical cross-sectional area of the QF in healthy individuals. Additionally, they suggest that ES might be useful in rehabilitation programs targeting the atrophied QF after periods of immobilization. This application of ES is supported by our findings, which demonstrated an 8.29 percent increase in thigh circumference measured at 10 cm above the superior patella using the ARP protocol on post-ACL reconstruction patients. Furthermore, the ARP protocol allowed for 300 percent greater gains in thigh girth in the ARP cohort over the control cohort. To our knowledge, no other study has been able to show mean circumferential gains of this magnitude.

Our positive results may be attributed to the direct current (DC) compounded with high frequency double exponential patented background waveform produced by the ARP unit. This unique waveform allows for several advantages including limited production of inhibitory protective muscle contractions, more efficient permeation of the QF and possibly decrease in pain associated with electrical current. Many ES apparatuses use fast-pulsed AC currents, such as faradic current, which has been shown to cause a level of sensory discomfort in patients training with ES greater than that experienced by patients performing strenuous conventional exercise. This discomfort, in the form of pain and burning sensation, has been a major limiting factor in the amplitude and frequency reached with ES.

The results of this study may have a significant impact for patients attempting to return to sport. It is well-documented that, although cleared, as few as thirty-three percent of patients return to competitive sport after ACL reconstruction. It has been suggested that this is due to persistent symptoms of instability coming from QF weakness and the subsequent fear of reinjury. We wonder whether the appearance of QF atrophy may also contribute to athletes fear of reinjury and whether the gains in thigh circumference may lead to a higher rate of return to sport and/or an earlier return to sport.
There were limitations to this study. First, we only used the end-point of measured thigh circumference. We did not use imaging modalities such as computed tomography or ultrasound to assess QT atrophy and hypertrophy, so gains appreciated in end-thigh circumference were not distinguishable from mass gained due to simultaneous increase of subcutaneous tissues as described by Halkjaer, et al, and Arvidsson et al. Second, our study was limited by our small sample size. This was mainly because this was a single-center study completed within one year. Third, our study was randomized, but not blinded to either the patients or the administrators. This may have affected the voluntary effort of patients in both groups but was unavoidable due to logistics of protocol administration. Finally, there was also no control for exercise of patients outside of the study. Individuals may have experienced gains in size due to activity exclusive of the study protocol. Further trials with greater sample size, control for physical activity outside of rehabilitation protocol, and assessment of pre- and posttest strength of both extremities and pre- and posttest imaging assessment should be pursued. Additionally, future studies should look at whether the APR cohort scores higher on return to sport functional testing and whether they have a higher rate of return to sport.

In conclusion, ES from the ARP trainer can be used to activate muscle fibers at frequencies far greater than both the critical fusion frequency (the minimum firing rate that produces a tonic response) and the normal firing rate for QF fibers. In the present study, this resulted in 3:1 gains in thigh girth in those patients receiving post-operative rehabilitation augmented with the ARP trainer versus patients who underwent a standard isometric rehabilitation program alone. These findings demonstrate an advantage in the use of the ARP trainer protocol to restore thigh girth after disuse atrophy following ACL reconstruction.

Conflict of Interest

None of the authors identify a conflict of interest.

Disclosure Statement

Dr. Darryl Kan is a member of the Accelerated Recovery Performance special projects team. To date there has been no associated financial gains related to the subject matter or materials discussed in the article.

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References
Denosumab-Associated Peri-Implant Atypical Femur Fracture: A Case Report

John P. Dupaix MD; Mariya I. Opanova MBBS; Lorrin S.K. Lee MD; Kevin Christensen MD

Abstract

Bisphosphonate use has been associated with atypical pathologic fracture and slowed bone turnover. We present a case of a bisphosphonate-associated peri-implant atypical femur fracture following use of a recon nail for treatment of a prior bisphosphonate-associated atypical femur fracture.

Keywords

denosumab, bisphosphonates, atypical femoral fractures, peri-implant fractures

Abbreviations

RA = rheumatoid arthritis  
THA = total hip arthroplasty

Introduction

Bisphosphonates are a drug class used to increase bone density in patients with osteoporosis by the reduction of osteoclast driven bone resorption. Their use has been associated with atypical subtrochanteric femur fractures hypothesized to be secondary to a decrease in bone remodeling.1-3 Like bisphosphonates, denosumab has been studied in the long-term treatment of postmenopausal women with osteoporosis. In their study of 4550 women with up to 8 years of denosumab use, Papapoulos, et al, report that markers of bone turnover continued to decrease and bone mineral density continued to significantly increase to 18.4% at the lumbar spine and 8.3% at the hip.4 Unfortunately, although the incidence was low, atypical femoral fracture and osteonecrosis of the jaw was also observed, similar to the complications observed in the long-term use of bisphosphonate. This has been reflected in several case reports.5-7

Recently a new clinical entity involving bisphosphonate-associated pathologic fracture of the femur has been identified: the bisphosphonate-associated periprosthetic fracture. Although the majority of case reports have identified stress fractures distal to the tip of the femoral stem following total hip arthroplasty,8-11 Lee, et al, identified a series of patients with atypical bisphosphonate associated peri-implant fractures with a low energy mechanism occurring at stress risers such as the end of the plate or the penultimate screw hole.12 These underwent revision surgery with a slower radiographic union at an average of 2-4 months. To our knowledge, this is the first report of a denosumab-associated atypical peri-implant femur fracture around a femoral nail.

Case Report

This is a case of a 92-year-old woman with a history of rheumatoid arthritis (RA), hypertension and remote history of bilateral atypical femur fracture status post bilateral fixation who presented to the emergency department in February of 2018 after a ground level presyncopal fall earlier that day. An angiotensin II receptor blocker (valsartan) was added to her low-dose beta blocker therapy a few weeks prior and she had been experiencing intermittent dizziness when rising to stand from sitting since initiation of her therapy. On the day of her presentation, she fell onto her buttocks when she stood up and felt dizzy and had immediate onset of inability to bear weight on her left lower extremity. She had been otherwise asymptomatic and functioning well prior to her fall. Her RA was mild and managed with 2.5mg of prednisone daily.

Most significant in her history was a history of sequential atypical femur fracture with subsequent surgical fixation. In 2008, following a multi-year history of treatment of osteoporosis with alendronate, she presented with an atypical subtrochanteric right femur fracture following a mechanical fall while walking her dog. She underwent uncomplicated fixation with a cephalomedullary device and returned to home following a brief stay in a short-term rehabilitation facility. There was concern for pathologic fracture and her prednisone was decreased from 5mg daily to 2.5 mg daily. Alendronate was continued.

In 2010, she suffered an atypical left subtrochanteric femur fracture, again following a mechanical fall (Figure 1). She underwent uncomplicated fixation of her fracture with an intramedullary recon nail (Figure 2). As the fracture was distal in the femur, fixation was not placed into the femoral neck and head. Bisphosphonates were initially discontinued following this fracture. However, two years later, she was started on denosumab injection every 6 months starting in mid-2012, which was continued up to her current presentation.

Radiographs obtained at the time of her current presentation demonstrated interval healing of her previous subtrochanteric fracture and an acute intertrochanteric fracture through the proximal locking screw with avulsion of the lesser trochanter (Figure 3). She was treated with a transition to a reamed cephalomedullary nail (Figure 4). Of note, she had broken the proximal interlocking screw at the site of the fracture. The medial fragment of the screw was left in situ as it did not block the intramedullary canal and the benefit versus risk analysis...
did not favor retrieval of the screw fragment. Antiresorptive agents were discontinued following her revision surgery. She recovered in a short-term rehabilitation facility followed by return to independent living at home. Interval healing has been noted on follow up radiographs.

Figure 1. Prior Initial Injury Films Depicting Atypical Subtrochanteric Femur Fracture. Note that the Contralateral Atypical Subtrochanteric Femur Fracture had been Treated with a Cephalomedullary Device.

Figure 2. Postoperative Films Following Treatment of Atypical Subtrochanteric Femur Fracture with Reamed Intramedullary Femoral Recon Nail.
Figure 3. Injury Films Demonstrating Healing of Previous Atypical Femur Fracture Following Reamed Intramedullary Nail Placement, but New Atypical Peri-implant Femur Fracture Through and Around Previously Placed Locking Screw.

Figure 4. Postoperative Imaging Following Transition to Cephalomedullary Femoral Nail.
Discussion

In 2014, the task force from the American Society of Bone and Mineral Research revised the criteria for the diagnosis of a bisphosphonate associated atypical femoral fracture to a fracture found “just distal to the lesser trochanter to just proximal to the supracondylar flare” with at least four of the five identified major features:

- The fracture is associated with minimal or no trauma, as in a fall from a standing height or less
- The fracture line originates at the lateral cortex and is substantially transverse in its orientation, although it may become oblique as it progresses medially across the femur
- Complete fractures extend through both cortices and may be associated with a medial spike; incomplete fractures involve only the lateral cortex
- The fracture is noncomminuted or minimally comminuted
- Localized periosteal or endosteal thickening of the lateral cortex is present at the fracture site (“beaking” or “flaring”)

Nevertheless, numerous studies have identified a number of cases where periprosthetic and peri-implant fractures have been associated with antiresorptive that present in a similar manner, if not in the location described in the criteria. Sayed-Noor and Sjoden reported on a patient with history of nine years of bisphosphonate use and six years status post cemented total hip arthroplasty (THA) who sustained a thigh injury that progressed to a displaced Vancouver C atypical femur fracture over the course of 4 months. This was treated with a long locked plate and went onto eventual healing. Tantavisut, et al., described a 75-year-old woman with a seven year history of bisphosphonate use and two year history status post THA that was consistent with an atypical periprosthetic acetabular fracture by pattern and histology. Robinson, et al., studied the differences between patients on long term bisphosphonates with atypical femur fractures and atypical periprosthetic femur fractures. Periprosthetic femur fractures were found primarily in patients who had undergone THA and presented as stress fractures just distal to the tip of the stem. There were no cases of femoral stem loosening in this group. Fractures were treated with long locked plate fixation. They found atypical femur fractures occurred much more commonly that atypical periprosthetic femur fractures at a rate of 89% vs 11%, respectively. They also noted that patients who suffered atypical periprosthetic femur fractures had an increased time to union (8 months vs 5 months), increased mortality (10% vs 1%) and increased complications (25% vs 12%), although only increased complications reached statistical significance ($P = .013$). And as noted previously, Lee, et al., found a series of patients who sustained bisphosphonate associated peri-implant fractures.

Connecting all these fractures—the atypical femur fracture, the atypical peri-prosthetic fracture and the atypical peri-implant fracture—is the occurrence of these fractures through areas of stress concentration under physiologic or low energy mechanisms. Whereas the native femur tends to fail in the tension sided subtrochanteric region, the presence of a prosthesis or implant changes the stress distribution of the femur and therefore the fracture location. Although a hip prosthesis appears to concentrate this stress just distal to the tip of the femoral stem, a plate or intramedullary implant appears to concentrate this stress at or near the end of the plate or nail, leading to fracture at the end of the plate or through a fixation hole near the end of the construct. This was the case observed in our patient. The presence of a stress riser with impaired resorption and accumulation of microfractures at this side may have led to the metal fatigue observed in the proximal locking screw and the subsequent intertrochanteric fracture.

An interesting finding in this case is that no fatigue failure or hardware complication has been observed on the right femur which was treated with a cephalomedullary nail for a bisphosphonate-associated atypical femur fracture two years prior to the placement of the left femoral nail which subsequently failed. This is similar to the findings of the cases of bisphosphonate-associated periprosthetic femur fractures where no stem loosening was noted and in the three dynamic hip screw cases reported by Lee, et al., where fracture consistently occurred distal to the plate. This suggests that failure in tension may be a key feature of antiresorptive-associated atypical femur fracture and constructs that protect the femur from tensile stress such as long cephalomedullary devices or long locked implants may be preferable in these patients.

We acknowledge that this is a retrospective review of a single patient with a rare presentation. However, we feel that this adds to knowledge of the variation in presentation of antiresorptive-associated peri-implant femur fracture and identifies denosumab-associated peri-implant fracture as a clinical entity. Although this patient was previously on bisphosphonate therapy and was on corticosteroid therapy, her steroid therapy was sub-physiologic and nearly a decade had passed since the discontinuation of her bisphosphonate therapy, lessening the possible effect of these medications.

Further studies and identification of patients with similar presentations could help to further elucidate this condition. Consideration of primary placement of a long cephalomedullary device for these fractures may also be considered.

Conflicts of Interest

None of the authors identify any conflicts of interest.
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References
Hawaiʻi Journal of Health & Social Welfare
ISSN 2641-5216 (Print), ISSN 2641-5224 (Online)

Aim:
The aim of the Hawaiʻi 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 Hawaiʻi and the Pacific region.

History:
In 1941, a journal then called The Hawaiʻi Medical Journal was founded by the Hawaiʻi Medical Association (HMA). The HMA had been incorporated in 1856 under the Hawaiian monarchy. In 2008, a separate journal called the Hawaiʻi Journal of Public Health was established by a collaborative effort of the Hawaiʻi State Department of Health and the University of Hawaiʻi at Mānoa Office of Public Health Studies. In 2012, these two journals merged to form the Hawaiʻi Journal of Medicine & Public Health, and this journal continued to be supported by the Hawaiʻi 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 Hawaiʻi Journal of Health & Social Welfare. The lead academic partners are now the six units of the UH College of Health Sciences and Social Welfare, including the John A. Burns School of Medicine, UH Public Health, the Myron B. Thompson School of Social Work, the School of Nursing and Dental Hygiene, the UH Cancer Center, and the Daniel K. Inouye College of Pharmacy. Other partners are the Hawaiʻi State Department of Health and the UH Office of the Vice Chancellor for Research. The journal is fiscally managed by University Health Partners of Hawaiʻi.

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