Original Article

Ultrasound Can Determine Joint Distraction During Hip Arthroscopy but Fluoroscopic-Guided Portal Placement Is Superior

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Purpose: To compare joint distraction measured on ultrasound (US) with joint space width (JSW) measured on fluoroscopy in hip arthroscopy and to determine whether ultrasound guidance is as safe and effective as fluoroscopy, the current gold standard, for establishing arthroscopic portals. **Methods:** Cadaveric whole-body specimens were positioned supine and subjected to 60 lbs. of unilateral axial traction using a distal femoral Steinman pin. Joint distraction was measured via JSW on fluoroscopic and ultrasound images. A single, fellowship-trained orthopaedic surgeon established anterolateral arthroscopy portals via ultrasound or fluoroscopic guidance in a randomized sequence. Total procedure time, number of times the spinal needle pierced the capsule, and iatrogenic chondral or labral injury were recorded. **Results:** Twelve full-body specimens (20 hips) underwent distraction, and 17 hips underwent portal placement with fluoroscopic (n = 8) or ultrasound (n = 9) guidance. JSW measured on ultrasound was significantly less laterally (13.0 vs 9.2 mm, $P < .001$), apically (16.7 vs 9.2 mm, $P < .001$), and medially (17.9 vs 9.2 mm, $P < .001$). Successful portal entry was achieved in every specimen. Average procedure time was 133 ± 51 seconds for the fluoroscopy group and 371 ± 260 seconds for the ultrasound group ($P = .026$). Fluoroscopic guidance required significantly less needle insertion attempts at 1.13 compared with 3.33 attempts for ultrasound ($P = .022$). Labral damage was greater in the ultrasound group at 66.67% compared with 12.50% for fluoroscopy ($P = .0497$). **Conclusions:** Joint distraction measured on ultrasound can be used to subjectively determine if the joint is adequately distracted in hip arthroscopy. Ultrasound-guided portal placement was associated with more needle insertion attempts, iatrogenic injury of the labrum, and overall procedure time in comparison to fluoroscopic guidance. **Clinical Relevance:** Fluoroscopy is the gold standard to confirm adequate joint distraction, aid in establishing arthroscopy portals, and evaluate resection of the femoral head during hip arthroscopy but exposes the patient to ionizing radiation, requires additional operators in the operating room, and involves the need for a heavy lead shield. Alternatives to fluoroscopy are needed, but ultrasound has not proven superior in our cadaveric model.

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Femoroacetabular impingement syndrome (FAIS) is characterized by a constellation of hip symptoms, clinical signs, and imaging findings, including impingement of the acetabular rim (pincer deformity) and femoral head (cam deformity).[1] This leads to abnormal hip joint kinematics and impingement between the femoral head and acetabulum during normal hip ranges of motion, increasing the risk for chondrolabral damage. Recently, FAIS has become increasingly recognized as a common source of hip pain and disability, which has led to a 5-fold increase in hip arthroscopy procedures from 2005 to 2013.[2,3] Functional outcomes following arthroscopic interventions are good at short-, mid-, and long-term follow-up with low complication rates.[4-7]

Currently, fluoroscopy remains the gold standard to confirm adequate joint distraction, aid in establishing arthroscopy portals, and to evaluate resection of the femoral head during hip arthroscopy for the treatment of FAIS.[8,9] The use of fluoroscopy for assessing acetabular parameters and torsion have been proven accurate when compared with an anteroposterior radiograph and magnetic resonance imaging (MRI) scan, respectively.[10,11] While fluoroscopy has its benefits, the disadvantages include ionizing radiation exposure, additional operators in the operating room, and the physical burden of a lead shield; the lead shield may lead to possible chronic posture problems for the surgeon and the operating room staff due to its weight. Although studies quantifying the cumulative radiation dose for both patients and arthroscopists have found that exposure falls below the current recommended annual limits, intraoperative fluoroscopy during hip arthroscopy has been hypothesized to increase the excess lifetime risk of death from cancer by 0.025%.[12-16]

Ultrasound (US) is an alternative imaging modality that lacks radiation and is commonly used for diagnostic evaluation and intra-articular injections to the hip.[17-19] When compared with fluoroscopy, US-guided injections were shown to be comparable in both the hip and spine.[17,20,21] US also has demonstrated comparable diagnostic abilities when compared with computed tomography with arthrography for the diagnosis of labral tears,[22] and when compared with MRI, it has a greater specificity (81.8% vs 63.6%) and positive predictive value (98.4% vs 97.5%) for diagnosing labral tears.[23] However, US does have a lower sensitivity (68.5% vs 84.8%), which may result in a greater rate of false negatives in cases with a low pretest probability of labral tearing.[23] US has good reliability in identifying FAIS and cam morphology, as well as determining alpha angles preoperatively in comparison to radiographs, computed tomography, and MRI.[24,25] While the utility of US has been demonstrated preoperatively and postoperatively,[26,27] there is currently a paucity of literature on the safety and efficacy of intraoperative US when compared with fluoroscopy. A recent systematic review found 5 technique articles that described the use of US for the hip intraoperatively.[28] Studies referring to hip arthroscopy for the treatment of FAIS showed arthroscopic portal placement under US guidance.[29,30] A clinical study demonstrated favorable complication rates for US-guided hip arthroscopy compared with a conventional fluoroscopic approach, but information regarding the external validity of this result is limited.[31] The purposes of this study were to compare joint distraction measured on US to joint space width (JSW) measured on fluoroscopy in hip arthroscopy and to determine whether US guidance is as safe and effective as fluoroscopy, the current gold standard, for establishing arthroscopic portals. The authors hypothesized that joint distraction measured on US would not be significantly different from JSW measured on fluoroscopy and that portal placement under US guidance would result in the accurate establishment of arthroscopic portals without iatrogenic injury.

Methods

Specimen Selection

A cadaver study was conducted at a university anatomy laboratory with ethical approval obtained from the local institutional review board. Fresh, whole-body specimens with negative serology for blood-borne pathogens and coronavirus disease 2019 without evidence of prolonged bed rest or obvious bony deformity were eligible for inclusion. Specimens with evidence of previous injury to the spine, pelvis, or lower extremities with or without history of previous surgical intervention to these regions were excluded from the study. Specimens with distinguishing marks such as tattoos overlying the hip were excluded from photo documentation. Two separate cohorts of full body specimens were used for each of the study aims, a distraction cohort and a portal placement cohort. For the portal placement cohort, each hip was randomized to receive anterolateral portal placement under fluoroscopic or US guidance. Portal placement was performed by a single, fellowship-trained orthopaedic sports medicine surgeon with experience in US (N.A.T.).

Assessing for Adequate Joint Distraction Using US

Cadaver whole-body specimens were positioned in the supine position on a standard radiolucent laboratory table. A distal femoral Steinman pin was placed transversely above the metaphyseal flare of the distal femur. Traction was applied through the pin with lead weights and countertraction was maintained through the bilateral axillae. An anteroposterior fluoroscopic

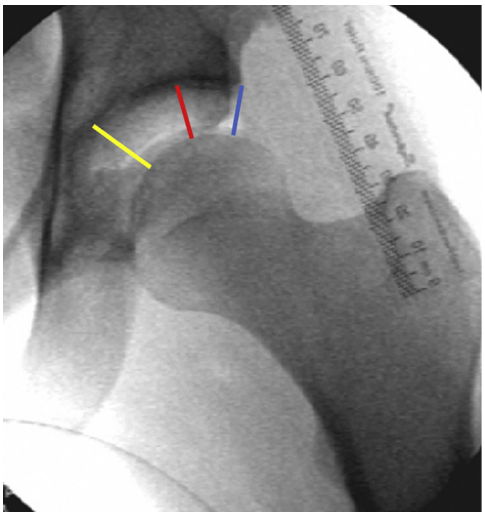

Fig 1. Technique for measurement of the joint space width medially (yellow line), apically (red line) and laterally (blue line) using fluoroscopy. Flexible radiopaque ruler superimposed for reference.

image with a radiopaque ruler placed longitudinally on the anterior superior iliac spine was taken to confirm adequate distraction and provide baseline calibration of the JSW measurement. The joint space was measured on the posteroanterior fluoroscopic image medially from the medial point of the sourcil, apically from the most proximal point of the femoral head, and laterally from the most lateral point of the sourcil along the acetabular sourcil line perpendicular to the surface of the femoral head (Fig 1). The US probe handler was blinded to this image and distraction was confirmed by a different member of the research team. The US probe handler then began by using a marking pen to delineate bony landmarks at the anterior superior iliac spine and greater trochanter. With a low-frequency (2- to 5-MHz) curved array transducer applied longitudinally approximately 3 cm superior to the greater trochanter, the probe handler assessed for adequate hip distraction by identifying the "light-saber sign," which represents the interface between the air vacuum within the hip and capsule of the joint.[30] Once the "light saber sign" was identified, the image was saved on the US machine (Sonosite SII; Sonosite Bothell, WA) and a scale was created on the image using the caliper function in order to measure the JSW (Fig 2).

Fluoroscopy-Guided Portal Placement

Cadaver positioning and preparation were similar to the technique described previously. However, maximum hip distraction was obtained by using an air arthrogram in addition to weighted traction, similar to the technique described by Hodax et al.[32] A large gauge spinal needle was inserted anteriorly into the capsule under fluoroscopic guidance at the head–neck junction, distant to the site of later anterolateral portal placement. After we confirmed access to the hip joint on fluoroscopic imaging, approximately 25 to 50 mL of air was injected under positive pressure, breaking the suction seal. The anterolateral portal was then established under fluoroscopic guidance using a technique similar to that described by Aoki et al.[33]

First, a fluoroscopic image of a large-bore spinal needle was taken over the anterior thigh to establish the appropriate angle of insertion, which was then marked with a marking pen. The spinal needle was inserted just anterior to the greater trochanter and guided to the capsule using fluoroscopic images. Insertion through the capsule was attempted, taking care to avoid damage to the cartilage of the femoral head or anterior labrum. If the spinal needle met with substantial resistance, the needle was removed and reinsertion was attempted. Once the surgeon felt the spinal needle enter the joint capsule, the inner trocar was removed. A guidewire was then inserted to confirm arthroscopic portal angle and intra-articular placement. A 1-cm incision was made approximately 1 cm proximal to and 1 cm anterior to the anterolateral tip of the greater trochanter to accommodate the cannulated trocar. The cannulated trocar was then advanced through the capsule using a twisting motion. Lastly, a 70° Stryker arthroscope was advanced into the hip joint (Stryker Corp., Kalamazoo, MI) and diagnostic arthroscopy was performed to evaluate for labral and cartilage damage.

US-Guided Portal Placement

Cadaver position and hip distraction was established using the same procedure as described previously for the fluoroscopy cohort, including an air arthrogram to maximize distraction. The anterolateral portal was then established under US guidance using a technique similar to that which was first described by Keough et al.[29] The surgeon began by marking bony landmarks including the anterior superior iliac spine and greater trochanter with a marking pen. With the transducer in the longitudinal oblique position parallel to the femoral neck and perpendicular to the skin the spinal needle was directed toward the center of the "light saber sign" (Fig 3). If the spinal needle met with substantial resistance, the needle was removed, and reinsertion was attempted. Once the surgeon felt the spinal needle enter the joint capsule the inner trocar was removed. A guidewire was then inserted to confirm arthroscopic portal angle and intra-articular placement. A 1-cm incision was made approximately 1 cm proximal to and 1 cm anterior to the anterolateral tip of the greater trochanter to accommodate the cannulated trocar. A cannulated trocar was then advanced through the capsule using a twisting motion. Lastly, a 70° Stryker arthroscope was advanced into the hip joint (Stryker Corp.).

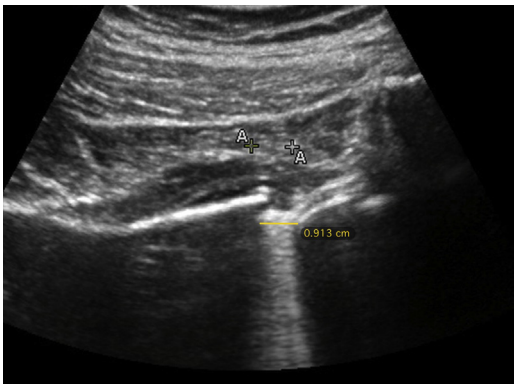

Fig 2. Measurement of the joint space width (yellow line) using ultrasound imaging with superimposed scale created with the caliper function.

Data Collection and Analysis

For the distraction cohort, 2 independent graders measured lateral JSW, apical JSW, and medial JSW on fluoroscopy and in one plane on US. Paired sample *t* tests were used to evaluate these continuous variables. The following variables were recorded during the portal placement procedure: (1) total procedure duration as defined by the time the skin was pierced to the placement of the anterolateral portal, (2) the number of needle insertion attempts into the capsule, (3) iatrogenic injury to the labrum, (4) iatrogenic injury to the cartilage on the femoral or acetabular side, and (5) failure to establish portals under US guidance with conversion to fluoroscopy. Incidence of iatrogenic injury to the labrum or cartilage was assessed under direct visualization using the anterolateral portal. On the labral side, injury was defined as evidence of translabral or sublabral needle or cannula insertion. On the cartilage side, injury was broadly defined as indentation or abrasion of articular cartilage that appeared likely to be induced by needle or cannula insertion. Continuous variables were reported as means and standard deviations and then compared between US and fluoroscopic guidance groups using a 2-tailed independent sample *t* test. Categorical variables were compared between the 2 groups using the Fisher exact test using SPSS Statistics (Version 27, IBM Corp., Armonk, NY).

Results

Assessing for Adequate Joint Distraction Using US

Twelve full-body specimens (20 hips) were analyzed. Four hips were excluded due to a history of total hip arthroplasty. The JSW was measured in 3 planes using fluoroscopic imaging (Table 1). The average JSW on fluoroscopic imaging measured 13.0 ± 3.8 mm laterally, 16.7 ± 4.0 mm apically and 17.9 ± 4.7 mm medially. The average JSW was measured in a single plane on US imaging at 9.2 ± 2.4 mm. The average JSW measured on fluoroscopic imaging was significantly greater than the average JSW measured on US in all 3 planes ($P < .001$).

US Versus Fluoroscopy for Portal Placement

Nine fresh cadaver whole-body specimens for a total of 17 hips underwent portal placement. Five of the cadavers were male and 4 were female specimens. One left hip of a female specimen was excluded due to a history of bipolar hemiarthroplasty. A total of 8 hips underwent portal placement with fluoroscopic guidance (5 male, 3 female) and a total of 9 hips (5 male, 4 female) underwent portal placement under US guidance.

The average total procedure time was 133 ± 51 seconds for the fluoroscopy group and 371 ± 260 seconds for the US group (Table 2). The total procedure time for the US group was significantly greater than the fluoroscopically guided group ($P = .026$). The fluoroscopy group required significantly less needle insertion attempts through the capsule to access the hip joint (1.25 ± 0.46 vs 3.33 ± 2.40, $P = .022$).

Iatrogenic injury to the cartilage or labrum occurred in one-half of all cases. The rate of any iatrogenic injury was greater in the US group 66.67% compared with the fluoroscopy group 37.5%. However, the greater rate of iatrogenic injury in the US group was not statistically significant ($P = .347$). The labrum was injured during portal placement in 6 of 9 US-guided (66.67%) and 1 of 8 fluoroscopically guided (12.5%) procedures ($P = .0497$). Cartilage was damaged in 5 cases, 3 fluoroscopically guided (37.5%) and 2 US-guided (22.22%). However, the rate of iatrogenic injury to the cartilage in the fluoroscopy group was not significantly greater than the US-guided group on Fisher exact testing ($P = .620$).

Discussion

The most important findings of this study were that joint distraction measured on US is significantly less than JSW measured on fluoroscopy, and US-guided

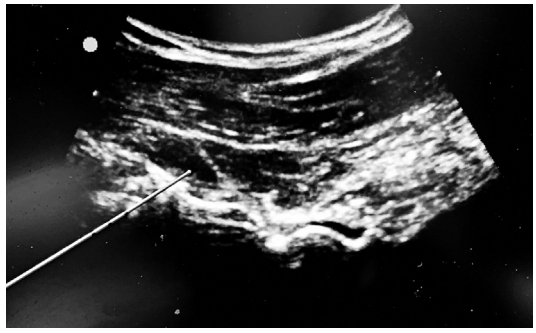

Fig 3. Spinal needle (indicated by probe) directed toward center of the "light saber sign " during ultrasound-guided placement of the anterolateral portal.

Table 1. Comparison of Distraction Measurements in Millimeters Using Fluoroscopy Measured in 3 Planes Versus Ultrasound Measured in One Plane

	Fluoroscopy	Ultrasound	P Value
Lateral	13.0 ± 3.8	9.2 ± 2.4	<.001*
Apical	16.7 ± 4.0		<.001*
Medial	17.9 ± 4.7		<.001*

*Statistically significant based upon predetermined significance level of .05.

portal placement was associated with more needle insertion attempts, iatrogenic injury of the labrum, and overall procedure time in comparison with fluoroscopic guidance. However, US can be used to subjectively determine whether the joint is adequately distracted in hip arthroscopy. This study highlights the challenges of US-guided portal placement early in the learning curve in comparison with conventional fluoroscopic guidance in hip arthroscopy. US is an accessible, cost-effective, and safe imaging modality that has growing interest for use during arthroscopic hip preservation surgery for FAIS. However, previous literature on the rates of chondral and labral injury is limited, and the reported rates of injury are varied. In a Technical Note for the US-guided establishment of hip arthroscopy portals, Hua et al.[34] identified 1 labral injury and 3 chondral injuries in their sample, with an overall complication rate of 22%. Weinrauch and Kermeci[30] report an institutional complication rate of <1% to 2%, but this was provided as an "expert opinion" statement in a surgical technique article that did not include any other patient outcomes data. In a retrospective cohort of 460 patients in which 38% of patients were in the US cohort, there was an overall 2.9% of injury to the labrum or femoral head; there was no difference in rates of injury between US and fluoroscopic guidance.[31] The reported rates of chondral and labral injury in our study, at 66.67% and 22.22%, respectively, are much greater than those reported previously. One possible explanation for this difference is that our results were from a full-body cadaveric setting where adequate distraction can be challenging to obtain, and tissues are more friable than those in live patients. In addition, in a previous study, Gordey and Wong[31] performed their procedures in the lateral decubitus position, versus the supine position in which we performed our portal establishment.[29] Lastly, our study builds on previous literature by reporting a greater rate of needle insertion attempts and overall procedure time to establish portals in the US cohort in comparison to the fluoroscopy cohort.

This study highlights the steep learning curve for interpreting and using US imaging for hip arthroscopy. Weinrauch and Kermeci[30] recommend that a surgeon should use US and fluoroscopic guidance for his or her first 30 cases in initial portal placement for hip arthroscopy. Keough et al.[29] also comment on the learning curve associated with US use, suggesting that surgeons become proficient with US examination of the hip first. Buck et al.[24] identified that while US had as 93% sensitivity/89% specificity in detecting an anterosuperior cam deformity, there was poor interobserver agreement, with kappa scores ranging from 0.196 to 0.42, indicating poor-to-moderate agreement.[35] This high rate of disagreement between the observers further highlights the technical challenges associated with using US.

Limitations

Limitations of the current study include those associated with cadaveric studies, including tissue deterioration and differences in tissue mobility/visualization compared with those encountered during surgery. Hip joint distraction measured via US may have been significantly less than joint distraction measured on fluoroscopy due to the limited accuracy to detect a true bony edge using US. A technical analysis by Hacihaliloglu[36] found that a bony edge measured on US is not a sharp transition region, but rather has a thickness that can reach a value of 4 mm in certain cases. As such, it is possible that the edge of the acetabulum and femur may have been overestimated by as much as 4 mm in the assessment of joint distraction using US. The largest limitation of the study is the user-dependency of US. While a single, fellowship-trained orthopaedic sports medicine surgeon with experience in US established the portals in this study, the surgeon's mode of practice and training was with fluoroscopic techniques. The results of this study should be applicable to the early learning curve for US-guided portal placement and are likely not transferrable to surgeons with more experience using US for hip arthroscopy in daily practice. The use of a musculoskeletal-trained radiologist for the administration and interpretation of the US may have affected our results.[28] However, the intent of this study was to assess the feasibility of a fluoroscopic-trained hip arthroscopist to incorporate US into their practice; having an musculoskeletal-trained radiologist present at every hip arthroscopy case to establish portals would not be a

Table 2. Procedure Variables for the Fluoroscopy-Guided and Ultrasound- Guided Cohorts for Portal Placement

	Fluoroscopy	Ultrasound	*P* Value
Number of cases	8	9	
Total procedure time (s)	133 ± 51	371 ± 260	.0258*
Needle insertion attempts	1.25 ± 0.46	3.33 ± 2.40	.0293*
Iatrogenic injury	3 (37.50%)	6 (66.67%)	.3469
Labral injury	1 (12.50%)	6 (66.67%)	.0497*
Cartilage injury	3 (37.50%)	2 (22.22%)	.6199

*Statistically significant based upon predetermined significance level of .05.

reasonable option. Our cadaveric model also does not account for synovitis or bleeding, which may limit US visualization during surgery. This is of particular importance for US, as local hematoma from multiple unsuccessful joint punctures may obscure US visualization of the joint.[34]

Conclusions

Joint distraction measured on US can be used to subjectively determine whether the joint is adequately distracted in hip arthroscopy. US-guided portal placement was associated with more needle insertion attempts, iatrogenic injury of the labrum, and overall procedure time in comparison with fluoroscopic guidance.

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