Retrospective Study

A Novel Piriformis Injection Technique Utilizing Combined Fluoroscopy and Ultrasound – A Pilot Study

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Background: Piriformis syndrome is a constellation of symptoms associated with low back, gluteal, and sciatic pain. One treatment for piriformis syndrome is the injection of local anesthetic, steroid, or botulinum toxin into the piriformis muscle. Various approaches for needle navigation into the piriformis muscle have been described using fluoroscopy or ultrasound. This study introduces a new method of image guidance combining fluoroscopy and ultrasound.

Objectives: The primary aim of this study was examining whether the imaging modality used for needle guidance was associated with significant differences in pre- and post-piriformis injection pain scores. Secondary objectives were assessing differences in adverse events and procedure time.

Study Design: This study is a retrospective cohort study.

Settings: This study was conducted at Oregon Health and Science University's Comprehensive Pain Center, Portland, OR, USA.

Methods: Institutional chart review was performed from 09/21/2014 to 01/21/2020 to identify patients that underwent piriformis steroid injections which generated a list of 95 patients and totaled 154 procedures. Inclusion criteria were met for 78 patients and 109 procedures. Pain scores were modeled longitudinally using robust variance estimates. The nonparametric Kruskal-Wallis test was used for procedure duration, while adverse events were too rare to evaluate statistically.

Results: Piriformis steroid injections using the combined ultrasound and fluoroscopy technique had the lowest mean post-procedure pain score of 1.3 (SD 1.7) and the largest change in pain with a score difference of -3.9 (SD 2.1). Procedure durations were 8 (quartiles 5 to 10), 10 (quartiles 7 to 13), and 11 minutes (quartiles 9 to 13) for fluoroscopy alone, ultrasound alone, and combined techniques, respectively. All 3 modalities had duration ranges of minimum time of 3-5 minutes and a maximum time of 25-28 minutes. Adverse events across all imaging strategies were noted in 5 patients at the time of procedure and in 7 patients during follow-up appointments, the most common symptom being transient leg weakness or numbness.

Limitations: The major limitation is the retrospective collection of data. Another limitation is that 6 different providers performed the injections, which may influence procedural consistency. Additionally, the inclusion of subjects with low pre-procedure pain scores could create a floor effect that minimized the occurrence of clinically significant shifts in pain scores. Adverse events were too few across all groups to assess.

Conclusion: Piriformis injections using combined fluoroscopic and ultrasound guidance provides comparable efficiency to standard techniques and may result in improved accuracy into the target and thus improved efficacy. Larger prospective trials are required to comprehensively examine the efficacy of this novel technique.

Key words: Piriformis, piriformis syndrome, steroid injections, injection techniques, ultrasound, fluoroscopy, pain score, minimally invasive, electromyography

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Piriformis syndrome was first described in 1947 and includes a constellation of symptoms characterized by deep gluteal pain, tenderness over the sciatic notch, irritation of the sciatic nerve, and pain associated with hypertrophy of the piriformis muscle (1). The reported incidence in the general population ranges from 6-8% (2).

The piriformis muscle originates from the ventrolateral surface of the S2-S4 sacral vertebrae and runs lateral through the greater sciatic foramen, inserting on the piriformis fossa of the medial greater trochanter (Fig. 1). The piriformis is located deep to the gluteus maximus muscle and is flanked by the gluteus medius and superior gemellus. It is innervated by the ventral rami of the S1 and S2 nerve roots and is responsible for abduction and external rotation of the femur.

Common characteristics of the condition include pain with prolonged sitting, pain with squatting, pain or paresthesia in the sciatic nerve distribution, and myofascial tenderness over the piriformis muscle. Treatment options for piriformis syndrome are varied but mainly consist of non-invasive therapies, such as physical therapy, anti-inflammatories, and muscle relaxants. Minimally invasive injections into the piriformis muscle are frequently used to aid in recovery. While blind injections used to be the mainstay of treatment, the evolution of imaging modalities and stimulation techniques have expanded available interventional approaches.

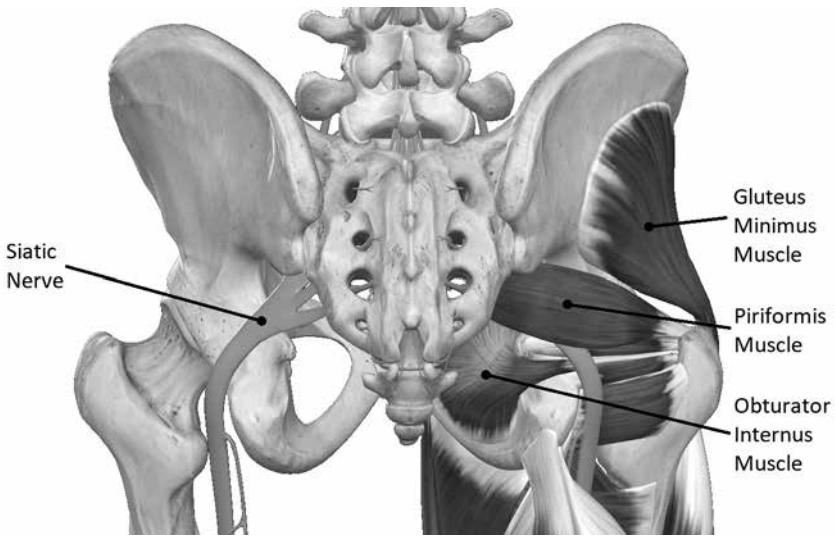

Fig. 1. *Human anatomy relevant to piriformis syndrome. The piriformis muscle arises on the deep anterior surface of the sacrum and then passes through the greater sciatic notch before inserting on the greater trochanter of the femur. Image courtesy of Complete Anatomy (3D4Medical, 2021).*

A PubMed literature review revealed several techniques for localizing the piriformis muscle, including computed tomography (CT) guided, fluoroscopically guided, ultrasound guided, and the aforementioned with or without electromyography (3-7). To date, no technique has been described that incorporates both fluoroscopy and ultrasound. The hypothesis is that this technique provides an added safety margin and accuracy by allowing for the real-time visualization of neurovascular structures, in addition to the identification of the bony insertions of the piriformis. This combination may be especially useful in obese patients in which anatomical landmarks are not easily discerned. The goal of the study is to evaluate whether a combined fluoroscopy and ultrasound technique resulted in improved pain relief with secondary outcomes of reduced adverse events and procedure times.

Methods

Study Design and Population

The study was developed after a thorough PubMed review of piriformis injection techniques. This is a retrospective cohort study designed to assess if the imaging modality utilized at the time of piriformis steroid injection affects patient outcomes in terms of pain reduction (observed through pre- and post-pain scores on a numeric rating scale 0-10), procedure times, or complication rates. The study cohort included patients presenting to Oregon Health and Science University (OHSU) from 09/21/2014 to 01/21/2020 for piriformis steroid injections. This study was approved by the institutional review board for a retrospective chart review and the collection, analysis, and publishing of relevant data.

A university analyst identified 95 patients, via an EPIC query, that received a piriformis injection during the stated time window, generating a list of 154 procedure charts to screen for further inclusion and exclusion criteria. Inclusion criteria consisted of patients who had an ultrasound

or fluoroscopically guided piriformis steroid injection or a combination of the 2 modalities. Exclusion criteria included patients < 18 years of age, pregnant at the time of piriformis injection procedure or follow-up, history of generalized pain syndrome at the time of the procedure, or a history of poorly controlled psychiatric disorder at the time of the procedure. Patients with repeat procedures were not excluded from analysis. Ultimately, 78 patients and 109 procedures met inclusion criteria.

Procedure in Detail

Patients were evaluated in the outpatient Comprehensive Pain Center at the OHSU. A diagnosis of piriformis syndrome was established through clinical workup, primarily history, and physical exam. Preprocedure pain scores were obtained on the day of the procedure at check-in. Post-procedure pain scores were obtained while the patient was in the recovery bay prior to discharge.

The 3 methods of image-guided needle placement are described below. After obtaining informed consent, the patient was placed in the prone position. Standard monitoring was then applied. A GE OEC9900 Elite fluoroscope was used for the fluoroscopy portion of the procedure, and a SonoSite X-PORTE ultrasound machine was used for the ultrasound portion of the procedure.

For all procedures, the area was sterilely prepped and draped in the usual fashion. After negative aspiration, a solution of local anesthetic and steroid was incrementally injected into the muscle.

Ultrasound Only Technique

Using ultrasound, the sacrum and left greater trochanter were identified. A low-frequency curvilinear transducer was used to scan the posterior gluteal and piriformis muscle. The piriformis muscle was identified by passively internally and externally rotating the knee in a flexed position and visualizing the piriformis gliding beneath the gluteus maximus.

Following this, an echogenic needle was advanced into the piriformis muscle using in-plane ultrasound guidance (Fig. 2). Doppler was used to visualize and avoid any vessels. The sciatic nerve was also identified and avoided during needle advancement.

Fluoroscopy Only Technique

Using fluoroscopy, the sacroiliac joint and the greater trochanter were identified (Fig. 3). Using a marking pen, a line was drawn on the patient's skin from the sacrum to the greater trochanter that represented the general area of the piriformis muscle by anatomic landmarks.

Following this, a site approximately 1 cm caudal and 2 cm lateral to the inferior portion of the sacroiliac joint was located along the originally marked line. A spinal needle was then guided into the piriformis muscle utilizing intermittent fluoroscopy using anteroposterior and lateral views, as well as tactile feedback.

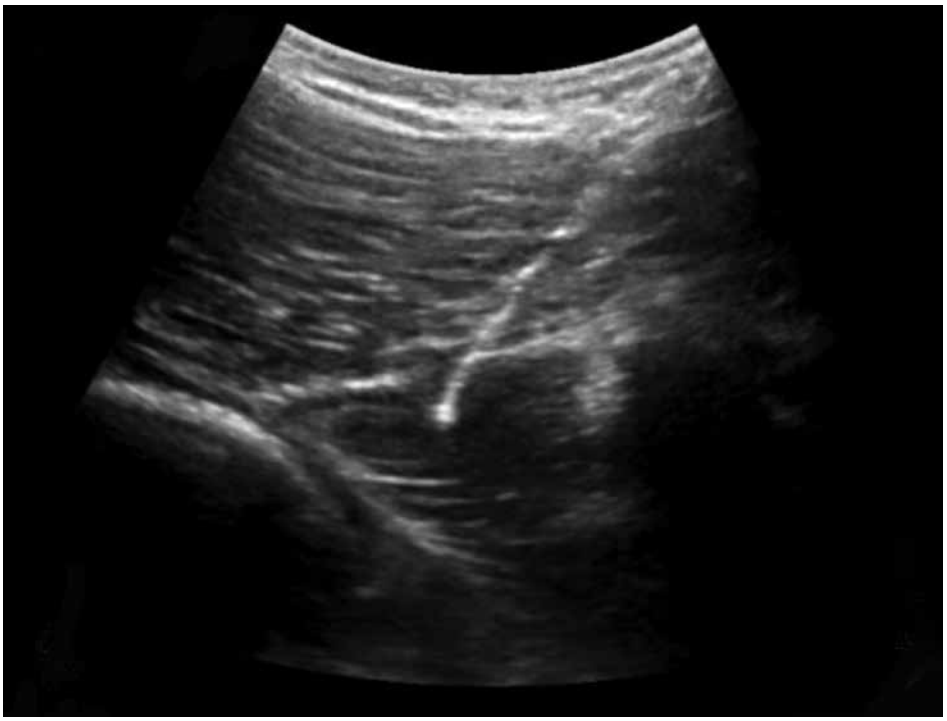

Fig. 2. *Image of ultrasound guided needle navigation into the piriformis muscle.*

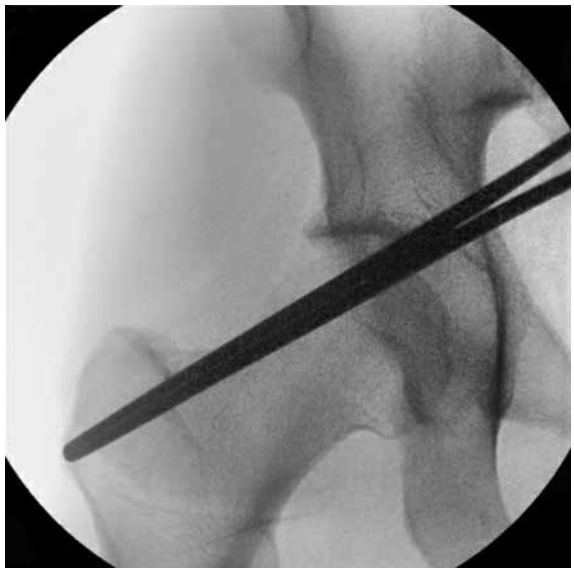

Fig. 3. *Fluorograph in PA view with forceps indicating piriformis muscle path and correlating bony landmarks.*

Correct needle position was confirmed using contrast with fluoroscopy showing the standard appearance of an intramuscular injection along the expected anatomical orientation of the piriformis muscle.

Combined Fluoroscopy and Ultrasound Technique

Using fluoroscopy, the sacroiliac joint and the greater trochanter were identified. Using a marking pen, a line was drawn on the patient's skin from the sacrum to the greater trochanter.

Using ultrasound, a curvilinear array transducer was then placed in-line with the marked line and moved along the line until the piriformis muscle and sciatic nerve were identified deep to the gluteus maximus muscle. The piriformis muscle was identified by passively internally and externally rotating the knee in a flexed position and visualizing the piriformis gliding beneath the gluteus maximus. Following this, using in-plane ultrasound guidance, an echogenic needle was advanced into the piriformis muscle. Doppler was used to visualize and avoid any vessels. The sciatic nerve was also identified and avoided during needle advancement.

Outcomes Assessment

The main outcome of interest was change in pain from pre- to post- procedure, using a pain rating numerical scale of 0-10; additional outcomes examined were procedure time and adverse events. Pre- and post-procedure pain ratings were collected on the day of the procedure. Other variables assessed included local anesthetic medication and dosages used in the procedure, procedure provider, patient body mass index (BMI), patient age, and patient gender. Relevant population characteristics were compared to ensure no statistically significant difference existed between the groups.

Statistical Analysis

Differences between imaging modality groups that may have affected modality choice or pain response to treatment, namely BMI, gender, and pre-procedure pain scores, were tested using linear regression or logistic regression with clustering on patients (8). Characteristics associated with modality at $P < 0.2$ would have been considered as potential confounders, but none met this threshold.

Mean pre- and post-procedure pain scores were modeled using a longitudinal mixed-effects regression approach with an observation for each measurement and all available data. This model included indicator variables for (a) imaging modalities and (b) time (1 = post, 0 = pre) along with (c) interaction terms to reflect differences in the change in pain score between modalities and included random effects to model correlations within person and procedure. Robust (empirical) variance estimators were used to compensate for a slight departure from normality. The statistician considered a model that included fixed effects for the provider performing the procedure and found that estimates of change in pain were only minimally affected, so the presented models do not adjust for provider. Post-procedure pain scores by imaging modality were calculated as the mean predicted values from this model with 95% confidence intervals; the differences between the mean changes were estimated using the regression coefficients of the interaction terms, and *P*-values are from the Wald test. The differences in change in pain scores between the combined and single modalities were pre-specified as the 2 main outcomes of interest.

Differences between imaging modalities in the duration of procedure and type and dose of anesthetic used were evaluated using Somer's D (as a clustered analog to the non-parametric Kruskall-Wallis test) and Fisher's exact test, respectively (8). Adverse events were reviewed descriptively but were too rare to evaluate statistically.

All analyses were completed using Stata/IC version 16 (9).

Results

Study Population and Dataset

The study flow chart is shown in Fig. 4. From the initial query, 95 patients and 154 procedures were further screened for eligibility. The resulting analytic dataset contained 78 patients and 109 procedures. Both male and female patients were included, with 32% of the subjects being male and 68% being female. The 109 procedures were performed by 6 different providers using either ultrasound, fluoroscopy, or a combination of ultrasound and fluoroscopy (Table 1). Most patients, 73.0% in the study, had only one steroid injection performed; 18.0% had 2 procedures, 5.3% had 3 procedures, and 3.9% had 4 procedures.

Population Variation

The distributions of age, gender, and BMI for procedures in each of the 3 imaging modalities are shown in Table 1. There were no statistically significant differences in population characteristics between the imaging modality groups.

Duration of Procedure

Duration was calculated by subtracting the start time from the end time in the procedure charts. Piriformis injections performed via fluoroscopy had the lowest median duration of procedure at 8 minutes (quartiles 5 to 10; $P = 0.013$; Table 1). All 3 imaging modalities had similar procedure duration ranges with a

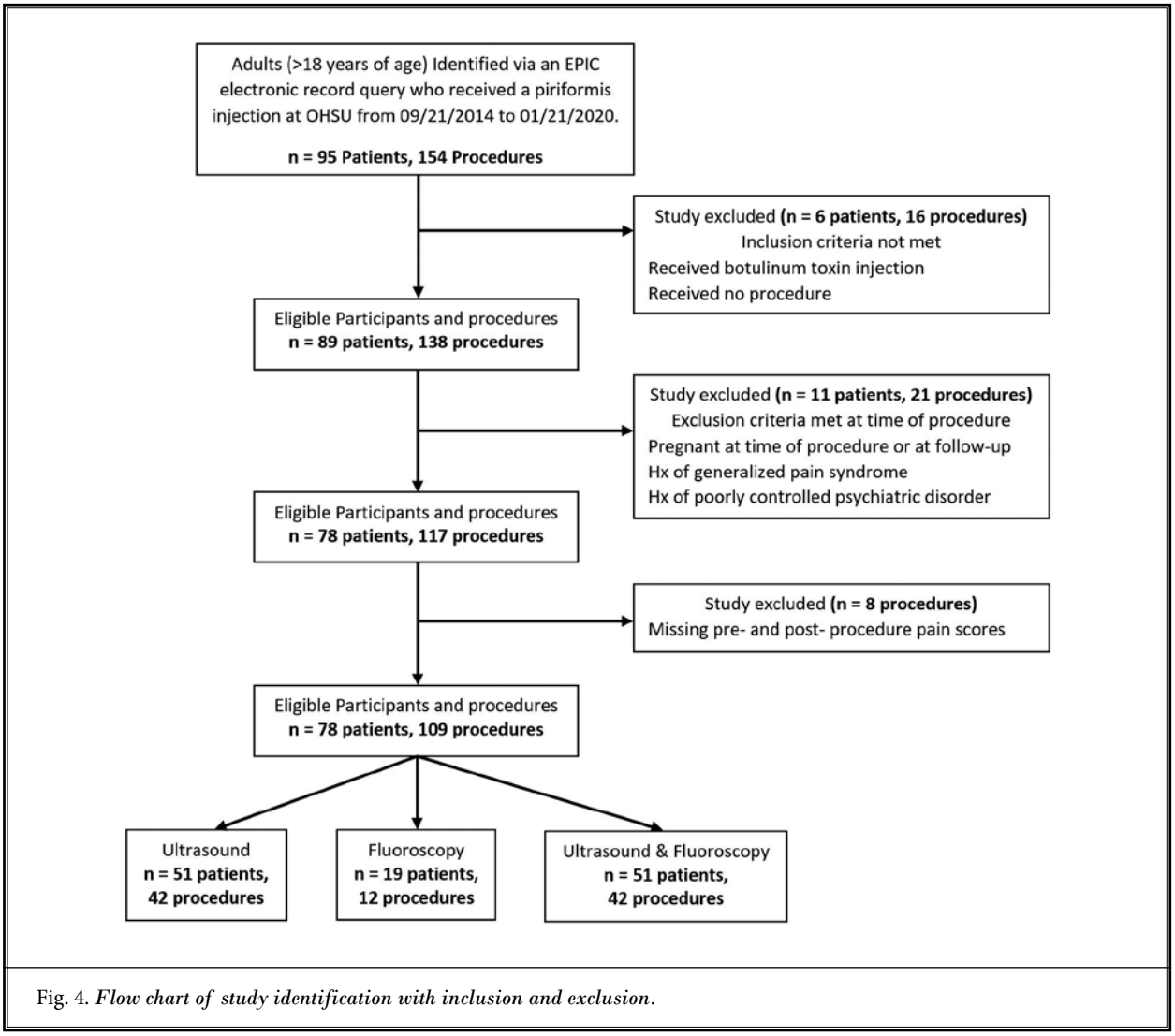

Fig. 4. *Flow chart of study identification with inclusion and exclusion.*

Table 1. *Patient and procedure characteristics by imaging modality.*

	Overall		Ultrasound		Fluoroscopy		Ultrasound & Fluoroscopy		*P* value
Procedures, n (row %)	109	(100.0)	51	(46.8)	19	(17.4)	39	(35.8)	
Unique patients, n[a] (row %)	78	(100.0)	42	(53.8)	12	(15.4)	32	(41.0)	
Patient characteristics (at time of procedure)									
Age (years), mean (SD)	56.9	(16.2)	54.5	(14.9)	59.8	(15.9)	58.5	(17.9)	0.413[b]
Body mass index (kg/m^2), mean (SD)	27.8	(6.6)	28.7	(6.7)	26.5	(7.8)	27.2	(5.6)	0.438[b]
Gender									
Male:Female ratio	0.47		0.42		0.46		0.56		
Female gender, n (%)	74	(67.9)	36	(70.6)	13	(68.4)	25	(64.1)	0.820[b]
Procedure characteristics									
Duration (minutes), median (25th, 75th percentile)	10	(7,13)	10	(7,13)	8	(5,10)	11	(9,13)	0.013[c]
Anesthetic used, strength: n (%)									
Ropivicaine, 0.5%	47	(43.1)	25	(49.0)	3	(15.8)	19	(48.7)	< 0.0001[d]
Bupivacaine, 0.5%	34	(31.2)	22	(43.1)	1	(5.3)	11	(28.2)	
Bupivacaine, 0.25%	24	(22.0)	1	(2.0)	14	(73.7)	9	(23.1)	
Lidocaine, 1.0%	2	(1.8)	1	(2.0)	1	(5.3)	0	-	
Other	2	(1.8)	2	(3.9)	0	-	0	-	
Anesthetic dose (mL), mean (SD)	4.3	(1.7)	4.4	(1.9)	4.1	(1.4)	4.1	(1.7)	0.635[b]

a: Counts do not sum to total because some patients received multiple injections using different modalities.
b: *P* value from the overall F test (linear) or likelihood ratio chi-square test (logistic) of a regression model with modalities as predictors and clustering on patient.
c: *P* value from F-test of Somers' D parameters accounting for clustering on patient.
d: *P* value from Fisher's exact test.

minimum time between 3 to 5 minutes and a maximum time between 25-28 minutes (one combined ultrasound and fluoroscopy procedure was recorded as 1 minute, which we believe to be an error and thus omitted).

Medication and Dosing Differences

Regarding the type of anesthetics used for the procedures, significant differences were found between the 3 imaging modalities ($P < 0.0001$) (Table 1). Ropivacaine 0.5% was the preferred anesthetic used in both the ultrasound only and the combined ultrasound & fluoroscopy groups. Bupivacaine 0.25% was the preferred anesthetic used in the fluoroscopy only group. In contrast, the mean anesthetic volume measured in milliliters was similar across all 3 imaging modalities ($P = 0.635$). The mean local anesthetic volume given for all 109 procedures was 4.25 mL (SD 1.7).

Pain Scores

Mean baseline pain scores were somewhat lower for ultrasound alone (4.7 [SD 2.1]) than for the other modalities (5.3 [2.1] and 5.5 [2.0]), though this difference was not statistically significant ($P = 0.227$ for ultrasound alone vs ultrasound and fluoroscopy) (Table 2).

Piriformis steroid injections using all 3 imaging modalities demonstrated clinically significant improvement of at least 3 points (Table 2, Fig. 5). Procedures performed using the combined approach had the lowest mean post-procedure pain score of 1.3 (SD 1.7) as well as the largest change in pain with a score differential of -3.9 (SD 2.1). The reduction in pain score was approximately 1.0 point greater in procedures using the combined approach than in those using ultrasound alone ($P = 0.029$). Pain score reduction with the combined approach was also 0.8 points greater than with fluoroscopy alone, though these scores did not differ significantly ($P = 0.296$).

Adverse Events

In total, 12 adverse events were reported in the study; 5 were noted at the time of the procedure, and 7 were noted during a follow-up appointment (Table 3). All adverse events were associated with mild and transient symptoms, meaning that symptoms either resolved or were not reported again at later follow-up visits.

Table 2. *Pain scores before and after procedure by modality, n = 78 patients and n = 109 procedures.*

		Pre-procedure pain score		Post-procedure pain score		Change			
Imaging modality	**N**	**Mean (SD)**	***P* value***	**Mean (SD)**	***P* value***	**Mean (SD)**	**Difference in pain change†**	**95% CI**	***P* value***
Ultrasound & fluoroscopy	39	5.3 (2.1)	[ref]	1.3 (1.7)	[ref]	-3.9 (2.1)	[ref]	-	-
Ultrasound	51	4.7 (2.1)	0.227	1.7 (1.9)	0.349	-3.0 (2.0)	1.0	(0.1, 1.9)	0.029
Fluoroscopy	19	5.5 (2.0)	0.543	2.4 (2.5)	0.159	-3.2 (2.2)	0.8	(-0.7, 2.3)	0.296

[ref], reference level for comparison, chosen as the novel modality for comparison to existing modalities.
All 3 methods were associated with clinically and statistically significant reductions in pain of 3 points or more.
**P* value, †interaction coefficient from a longitudinal model for pain with design variables for modalities, pre vs post, interactions between those factors, and random intercepts for patients and procedures. Post-procedure P values calculated using contrasts.

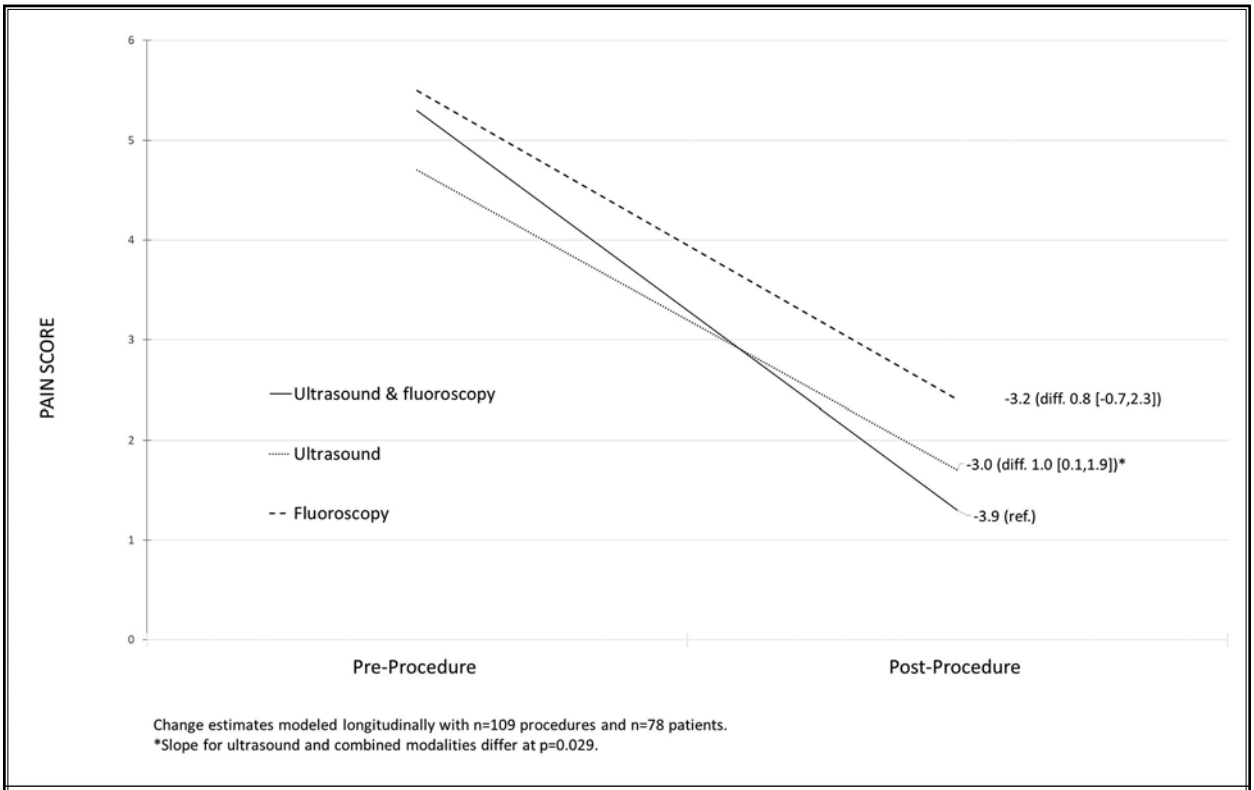

Fig. 5. *Image modality pre- and post- procedure pain scores.*

Some of the adverse events were found to have etiologies unrelated to the procedure. For example, after a fluoroscopy guided injection, one patient noted swelling and extreme pain at the injection region. After further investigation with MRI, a partial thickness tear of the left hamstring was found, explaining the root of his pain. Another instance of a reported increase in pain was due to a lumbosacral plexopathy from a previous injury.

There were too few adverse events to evaluate group differences statistically.

Discussion

Anatomically, the sciatic nerve most commonly runs ventral and inferior to the piriformis muscle; however, 6 variants have been described in the literature (10). Additionally, variations in the muscle size, configuration, and tendinous insertions have also been noted, thus making it a less reliable target with strict fluoroscopic based techniques (11). In a recent cadaveric study comparing the use of ultrasound or fluoroscopy for piriformis injections, ultrasound was vastly

Table 3. *List of adverse events at time of procedure and at follow up.*

Imaging Modality Used	Adverse Symptom Noted
At time of procedure	
Ultrasound	Leg weakness & leg numbness
Ultrasound	Increased pain
Ultrasound & fluoroscopy	Leg weakness & leg numbness
Ultrasound & fluoroscopy	Leg weakness & leg numbness
Ultrasound & fluoroscopy	Increased pain
At follow-up	
Fluoroscopy	Pain at injection site
Fluoroscopy	Itching
Ultrasound	Increased pain
Ultrasound	Leg numbness & leg pain
Ultrasound	Leg numbness
Ultrasound	PTSD nightmares
Ultrasound & fluoroscopy	Leg numbness

All symptoms were resolved or were not noted at time of follow-up

superior in targeting the piriformis muscle compared to fluoroscopy alone (95% vs 30% targeting accuracy). Furthermore, this study revealed that fluoroscopic dye patterns can be analogous between piriformis and gluteus maximus injections, further advocating for the use of ultrasound (12).

The earliest literature using fluoroscopically guided injections into the piriformis was published by Fishman et al (13) in which a combination of fluoroscopy and electromyography (EMG) was used to identify the piriformis muscle. While fluoroscopy is a ubiquitously used modality, EMG is not. Due to decreasing reimbursements and inadequate training, EMG is a technique which is becoming less prevalent in the pain physicians' armamentarium. Contrast this to ultrasound, which has seen an explosive growth over the last decade. The advantages of ultrasound modality include reducing ionizing radiation exposure, real time neurovascular imaging, the avoidance of contrast related reactions, and more targeted medication delivery. Although using a CT-guided technique can also provide direct visualization of the tissue, it is more time-consuming, costly, and includes the added risk of radiation exposure (3).

Our initial fluoroscopic target was adapted from Honorio Benzon et al (1) in which the sciatic nerve was found reliably with a combination of fluoroscopy and nerve stimulation 2 cm lateral and 1 cm caudal to the sacroiliac joint. The downside of their approach was the lack of real-time visualization of neurovascular structures. There are case reports establishing the risk of neural injury associated with unintentional sciatic nerve injections (12,13) a tangible risk during piriformis muscle injections given the variable anatomic location of the sciatic nerve. By combining fluoroscopy with ultrasonography, bony landmarks as well as neurovascular landmarks can be identified.

We have found no other reports describing combined ultrasound and fluoroscopy modalities. The combination of the 2 imaging modalities resulted in a more efficient procedure when compared to either alone. Furthermore, by combining the 2 modalities, the inherent deficiencies of either stand-alone technique, lack of real-time tissue visualization in fluoroscopy, and inefficient bony landmark identification with ultrasound were eliminated.

The technique described in this study involves fluoroscopy to initially locate the sacroiliac joint and the greater trochanter, where a line can be drawn between the 2 identified landmarks. This line acts as a visual target for the ultrasound probe to follow, allowing a more accurate and efficient localization of the piriformis muscle and sciatic nerve. This approach may be particularly helpful in patients whose anatomical landmarks are not easily discerned with ultrasound alone. Both imaging modalities are readily available to most pain management clinicians and thus the described technique can be easily adapted into most pain practices.

Piriformis injections using all 3 imaging modalities provided clinically significant improvement in pain. However, patients undergoing the combined fluoroscopy and ultrasound technique, on average, experienced greater clinical outcomes, including lower post-procedure pain scores and greater change in pain score.

In terms of efficiency, piriformis injections performed via fluoroscopic guidance alone had the fastest procedure times compared to the other modalities. This outcome was anticipated since ultrasound guidance generally requires more time than fluoroscopy guided procedures. The average duration of piriformis injections performed using the combined approach was 0.1 seconds less than the average duration for injection with ultrasound guidance only. This finding suggests comparable clinical efficiency between the 2 imaging modalities.

Furthermore, this combined technique may be more time efficient in obese patients where the thicker adipose layers can make obtaining needed ultrasound views more challenging. This study population had a

combined average BMI of 27 and thus cannot support this hypothesis.

This retrospective cohort study encompasses a larger study size relative to past studies with sample sizes of 10 or less. The male and female ratios were well matched between the study groups; however, 68% of the study population was female. A larger sample size may have eliminated this bias, or this may represent the known difference in incidence between genders of piriformis syndrome. The limited sample size creates questions regarding the generalizability of broad populations.

An additional limitation of this study concerns low pre-procedure pain scores creating a floor effect with a minimal possible change in pain score. This is especially pertinent when analyzing for a clinically significant pain reduction using the numerical rating scale (NRS). A change in NRS greater than -2 points has been deemed clinically significant (14). Low pre-procedure pain score eliminates or reduces the occurrence of a clinically significant shift in pain scores. For this reason, we suggest future studies utilize an inclusion criterion of a pre-procedure pain score greater or equal to 3/10.

Piriformis injections analyzed in this study were performed by 6 different providers creating a concern regarding procedural consistency, which may have affected outcomes, including variation in procedural time and efficacy of results. One provider performed all but 2 of the fluoroscopy only procedures. The skill of this provider may be a causal factor in the smaller mean procedure time and absence of adverse events in the fluoroscopy only group.

All local anesthetics used in this study utilized the same mechanism of action (15). The major pharmacologic differences between the anesthetics were onset and duration of action. Lidocaine has an onset of 2-4 minutes and a duration of 30 to 60 minutes, while Bupivacaine and Ropivacaine have onsets of 6-10 minutes and durations of 2 to 6 hours (15). Dosages used were in accordance with standard protocols to provide equipotent effects, and post-procedure pain scores were obtained within the local anesthetic window of action. For this reason, the significant variation in local anesthetic used is unlikely to have affected the study results.

Adverse events across all imaging strategies consisted of subacute and mild symptoms. Adverse events reported at subsequent follow-ups were either resolved, unmentioned, or found to have etiologies unrelated to the procedure. Statistical analysis of adverse events between groups was unable to be performed with confidence as there were only 12 reports across all groups. The number of adverse events reported by group was proportional to the number of procedures performed in each group. The ultrasound, fluoroscopy, and combined groups consisted of 46.8%, 17.4%, and 35.8% of the total procedures, respectively, and provided 50%, 16.7%, and 33.3% of the reported adverse events, respectively. A randomized control study with a large population would be preferred to further evaluate the safety and efficacy of the combined fluoroscopy and ultrasound technique described in this paper.

Conclusion

This pilot study suggests that there may be superior outcomes with the use of combined imaging involving both ultrasound and fluoroscopy compared to the use of either modality alone. The piriformis muscle resides in the pelvic cavity surrounded by nerves and vasculature thus injections to the area must be performed with accuracy and caution for optimal outcomes. By combining the rapid identification capabilities of fluoroscopy with real-time visualization from ultrasound, it was hypothesized that a more accurate and efficient placement of injections could be achieved. Given the clinically and statistically significant advantages demonstrated, the study supports the initial hypothesis and the use of this novel technique over standard ultrasound guided injections. However, given the limitations of this pilot study, further investigation into the benefits of this technique is warranted.

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Contributors

Conceived the study: SC, EZ. Study design: BM, SC, KR. Data capture: SH. Analysis and interpretation of the data: BM, SH, SC, KR. Contributed to the writing and review of the manuscript: BM, SH, SC, KR, EZ. Served as corresponding author: SC.

Patient Consent for Publication

Patient consent was obtained to publish the ultrasound and fluoroscopy images.

Ethics Approval

This retrospective cohort study was approved by the Oregon Health and Science Institutional Review Board (IRB) (IRB number 00021188).

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