Reviews

Minimally Invasive and Conservative Interventions for the Treatment of Sacroiliac Joint Pain: A Review of Recent Literature

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Sacroiliac joint (SIJ) pain is responsible for approximately a third of reported back pain. Patients with SIJ pain report some of the lowest quality of life scores of any chronic disease. Understanding of the physiology and pathology of the SI joint has changed dramatically over the years, and SI joint pain and injury can now be thought of in two broad categories: traumatic and atraumatic. Both categories of SI joint injury are thought to be caused by inflammation or injury of the joint capsule, ligaments, or subchondral bone in the SI joint. Treatment of SI joint pain usually involves a multi-pronged approach, utilizing both, multi-modal medical pain control and interventional pain/surgical techniques such as steroid injections, radiofrequency nerve ablation, and minimally invasive sacroiliac arthrodesis. Though conservative management through multi-modal pain control and physical therapy have their role as first line therapies, an increasing body of evidence supports the use of minimally invasive procedures, both as adjuvant treatments to conservative management and as second line therapies for patient's that fail first line treatment.

INTRODUCTION

15-25% of axial low back pain arises from pathologies of the sacroiliac (SI) joint, a synovial or diarthrosis-amphiarthrosis joint, whose primary function is to transfer weight to and from the lower extremities to the axial skeleton.[1,2] Understanding of the physiology and pathology of the SI joint has changed dramatically over the years, and SI joint pain and injury can now be thought of in two broad categories: traumatic and atraumatic. Common traumatic include pelvic fractures, motor vehicle collisions, and torsion injuries from heavy lifting, while common atraumatic causes include osteoarthritis, pregnancy, and structural pathologies of the axial skeleton (spondyloarthropathies and scoliosis).[1,3,4]

Both categories of SI joint injury are thought to be caused by inflammation or injury of the joint capsule, ligaments, or subchondral bone in the SI joint (all of which have been proven to nociceptors on immunohistology).[5] The most common patient presentation is that of a deep pain that follows an inciting event (an important point of differentiation from radicular pain, which is often insidious), radiating down the posterior thigh and up to the knee, reproducible upon sitting down, lying on the ipsilateral side, or when climbing stairs.[6]

Patients with certain comorbidities are at a higher risk for developing SI joint pain. These include: lower bone density, variability in auricular surface (allows forward-backward motion), autoimmune diseases, leg length discrepancy, advanced age, history of trauma, obesity.[7] Image guided (CT being the most efficacious imaging modality) injections of local anesthetic agents are the diagnostic gold standard, the diagnostic standard being provocation of symptoms upon inflated and symptomatic relief following local anesthetic infiltration.[8]

Treatment of SI joint pain usually involves a multi-pronged approach, utilizing both, multi-modal medical pain control and interventional pain/surgical techniques

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such as steroid injections, radiofrequency nerve ablation, and minimally invasive sacroiliac arthrodesis.[9] In this review we will discuss the benefits and limitations of several forms of SI joint pain treatment, with a special focus on minimally invasive interventional options.

MEDICAL MANAGEMENT

Sacroiliac joint (SIJ) pain is responsible for approximately a third of reported back pain. Patients with SIJ pain report some of the lowest quality of life scores of any chronic disease. There is also a large economic burden involved in treating chronic back pain. Very careful management should be used to approach chronic back pain, starting with conservative measures.[10] Physicians employ non-surgical methods for initial treatment of SIJ pain.[10] This includes over the counter medications like NSAIDs or acetaminophen. Muscle relaxants, anti-depressants, gabapentin, and opioids may be used based on case presentation.[11] Long-term opioid usage is discouraged.[10] Topical menthol and lidocaine patches are alternative low-risk options.[10]

With the exception of opioids, pharmacologic treatment is first line for back pain. They are generally indicated for short-term relief. Muscle relaxants are indicated if other non-opioid analgesics do not improve pain. They should be used for no longer than two weeks.[12] Gabapentin is an anticonvulsant that may be used for chronic back pain but has limited efficacy when compared to other drugs like NSAIDs.[11] Opioids should only be used for treatment if other non-opioid analgesics are inadequate. If opioids are used for several months with no relief, they should be immediately discontinued.[12] Surgery should only be considered if all other conservative methods of treatment fail.[10]

NSAIDs decrease inflammation of the SI joint.[10] Opioids close calcium channels and open potassium channels. This causes hyperpolarization and a decrease in neuronal excitability. Opioids have an inhibitory effect, turning down the perception of pain.[13] Other treatments dampen nociceptive signaling through different mechanisms.[11]NSAIDs are very effective in treatment of ongoing back pain are usually chosen as first-line therapy for chronic back pain. Opioids show benefit only for short periods. Topical treatments do not show any benefit over placebo. Anti-depressants, with the exception of duloxetine, do not show much improvement. Topiramate is another anticonvulsant that is associated with improvement of chronic low back pain when compared to placebo. Acetaminophen did not show improvement in pain.[11]

Chronic over-usage of NSAIDs can result in gastroduodenal ulcers.[12] Chronic NSAID usage is also associated with severe cardiovascular complications.[14] Major depressive disorder and opioid use disorder are major risk factors to consider when prescribing opioids. There is a large risk of dependence, especially in these populations. Younger patients are more likely to become dependent on opioids. Opioids are the leading cause of death of routine medical treatment. This is considered an epidemic in the United States. With no real evidence that opioids provide long-term benefit of pain, this is a large risk.[15] NSAIDs show to provide the largest improvement of SIJ pain with the least amount of side effects when managed correctly.[11]

PHYSICAL THERAPY

The goals of treatment in physical therapy for SIJ pain include improving the mechanics of the lumbar spine, pelvis, and hip. This aids in restoration of patient mechanical function. Physical therapy (PT) is often augmented with pharmacologic treatment to increase positive outcomes in SIJ pain. PT should be implemented in the acute phase of pain. The acute phase starts one to three days after pain onset. This evaluates the patient's strength, flexibility, and proprioception. PT is often used in the recovery phase as well, which is 3 days to 8 weeks after pain onset. PT is one of the first-line treatments for SIJ pain. PT is indicated for initial conservative treatment of low back pain.[10]

PT techniques include direct manipulation, direct mobilization, or indirect methods.[10] Rotational manipulation of the lumbar spine improves its normal functioning. This maneuver relaxes hypertonic spinal muscles, decreases intradiscal pressure, and increases range of motion of the SI joint.[16] It can also regulate pain by minimalizing swelling and muscle spasms, adjusting joint defects, and stretching joint soft tissue.[17]

SIJ pain can be caused by pelvic asymmetry, joint hypomobility, or joint hypermobility. This can cause a spasm in the piriformis muscle. This spasm creates radicular pain and may increase tension in the hip and thigh muscles. One of the mechanisms of manipulation involves decreasing the tension in these muscles to resolve dysfunction. Spinal manipulation is used for pain associated with pelvic asymmetry and altered range of motion.[18]

The gluteus maximus aids in stabilization of the SIJ. Therefore, this muscle is a target of some exercise therapies. Strengthening the gluteus maximus may provide more support to the SIJ during weightbearing activities. It may also increase compressive force across the joint. A gluteus maximum strengthening program can decrease SIJ pain while increasing strength and functioning.[19] Strengthening of the pelvic core muscles provides benefit due to the attachment to SIJ musculature and fascia.[10]

Manipulation shows increased range of motion when done repeatedly. It also improves unilateral innominate rotation and disability. Patients receiving a single manipulation treatment will likely see no benefit.[18] At least five sessions of lumbar and SIJ manipulation can decrease SIJ pain and functional disability. These methods can return patients to their SIJ mobility baseline.[16] Both exercise therapy and manipulation therapy can improve pain and disability associated with SI joint pain when compared to baseline. These methods can improve outcomes for up to 24 weeks.[17] All styles of PT have shown to provide an improvement in patients with low back pain. There is no current evidence that shows that one style is superior to another.[20]

No adverse effects are associated with PT if done properly and under supervision.[20] PT is generally much safer than OTC drugs, and even more so than surgery. Injuries surrounding PT are infrequent. Most reported adverse effects associated with PT involve discomfort or SOB. These are self-limited and resolve within 24 hours.[16] Certain styles of PT are potentially less effective when SIJ pain presents with comorbidities like osteoporosis or lumbar disc herniation.[16]

While many studies show a great advantage of PT in SIJ pain, many studies are done by very experienced physical therapists with high inter-examiner reliability. Results of PT in SIJ pain may depend on the skill and availability of the physical therapist assigned to the patient. Also, factors such as age and BMI may affect the generalizability of the effectiveness of PT.[19]

PT is seen as first-line care for SIJ pain but is not always easily accessible to patients that need it. Patients may not be able to see a physical therapist due to insurance-related issues. Some plans need a referral from a doctor to get PT. Some patients may be unaware that they are eligible to receive PT under their current plan. The insurance copay for PT may be unmanageable for some patients. So, while many patients would benefit from PT, there are regulatory and health insurance-related limitations that can prevent their access to PT.[21]

STEROID INJECTIONS

Steroid injections at the SIJ are used to decrease pain, inflammation, and swelling. Inflammation releases cytokines, which cause pain in the joint. Steroids will dampen the body's autoimmune reaction to these cytokines, therefore decreasing pain.[14] The inflammatory properties of glucocorticoids are a result of pleiotropic effects on their receptors. Once complexed with the receptors, glucocorticoids migrate to the nucleus to upregulate the production of anti-inflammatory genes. They can also downregulate pro-inflammatory molecules like cytokines, chemokines, as well as certain enzymes. This a slow process that can take many days to weeks.[14]

Pain in the SI joint is common because this area is highly innervated. Intra-articular corticosteroid injections are indicated in patients with SIJ pain when other, more conservative measures like NSAIDS and PT have failed.[22]. Some of the most typically used corticosteroids in SIJ injections are methylprednisone, dexamethasone, triamcinolone, and betamethasone [14]. Delivery of the injection to the superior part of the SIJ may show greater reduction in pain levels.[23]

Cortico-steroid intervention is most commonly indicated when back pain becomes severe, persistent, and bypasses the acute window. Many patients choose this method when pharmacological options are not sufficient, and they are also not a candidate for surgery. Many experts consider SIJ steroid injection to be the gold standard. Most patients who receive SIJ steroids see benefits after 1-3 physical injections. The benefit of this treatment increases when combined with physical therapy.[14]

Steroid injections are showing to be an increasingly effective option for older patients. Oral pain medications and surgery appear to have too many severe adverse effects to provide any real benefit for older patient populations.[14] If SIJ pain is only partially alleviated after the first injection, repeat injections may be beneficial. Repeat injections may also be indicated after the symptoms recur or prior injection's effects wear off.[22] In comparison to peri-articular treatment, intraarticular treatment displayed significantly stronger pain reduction.[24]

There are mixed results regarding the efficacy of steroid injections for SI joint pain.[23] Steroid injections may provide an initial, short-term benefit.[25] Steroid injections are not efficacious for the long-term treatment of joint pain.[26] If patients do not receive initial relief from SI joint pain immediately following steroid joint injection, it is unlikely that they will have pain improvement at follow-up.[27]

Corticosteroids provide pain relief by causing immunosuppression, but this mechanism is also responsible for any adverse effects. Steroids suppress the immune system to prevent an autoimmune reaction inflammation-induced cytokine release. Other potential adverse effects include Cushing's syndrome, weight gain, fluid retention, mood disturbances, and GI upset.[14] Corticosteroid ester preparations have been associated with vascular adverse effects. Those with large crystal aggregations have seen an association with infarct.[14] It is possible to develop a small hematoma after needle placement. Adverse effects are typically minimal and the majority of patients reported they would undergo the procedure again.[24]

In certain patient groups, steroid injections have a more impressive therapeutic index than other pain reduction efforts. There is an increasing number of adverse effects associated with chronic opioid and NSAID use, as well as with spinal surgery. The effectiveness of SIJ injection treatment, especially in the long term, is decreased in patients with high-grade arthritis.[26] Good outcomes from steroid injections rely on proper image guidance using modalities like CT or MRI. Without proper use of these techniques, pain relief is minimal. Intra-articular corticosteroid injections are a safe and effective method of reducing SIJ pain when performed correctly.[24]

Understanding of SIJ anatomy is critical for accurate needle placement, which ensures the best outcomes in pain reduction.[24] The SI joint is a particularly difficult joint for steroid injections, which makes imaging very important. The SI joint is oriented in a multiplanar fashion, with the joint surfaces meeting together incongruently. The upper part of the joint can become fibrotic during adulthood. The lower portion is synovial. Along with the broad dorsal and interosseous ligaments that support it, these factors can make fluoroscopic guidance of the SIJ difficult. CT scan has shown to be the better imaging option because it can find the posterior joint gap. This allows physicians to find the best angle to enter the joint space.[28]

Development of advanced imaging guiding technology has significantly increased the safety and efficacy of these procedures. The SI joint has very unique anatomical landmarks. This can make it difficult to insert the needle in the joint space with imaging. Incorrect placement of steroids in SIJ injection is one of the major factors that produce inconsistent results in patients with back pain. However, when the imaging is used correctly, success rate is approximately 97%.[28]

Many physicians may not use contrast material to determine the distribution of the corticosteroids in the SIJ. Measuring the flow of the contrast agent can show if there is a flow restriction. Restrictions in flow of the therapeutic agent are another reason for poor outcomes in SIJ injection. Causes of restriction could be needle direction, trauma to the joint, mass in the joint, or narrowed joint space. Checking for flow restrictions and proper imaging tools will increase the likelihood of good pain outcomes for those receiving SIJ steroid injection.[23]

RADIOFREQUENCY ABLATION

Patients with sacroiliac pain that is refractory to initial treatment, often turn to opiates to help manage their chronic pain. This can lead to adverse side-effects in addition to addiction. Sacroiliac joint pain treatment with radiofrequency ablation (RFA) has been shown in a retrospective study to reduce opioid use in patients and provide pain and disability relief to patients.[29]

Radiofrequency ablation is a minimally invasive procedure aimed at providing relief from pain in patients with conditions such as sacroiliac joint pain. Radiofrequency signals are aimed at nociceptive nerves of interest by an insulated needle. The radiofrequency signals create heat energy which ablates the nerve.[30] For the treatment of sacroiliac joint pain, radiofrequency lesions are created at the superior lateral portions of the S2 and S3 foramina, the medial branches of the higher dorsal rami in the lumbar region, at the sacral ala, and the sacroiliac junction.[31]

Three forms of RFA currently used include: pulsed, thermal, and cooled.[30]

PULSED

Pulsed RFA works by application of short pulses of radiofrequency signals from the generator into neural tissues. Heat is generated during these pulses. Due to the pulsatile nature of pulsed RFA treatment, the average tissue temperature rise is similar to traditional RFA, however, the voltage used is much less than traditional RFA. This allows higher voltages to be applied to the electrode in pulsed RFA while preventing increased temperatures from increasing to >45°C, which would denature the nerve.[32] Dutta et. al. found significant evidence of pain relief as well as functional improvement following treatment with pulsed RFA relative to that seen following treatment with intraarticular steroid injections. These benefits were seen with no accompanying complications or side effects. However, as this was a small randomized, prospective, single-blinded study, larger randomized, controlled and multi-centered study with long-term follow-up would need to be completed in order to establish the efficacy of pulsed RFA for sacroiliac joint pain.[31]

THERMAL

Thermal RFA utilizes a bipolar technique referred to as the "palisade," where two separate electrodes are placed. They are placed along the lateral branch nerve instead of the S1-S3 dorsal ganglia. The current is then driven between the two electrodes causing a continuous thermal lesion.[33] To avoid injury to ventral nerve roots, periforaminal placement of the radiofrequency probes are completed under fluoroscopic guidance. A study showed that compared to patients given intra-articular steroids, patients treated with thermal RFA achieved similar relief of symptoms at the one month follow-up. However, at the 3 and 12 month follow up in patient groups treated with thermal RFA, 50% showed still showed clinical improvement at 3 and 12 month follow up, whereas patients treated with intraarticular steroids did not.[33]

COOLED

Cooled RFA utilizes a probe that cools tissues abutting the electrode during the ablation. This results in larger lesions to the target nerves relative to the other forms of RFA.[34] This results in an equal or superior outcome relative to conventional RFA techniques.

Studies have indicated no moderate to severe complications from the cooled RFA procedure.[35] Occasional soreness and numbness have been reported at the procedure site, with complete resolution within 2 weeks.[36,37] One study found a patient to have transient leg pain following the procedure, this was found to resolve following one week of oral steroid treatment.[38] Svetlana et. al. found that repeated treatment with cooled RFA provided longer-lasting relief of pain symptoms relative to one-time treatment. Medical costs for the patient were also found to be decreased by almost 20% by choosing repeat therapy in place of other therapies for management of pain.[39]

A metanalysis from Shih et.al. found that all three RFA techniques improved sacroiliac joint pain in patients compared to baseline pain for up to one year. Per the metanalysis, no significant differences were noted between the three techniques. Efficacy at six months of the cooled RFA was found to be better than that of thermal RFA, which was found to be better than pulsed RFA.[30]

Magnetic Resonance Imaging Guided High Intensity Focused Ultrasound (MRgHIFU) is a non-invasive ablation modality used to created thermal lesions inside the body under real-time temperature monitoring. Kaye et al. suggest that MRgHIFU may be a potential modality for treatment of SI joint dysfunction for a number of reasons. Use of MRgHIFU avoids insertion and repositioning of probes as well as allowing for continuous monitoring of the heat. This allows for continuity of the lesion during the procedure. MRgHIFU ablation of the SI joint may present a potential risk of damaging thermal exposure to adjacent sacral nerves, bone, and muscle. Vertebral nerve roots may also be damaged during the procedure. The authors of this study conclude that additional studies must be completed, however, MRgHIFU shows to be a promising treatment option for sacroiliac joint pain in the future.[40]

PLATELET RICH PLASMA, PROLOTHERAPY, AND BIOLOGICS

PLATELET RICH PLASMA

Platelet rich plasma (PRP) is made of a high concentration of autologous platelets suspended in a small amount of plasma post centrifugation. Platelet α-granules are a source of growth factors such as fibroblast growth factor (FGF), transforming growth factor beta-1 (TFG-β 1), platelet derived growth factor (PDGF), and platelet-derived angiogenesis factors (PDAF). PRP possess these growth factors in higher concentrations.[41,42] In addition, platelets are also responsible for releasing substances such as fibronectin, vitronectin, and sphingosine 1-phosphate which are all essential to wound healing.[42] PRP is injected under ultrasound guidance into the sacroiliac joint.[43]

The various growth factors in PRP stimulate angiogenesis and increased fibroblast differentiation and can accelerate overall wound healing time by two to three-fold relative to normal [42]. PRP is becoming more commonly employed to improve healing of soft tissues and to improve bone regeneration.[41,44] Adverse effects of PRP therapy include post-injection pain and stiffness and are noted to be generally mild in nature.[25]

Efficacy of PRP therapy in treatment of sacroiliac joint pain still remains uncertain. Two major prospective trials have been completed to date. Singla et al. published a RCT that compared patients treated with steroid injections to those treated with PRP for treatment of SI joint pain. They evaluated patients at 2,4, and 6 weeks as well as at 3 months assessing outcomes of pain via the visual analog score (VAS), modified Oswestry Disability Questionnaire (MODQ) scores, and short-form health survey scores (SF-12). Up till week four, both groups noted improvements in VAS, MODQ, and SF-12 scores, however, no significant difference was seen between the two groups. VAS, MODQ, and SF-12 scores were found to be significantly higher in the PRP treatment group at 6 weeks and 3 months. They found at the 3-month mark, 90% of the PRP treatment group reported being pain-free, compared to only 25% of the steroid treatment group. Limitations of this study included a small sample size of only 40 participants.[25] This study was completed at 3 months, limiting the data gathered on long-term efficacy of PRP therapy. In order to address this, Wallace et al. completed a prospective nonrandomized interventional study of 50 patients. Oswestry Disability Index (ODI) was the primary outcome measured and Numeric Rating Scale for Pain (NRS) was the secondary outcome measured. Outcomes were measured at 2 and 4 weeks as well as at 3 and 6 months. The study found a reduction in pain and improvement in disability at 6 months from treatment, however, the majority of benefit was found to occur within the first 4 weeks of treatment. The main limitation of this study was the lack of a control or placebo group. The study also lacked blinding and randomization as there was only one treatment group.[45]

Various case studies have also shown the benefits of PRP therapy. A case study by Ko et al. followed four women with sacroiliac joint pain after treatment with PRP therapy. All four women experienced significant improvement in pain at one year. All four women also reported significantly improved pain metrics as far out as four years, although the benefit was not as pronounced as it was during the first year. All four women were also able to return to pre-injury levels of activity.[46] This implies a promising treatment option for both short-term and long-term pain relief. However, at this time additional large-scale prospective studies are needed to better elucidate the efficacy of PRP to other treatment therapies.[45]

In addition to PRP, various other biologics such as mesenchymal stem cells (MSC's) have been used in the treatment of SI joint pain. According to the American Society of Interventional Pain Physicians (ASIPP) Guidelines, the literature is currently limited, and the use of biologics is limited to clinically diagnosed patients that have tried and failed conservative therapy for SI joint pain.[47]

PROLOTHERAPY

Prolotherapy is a procedure where a natural irritant is injected to induce an influx of inflammatory cells, which enlists a healing response. There are three main types of prolotherapy solutions. These include osmotic agents, irritants, and chemotactic agents. Osmotic agents include agents such as hyperosmolar dextrose and zinc sulfate. Irritants act by damaging cell membranes or cause local cells to become antigens. Chemotactic agents such as sodium morrhurate are used to induce direct chemotactic effects on inflammatory cells.[48,49]

BIOLOGICS

Biologics are another form of treatment currently being investigated for the treatment of SI joint pain. Adult stem cells also referred to as "medical signaling cells" or "mesenchymal stem cells" (MSCs) are the most studied of the biologic agents. MSC's do not possess the major histocompatibility complex Class II (MHC class II) proteins. This gives them the ability to conform to a variety of cell types while also decreasing the chance of treatment rejection. Their unique ability to conform to various cell types allows these cells to differentiate into cells that are required for the healing process.[47]

Although a small number of studies are available regarding the use of prolotherapy and biologics in the treatment of axial spine pain, additional studies with higher quality evidence are necessary to establish the benefit of these therapies.[48]

SURGICAL TECHNIQUES

The Sacroiliac Joint (SIJ) transmits flexion movements at the hips and compression forces from the upper body to the proximal and distal lower extremities, but the joint itself does not have great stability against opposing compression forces.[50] Minimally invasive sacroiliac arthrodesis is increasing in attractiveness as a treatment for chronic joint pain to help stabilize the joint.[51] The population who may be best suited for a minimally invasive arthrodesis ideally includes patients who are refractory to conservative medical management including: sacroiliac belt, NSAIDs, activity modification, radiofrequency ablation, and physical therapy, have >75% positive relief from sacroiliac steroid injection, or those with continued/recurrent SIJ pain.[10]

The difference in patient-reported outcomes between conservative management and surgical management is demonstrated in a randomized controlled trial that included 52 subjects who underwent either unilateral or bilateral minimally invasive sacroiliac arthrodesis using SI-Bone triangular titanium implants, and 51 subjects who received conservative medical management, which included physical therapy sessions for 6 months (2 subjects received additional sacroiliac corticosteroid injections and 1 subject received injections plus radiofrequency ablation).[52] The self-rated results demonstrated significant low back pain improvement at 6 months and 24 months in the surgical group compared to the conservative management group.[52]

Additionally, the surgical group found significant improvement in leg pain and a 22% decrease in opioid use at 2 years.[52] With the vast improvement in pain control and quality of life, 4 adverse events were noted because of the device implantation or surgical procedure, which included 2 cases of increased sacroiliac joint pain, 1 case of gluteal hematoma, and 1 case of nerve root impingement.[52]

MECHANISM OF ACTION

The SIJ has several ligaments (anterior sacroiliac, interosseus, sacrospinous, and sacrotuberous) and muscles (gluteus maximus, pyriformis, and biceps femoris) to help stabilize the joint.[53] SIJ instability can produce pain both locally and refer pain to the lower extremities because the posterior surface of the joint is innervated by L3 and S4 dorsal rami collaterals, and the anterior surface of the joint is supplied by the L2 and S2 nerve.[53] The SIJ usually has a small range of motion (ROM) and displacement; however, if hypermobility or deterioration of the joint occurs then compression of innervated ligaments could arise.[54]

There are two main minimally invasive surgical approaches to achieve SIJ fusion: posterior or lateral trans-iliac.[55] The posterior approach requires dissection of the gluteal fascia and the lateral approach requires dissection through the lateral gluteus muscle to the ilium.[50,55] SIJ fixation may offer pain relief by providing joint stability and decreasing rotational movement and displacement of the joint, as well as removing innervated tissue for the implant.[54,56] On the other hand, prior arthrodesis is also a cause for SIJ pain because surgical fixation at one level can cause degeneration of an adjacent region.[50]

TECHNIQUE

Similar to other surgical procedures, SIJ fixation can be performed through open or percutaneous (minimally invasive) techniques- each with its own limitations and benefits (Table 1). The open technique can be performed through an anterior or posterior approach. The anterior open approach requires an incision in the lateral rectus abdominal muscles while the psoas major muscle, iliac muscle, and femoral nerve (L2, L3, L4) are retracted to reach the peritoneum.[57] The posterior open approach requires an incision from the posterior superior iliac spine (PSIS) down to the midpoint between the PSIS and the posterior inferior iliac spine that is then continued laterally for 5 cm.[58] Additionally, an incision of the gluteus medius superficial fascia and dissection of the gluteus maximus from the posterior ileum is performed with removal of the articular cartilage from the sacral and iliac surfaces, and finally the SIJ is disarticulated.[58] The minimally invasive technique to SIJ fusion can be performed through a posterior or lateral approach. For the posterior minimally invasive approach, the first step is to make a lateral incision on the buttocks and dissect the gluteal fascia to reach the ilium.[59]

A Steinmann pin is inserted through the ilium and SI joint to reach the sacrum, lateral to the sacral foramina.[59] Next, a broach is driven across the joint to form a channel for the first implant, and a x-ray or CT guide is used to verify correct placement.[59] Ideally, 2 or 3 implants across S1 and S2 sacral spinal levels are desired.[59] Important to note, greater stability can be achieved by placing the implants further from the SIJ, and greater reduction in movement is achieved by using a longer implant at S1.[59] The lateral minimally invasive approach consists of dissection through the lateral gluteus muscle to the ilium and then insertion of the device to fix the ilium to the sacrum across the SI joint.[55] There are several different devices and companies that can be used for the minimally invasive techniques.[59]

For instance, the iFuse implant system (SI-Bone) devices consist of porous titanium plasma spray-coated triangular titanium implants, and successful joint stabilization can be achieved through the unique shape, coating, and interference fit of these implants.[59] In more detail, the interference fit allows for accurate fixation, the shape reduces implant rotation, and the porous exterior augments ingrowth of bone resulting in stronger fusion.[59] All the fusions are obtained through the bony ingrowth, therefore no grafts are needed for this system.[59] One long-term prospective study observing 103 patients who underwent minimally invasive trans-iliac approach SI-Bone implants found at 3 years, mean SIJ pain score decreased to 26.2 (a 55-point improvement from baseline, $p<0.0001$), and a mean Oswestry Disability Index (ODI) was 28.2 (a 28-point improvement from baseline, $p<0.0001$).[61] Additionally, 82% of subjects were very satisfied with the procedure at 3 years and no adverse events definitively related to the study device or procedure were reported; one subject underwent revision surgery at year 3.7.[61] Important to note, 15 subjects experienced SIJ pain contralateral to the originally treated side of whom four underwent contralateral SIJ fusion and the proportion of subjects who were employed outside the home full- or part-time at 3 years decreased somewhat from baseline ($p=0.1814$).[61]

To compare devices within the same company, one randomized control trial aimed to study patient reported outcomes after undergoing arthrodesis with either SI-Bone triangular titanium dowel implants (TDIs) versus cylindrical threaded implants (CTIs).[51] The results demonstrated significantly longer procedure length for the cylindrical threaded implants (avg of 60 min) when compared to the triangular dowel implants (avg 41.2 min).[51] Favorably, Both groups found significant improvement in all patient-reported outcomes (Visual analog scale, Oswestry disability index, and Short Form-12) at 6 months when compared to preoperative values, and there was no significant difference between CTI and TDI patient-reported outcomes at 6 months and 1 year.[51] Another company, PainTEQ, has recently launched a study to investigate the function and motion of patients who have received a bilateral SIJ fusion using the LinQ Sacroiliac Joint Fusion System.[62] PainTEQ uses a minimally invasive outpatient posterior approach that involves implanting one small bone allograft into the SIJ through a single incision on the patient's back.[63] Alternatively, CornerLoc, is a corporation that performed a case series to explore patient characteristics, operating times, recovery times, adverse events, and patient satisfaction and

Table 1. Benefits and risks of open vs. minimally invasive surgical procedure

Study type	Author (year)	Groups studied and intervention	Results and findings	Conclusions
Review article	Joukar et al. (2020)[59]	55 studies that were reviewed to understand the efficacies of open versus minimally invasive SIJ fixation	Minimally invasive techniques involve less tissue damage, blood loss, and duration of hospitalization, leading to better clinical outcomes	Despite the satisfactory data on clinical outcomes of SIJ fixation surgery, the data on biomechanics of the SIJ in general and fixation techniques, in particular, are sparse.
Multi-center, retrospective comparative cohort study	Smith et al. (2013)[60]	149 patients treated with OS and 114 treated with MIS SI joint fusion. Operative measures including surgical operating time, length of hospitalization, and estimated blood loss (EBL) were collected along with demographics and medical history, surgical complications, and 12- and 24-month pain scores. Improvements in pain were compared after matching for age and gender and controlling for a history of lumbar spine fusion using repeated measures analysis of variance.	Compared to OS patients, MIS patients were on average 10 years older (mean age 57 vs. 46) and 69% of all patients were female. MIS operative measures of EBL, operating time, and length of hospitalization were significantly lower than open surgery ($p < 0.001$). Pain relief, measured as change from baseline to 12 months in VAS pain rating, was 3.5 points lower in the MIS vs. OS group (−6.2 vs. -2.7 points, $p < 0.001$). When matched for age, gender, and a history of prior lumbar spinal fusion, postoperative pain scores were on average 3.0 points (95% CI 2.1 – 4.0) lower in MIS vs. OS (rANOVA $p < 0.001$).	In this multi-center comparative study, patients who underwent either OS or MIS SI joint fusion showed postoperative improvements in pain score. Compared to OS patients, patients who underwent MIS SI joint fusion had significantly greater pain relief and more favorable perioperative surgical measures
Review article	Martin et al. (2020)[55]	Literature review of studies with the term “sacroiliac joint fusion” that had at least 12 months of clinical follow-up, reported on minimally invasive techniques and included patient-reported outcome measures.	Compared with open fusion, minimally invasive SI joint fusion was associated with shorter operative times (70 versus 163 minutes), lower estimated blood loss (33 versus 288 mL), and lower hospital length of stay (1.3 versus 5.1 days, all comparisons $P < .0001$) Operative complications occurred in 21% and 18% of the open and minimally invasive groups. At 12 months, pain scores improved by 2.7 points in the open group and 6.2 points in the minimally invasive group. The 2-year pain scores (available in only 96 patients) showed improvement of 2 points in the open group and 5.6 points in the minimally invasive group.	Minimally invasive SI joint fusion provides clinically significant improvement in pain scores and disability in most patients, across multiple studies and implant manufacturers.

improvement of 52 cases after minimally invasive SIJ fusion using CornerLoc grafts.[64]

Only 28 of the 52 patients offered a response and 24/28 indicated functional improvement after surgery and 4/28 indicated no improvement.[64] 79% of the patients who offered a response were satisfied with their results, and there were 0 neurologic, infections, adjacent fractures, hardware complications, or hospitalizations complications reported.[64] Another 12 month retrospective patient study using CornerLoc was performed on 10 patients and found that the average pain reduction was 62.3% at 12 weeks and 79.2% at 12 months.[65] Every patient displayed improved posture and gait at follow-up, and the overall satisfaction with the procedure was 4.95/5.[65] Further results of these 10 patients include: 7 patients (70%) showed marked improvement in overall daily activity level, 1 patient (10%) show moderate improvement, and 2 patients (20%) showed limited to no increase in activity level due to other health factors unrelated to the procedure.[65]

To compare companies directly, Less Exposure Surgery Society performed a comparison study of mechanical pull-out strength of SacroFuse (Sacrix LLC) Gen II threaded implant versus SI-Bone iFuse triangular implants for SIJ fixation.[66] Pull-out strength is a critical element for screw fixation stability.[66] The pullout strength for SacroFuse Gen II implant was greater than the SI-Bone iFuse implant by 614.76 Newtons (p<.05), and the SacroFuse implant also showed a 400% increase in axial performance compared to iFuse.[66]

EFFICACY

In a retrospective study with up to a 6 year follow-up reports, patients treated with continued conservative management had no long-term improvement in pain (mean worsening of 1 point) or disability (mean Oswestry Disability Index worsened by 4-6 points), increased their use of opioids, and had poor long-term work status.[67] Minimally invasive techniques involve less tissue damage, blood loss, and duration of hospitalization leading to better clinical outcomes while open surgical fusion require longer operative time, blood loss, and procedure time.[59,60] One study aimed to narrow down these facts and discovered that compared with open fusion, minimally invasive SI joint fusion was associated with shorter operative times (70 versus 163 minutes), lower estimated blood loss (33 versus 288 mL), and lower hospital length of stay (1.3 versus 5.1 days, all comparisons $P < .0001$).[55]

In direct correlation to these details, the operative complications occurred in 21% and 18% of the open and minimally invasive groups.[55] At 12 months, pain scores improved by 2.7 points in the open group and 6.2 points in the minimally invasive group and the 2-year pain scores (available in only 96 patients) showed improvement of 2 points in the open group and 5.6 points in the minimally invasive group.[55] Another study directly compared minimally invasive surgery (MIS) joint fusion with triangular titanium implants to open surgery (OS) using SI joint fusion.[60] MIS operating time and length of hospitalization were significantly lower than open surgery (p < 0.001).[60] Pain relief, measured as change from baseline to 12 months in visual analog scale pain rating, was 3.5 points lower in the MIS vs. OS group (−6.2 vs. -2.7 points, p < 0.001).[60] When matched for age, gender, and a history of prior lumbar spinal fusion, postoperative pain scores were on average 3.0 points (95% CI 2.1 – 4.0) lower in MIS vs. OS (rANOVA p < 0.001).[60] The reoperation rate after open surgery ranged from 0% to 65% (mean 15%) and the reoperation rate after MIS ranged from 0% to 17% (mean 6%).[68]

ADVERSE EFFECTS

Adverse outcomes encountered after MIS include new-onset facet joint pain, trochanteric bursitis, deep wound infections, new onset of low-back or leg pain, and superficial cellulitis.[68] Other complications faced involved radiculopathy, vascular necrosis of the hip, piriformis syndrome, implant penetration into the sacral neural foramen, peripheral neuropathy, a nondisplaced fracture, and pulmonary emboli/deep vein thrombosis.[68] Fourteen studies of 720 patients (499 females/221 males) with a mean follow-up of 22 months reported ninety-nine patients (13.75%) underwent bilateral SI joint arthrodesis resulting in a total of 819 SI joints fused.[69] There were 91 reported procedural-related complications (11.11%) with the most common adverse event being surgical wound infection/drainage (n = 17) .[69] Twenty-five adverse events were attributed to placement of the implant (3.05%) with nerve root impingement (n = 13) being the most common and the revision rate was 2.56%.[69]

LIMITATIONS

The patient needing to be a suitable surgical candidate is the first limitation that is encountered in order to receive the minimally invasive SIJ fixation procedure. Surgical risk is a complex term that comprises disease-related factors, patient-related factors (anatomical variances, past surgical history, comorbidities, smoking status, and lifestyle), surgery-related factors, and system-related factors (quality of preoperative and postoperative care, follow-up care and compliance, and lifestyle modification).[70] An important question to also consider is if the SIJ is the true pain generator, or if it is pain secondary to another cause because the pain may not be irradicated if the pain generator was not correctly identified.[68] It is also imperative to identify the bone quality and density in order to determine if the implant will have successful stability achieved, and to consider that many patients may have had previous low-back surgery or underwent surgery during their follow-up period.[59,68]

Another limitation is there are unanswered questions regarding the effects of different implant devices and how their shapes impact structure, function, and motion of the SIJ as well as long-term patient outcomes.[59] For example, a review article reports a study that found an increased range of motion (ROM) when using one or two implanted devices compared to three implants for the iFuse System devices; however, the article also cited a study that found no significant difference in movement and translation when comparing the number of implants for RIALTO devices.[54,71] The same review article additionally reports conflicting evidence by citing a study that showed no significant difference in ROM for flexion-extension and axial rotations, but significant reduction measured in lateral bending for the Integrity-SI system devices and compared this with a study that found significant reduction in the ROM in all three directions.[54,72]

CONCLUSION

Sacroiliac joint pain is a considerable contributor to the common affliction of persistent lower back pain that diminishes the quality of life for patients by limiting daily activity and work capacity. Though conservative management through multi-modal pain control and physical therapy have their role as first line therapies, an increasing body of evidence supports the use of minimally invasive procedures, both as adjuvant treatments to conservative management and as second line therapies for patient's that fail first line treatment. Given the novelty of minimally invasive procedures in the SI joint pain space, there is a need for more clinical studies and comprehensive reviews to further elucidate their role in treatment pathways.

REFERENCES

1. Cohen SP. Sacroiliac joint pain: A comprehensive review of anatomy, diagnosis and treatment. *Anesth Analg*. Published online 2005. doi:10.1213/01.ANE.0000180831.60169.EA

2. Kok HK, Mumtaz A, O'Brien C, Kane D, Torreggiani WC, Delaney H. Imaging the Patient with Sacroiliac Pain. *Can Assoc Radiol J*. Published online 2016. doi:10.1016/j.carj.2015.08.001

3. Slipman CW, Whyte WS, Chow DW, Chou L, Lenrow D, Ellen M. Sacroiliac joint syndrome. *Pain Physician*. Published online 2001. doi:10.1016/b978-0-323-08340-9.00063-3

4. Fortin JD. Sacroiliac joint dysfunction: A new perspective. *J Back Musculoskelet Rehabil*. Published online 1993. doi:10.3233/BMR-1993-3308

5. Szadek KM, Hoogland PVJM, Zuurmond WWA, De Lange JJ, Perez RSGM. Possible nociceptive structures in the sacroiliac joint cartilage: An immunohistochemical study. *Clin Anat*. Published online 2010. doi:10.1002/ca.20908

6. Chou LH, Slipman CW, Bhagia SM, et al. Inciting events initiating injection-proven sacroiliac joint syndrome. *Pain Med*. Published online 2004. doi:10.1111/j.1526-4637.2004.04009.x

7. Rubin DI. Epidemiology and Risk Factors for Spine Pain. *Neurol Clin*. Published online 2007. doi:10.1016/j.ncl.2007.01.004

8. Le Huec JC, Tsoupras A, Leglise A, Heraudet P, Celarier G, Sturresson B. The sacro-iliac joint: A potentially painful enigma. Update on the diagnosis and treatment of pain from micro-trauma. *Orthop Traumatol Surg Res*. Published online 2019. doi:10.1016/j.otsr.2018.05.019

9. Wise CL, Dall BE. Minimally invasive sacroiliac arthrodesis: Outcomes of a new technique. *J Spinal Disord Tech*. Published online 2008. doi:10.1097/BSD.0b013e31815ecc4b

10. Schmidt GL, Bhandutia AK, Altman DT. Management of sacroiliac joint pain. *J Am Acad Orthop Surg*. 2018;26(17):610-616. doi:10.5435/JAAOS-D-15-00063

11. Casiano VE, Dydyk AM, Varacallo M. *Back Pain*. StatPearls Publishing; 2020.

12. Institute for Quality and Efficiency in Health Care. *Systematic Guideline Search and Appraisal, as Well as Extraction of Relevant Recommendations, for a DMP "Chronic Back Pain" [Internet].* Institute for Quality and Efficiency in Health Care (IQWiG); 2015.

13. Stein C. Opioid Receptors. doi:10.1146/annurev-med-062613-093100

14. Schilling LS, Markman JD. Corticosteroids for Pain of Spinal Origin. Epidural and Intraarticular Administration. *Rheum Dis Clin North Am*. 2016;42(1):137-155. doi:10.1016/j.rdc.2015.08.003

15. Dengler J, Sturesson B, Kools D, et al. Risk Factors for Continued Opioid Use in Conservative Versus Surgical Management of Low Back Pain Originating From the Sacroiliac Joint. *Glob Spine J*. 2018;8(5):453-459. doi:10.1177/2192568217733707

16. Shokri E, Kamali F, Sinaei E, Ghafarinejad F. Spinal manipulation in the treatment of patients with MRI-confirmed lumbar disc herniation and sacroiliac joint hypomobility: A quasi-experimental study. *Chiropr Man Ther*. 2018;26(1). doi:10.1186/s12998-018-0185-z

17. Nejati P, Safarcherati A, Karimi F. Effectiveness of Exercise Therapy and Manipulation on Sacroiliac Joint Dysfunction: A Randomized Controlled Trial.

18. Zamanlou M, Akbari M, Jamshidi AA, Amiri A, Nabiyouni I. Manipulation Effect on Lumbar Kinematics in Patients with Unilateral Innominate Rotation and Comparison with Asymptomatic Subjects. *J Biomed Phys Eng*. 2018;9(3). doi:10.31661/jbpe.v0i0.760

19. Added MAN, de Freitas DG, Kasawara KT, Martin RL, Fukuda TY. Strengthening the Gluteus Maximus in Subjects with Sacroiliac Dysfunction. *Int J Sports Phys Ther*. 2018;13(1):114-120. doi:10.26603/ijspt20180114

20. Kamali F, Zamanlou M, Ghanbari A, Alipour A, Bervis S. Comparison of manipulation and stabilization exercises in patients with sacroiliac joint dysfunction patients: A randomized clinical trial. *J Bodyw Mov Ther*. 2019;23(1):177-182. doi:10.1016/j.jbmt.2018.01.014

21. Frogner BK, Harwood K, Holly C, Andrilla A, Schwartz M, Pines JM. Physical Therapy as the First Point of Care to Treat Low Back Pain: An Instrumental Variables Approach to Estimate Impact on Opioid Prescription, Health Care Utilization, and Costs Health Services Research. doi:10.1111/1475-6773.12984

22. De Luigi AJ, Saini V, Mathur R, Saini A, Yokel N. Assessing the Accuracy of Ultrasound-Guided Needle Placement in Sacroiliac Joint Injections. *Am J Phys Med Rehabil*. 2019;98(8):666-670. doi:10.1097/PHM.0000000000001167

23. Scholten PM, Patel SI, Christos PJ, Singh JR. Short-Term Efficacy of Sacroiliac Joint Corticosteroid Injection Based on Arthrographic Contrast Patterns. *PM R*. 2015;7(4):385-391. doi:10.1016/j.pmrj.2014.10.007

24. Althoff CE, Bollow M, Feist E, et al. CT-guided corticosteroid injection of the sacroiliac joints: quality assurance and standardized prospective evaluation of long-term effectiveness over six months. *Clin Rheumatol*. 2015;34(6):1079-1084. doi:10.1007/s10067-015-2937-7

25. Singla V, Batra YK, Bharti N, Goni VG, Marwaha N. Steroid vs. Platelet-Rich Plasma in Ultrasound-Guided Sacroiliac Joint Injection for Chronic Low Back Pain. *Pain Pract*. 2017;17(6):782-791. doi:10.1111/papr.12526

26. Savran Sahin B, Aktas E, Haberal B, et al. Sacroiliac pain and CT-guided steroid injection treatment: high-grade arthritis has an adverse effect on outcomes in long-term follow-up.

27. Schneider BJ, Huynh L, Levin J, Rinkaekan P, Kordi R, Kennedy DJ. Does immediate pain relief after an injection into the sacroiliac joint with anesthetic and corticosteroid predict subsequent pain relief? *Pain Med (United States)*. 2018;19(2):244-251. doi:10.1093/pm/pnx104

28. Wang D. Image Guidance Technologies for Interventional Pain Procedures: Ultrasound, Fluoroscopy, and CT. *Curr Pain Headache Rep*. 2018;22(1). doi:10.1007/s11916-018-0660-1

29. Tinnirello A. Reduction of opioid intake after cooled radiofrequency denervation for sacroiliac joint pain: a retrospective evaluation up to 1 year. *Korean J Pain*. 2020;33(2):183-191. doi:10.3344/kjp.2020.33.2.183

30. Shih CL, Shen PC, Lu CC, et al. A comparison of efficacy among different radiofrequency ablation techniques for the treatment of lumbar facet joint and sacroiliac joint pain: A systematic review and meta-analysis. *Clin Neurol Neurosurg*. 2020;195:105854. doi:10.1016/j.clineuro.2020.105854

31. Dutta KM, Dey SM, Bhattacharyya PM, Agarwal Sharat M, Dev PM. Comparison of Efficacy of Lateral Branch Pulsed Radiofrequency Denervation and Intraarticular Depot Methylprednisolone Injection for Sacroiliac Joint Pain. *Pain Physician J*. Published online 2018:489-496.

32. Chua NHL, Vissers KC, Sluijter ME. Pulsed radiofrequency treatment in interventional pain management: Mechanisms and potential indications - A review. *Acta Neurochir (Wien)*. 2011;153(4):763-771. doi:10.1007/s00701-010-0881-5

33. Cánovas Martínez L, Orduña Valls J, Paramés Mosquera E, Lamelas Rodríguez L, Rojas Gil S, Domínguez García M. Sacroiliac joint pain: Prospective, randomised, experimental and comparative study of thermal radiofrequency with sacroiliac joint block. *Rev Española Anestesiol y Reanim (English Ed)*. 2016;63(5):267-272. doi:10.1016/j.redare.2015.12.001

34. Kapural L, Nageeb F, Kapural M, Cata JP, Narouze S, Mekhail N. Cooled radiofrequency system for the treatment of chronic pain from sacroiliitis: The first case-series. *Pain Pract*. 2008;8(5):348-354. doi:10.1111/j.1533-2500.2008.00231.x

35. Sun HH, Zhuang SY, Hong X, Xie XH, Zhu L, Wu XT. The efficacy and safety of using cooled radiofrequency in treating chronic sacroiliac joint pain: A PRISMA-compliant meta-analysis. *Med (United States)*. 2018;97(6). doi:10.1097/MD.0000000000009809

36. Ho KY, Hadi MA, Pasutharnchat K, Tan K. Cooled radiofrequency denervation for treatment of sacroiliac joint pain: two-year results from 20 cases. *J Pain Res*. 2013;6:505. doi:10.2147/jpr.s46827

37. Patel N. Twelve-Month Follow-Up of a Randomized Trial Assessing Cooled Radiofrequency Denervation as a Treatment for Sacroiliac Region Pain. *Pain Pract*. 2016;16(2):154-167. doi:10.1111/papr.12269

38. Tinnirello A, Barbieri S, Todeschini M, Marchesini M. Conventional (simplicity III) and cooled (SInergy) radiofrequency for sacroiliac joint denervation: One-year retrospective study comparing two devices. *Pain Med (United States)*. 2017;18(9):1731-1744. doi:10.1093/pm/pnw333

39. Kurklinsky S, Boone MK, Candler SA, Schwab A, Ghazi S. Repeat Cooled Radiofrequency Ablation Is Beneficial for Chronic Posterior Sacroiliac Joint Pain. *Pain Med*. 2020;21(8):1532-1537. doi:10.1093/pm/pnz295

40. Kaye EA, Maybody M, Monette S, Solomon SB, Gulati A. Ablation of the sacroiliac joint using MR-guided high intensity focused ultrasound: A preliminary experiment in a swine model. *J Ther Ultrasound*. 2017;5(1). doi:10.1186/s40349-017-0095-x

41. Urits I, Viswanath O, Galasso AC, et al. Platelet-Rich Plasma for the Treatment of Low Back Pain: a Comprehensive Review. *Curr Pain Headache Rep*. 2019;23(7):1-11. doi:10.1007/s11916-019-0797-6

42. Wang HL, Avila G. Platelet rich plasma: myth or reality? *Eur J Dent*. 2007;1(4):192-194.

43. Broadhead DY, Douglas HE, Bezjian Wallace LM, et al. Use of Ultrasound-Guided Platelet-Rich Plasma Injection of the Sacroiliac Joint as a Treatment for Chronic Low Back Pain. *Mil Med*. 2020;185(7-8):e1312-e1317. doi:10.1093/milmed/usz398

44. Dhillon M, Behera P, Patel S, Shetty V. Orthobiologics and platelet rich plasma. *Indian J Orthop*. 2014;48(1):1-9. doi:10.4103/0019-5413.125477

45. Wallace P, Bezjian Wallace L, Tamura S, Prochnio K, Morgan K, Hemler D. Effectiveness of Ultrasound-Guided Platelet-Rich Plasma Injections in Relieving Sacroiliac Joint Dysfunction. *Am J Phys Med Rehabil*. 2020;99(8):689-693. doi:10.1097/PHM.0000000000001389

46. Ko GD, Mindra S, Lawson GE, Whitmore S, Arseneau L. Case series of ultrasound-guided platelet-rich plasma injections for sacroiliac joint dysfunction. *J Back Musculoskelet Rehabil*. 2017;30(2):363-370. doi:10.3233/BMR-160734

47. Navani A, Manchikanti L, Albers SL, et al. Responsible, Safe, and Effective Use of Biologics in the Management of Low Back Pain: American Society of Interventional Pain Physicians (ASIPP) Guidelines.

48. Desai MJ, Mansfield JT, Robinson DM, Miller BC, Borg-Stein J. Regenerative Medicine for Axial and Radicular Spine-Related Pain: A Narrative Review. *Pain Pract*. 2020;20(4):437-453. doi:10.1111/papr.12868

49. DeChellis DM, Cortazzo MH. Regenerative medicine in the field of pain medicine: Prolotherapy, platelet-rich plasma therapy, and stem cell therapy-Theory and evidence. *Tech Reg Anesth Pain Manag*. 2011;15(2):74-80. doi:10.1053/j.trap.2011.05.002

50. Kiapour A, Joukar A, Elgafy H, Erbulut DU, Agarwal AK, Goel VK. Biomechanics of the sacroiliac joint: Anatomy, function, biomechanics, sexual dimorphism, and causes of pain. *Int J Spine Surg*. 2020;14(Suppl 1):S3-S13. doi:10.14444/6077

51. Claus CF, Lytle E, Kaufmann A, et al. Minimally Invasive Sacroiliac Joint Fusion Using Triangular Titanium versus Cylindrical Threaded Implants: A Comparison of Patient-Reported Outcomes. *World Neurosurg*. 2020;133:e745-e750. doi:10.1016/j.wneu.2019.09.150

52. Dengler J, Kools D, Pflugmacher R, et al. Randomized Trial of Sacroiliac Joint Arthrodesis Compared with Conservative Management for Chronic Low Back Pain Attributed to the Sacroiliac Joint. *J Bone Jt Surg- Am Vol*. 2019;101(5):400-411. doi:10.2106/JBJS.18.00022

53. Manfré L. Percutaneous sacroiliac joint fixation in sacroiliac instability: The first case report using a fully CT-guided technique. *Interv Neuroradiol*. 2014;20(5):621-625. doi:10.15274/INR-2014-10049

54. Casaroli G, Bassani T, Brayda-Bruno M, Luca A, Galbusera F. What do we know about the biomechanics of the sacroiliac joint and of sacropelvic fixation? A literature review. *Med Eng Phys*. 2020;76:1-12. doi:10.1016/j.medengphy.2019.10.009

55. Martin CT, Haase L, Lender PA, Jr DWP. Minimally Invasive Sacroiliac Joint Fusion: The Current Evidence. *Int J Spine Surg*. 14:20-29. doi:10.14444/6072

56. Bruna-Rosso C, Arnoux PJ, Bianco RJ, Godio-Raboutet Y, Fradet L, Aubin CÉ. Finite element analysis of Sacroiliac joint fixation under compression loads. *Int J Spine Surg*. 2015;10. doi:10.14444/3016

57. Murakami E, Kurosawa D, Aizawa T. Sacroiliac joint arthrodesis for chronic sacroiliac joint pain: An anterior approach and clinical outcomes with a minimum 5-year follow-up. *J Neurosurg Spine*. 2018;29(3):279-285. doi:10.3171/2018.1.SPINE17115

58. Ebraheim NA, Lu J, Biyani A, Yeasting RA. Anatomic considerations for posterior approach to the sacroiliac joint. *Spine*. 1996;21(23):2709-2712. doi:10.1097/00007632-199612010-00002

59. Joukar A, Kiapour A, Elgafy H, Erbulut DU, Agarwal AK, Goel VK. Biomechanics of the Sacroiliac Joint: Surgical Treatments. *Int J Spine Surg*. 2020;14(3):355-367. doi:10.14444/7047

60. Smith AG, Capobianco R, Cher D, et al. Open versus minimally invasive sacroiliac joint fusion: a multi-center comparison of perioperative measures and clinical outcomes. *Ann Surg Innov Res*. 2013;7. doi:10.1186/1750-1164-7-14

61. Darr E, Meyer SC, Whang PG, et al. Long-term prospective outcomes after minimally invasive trans-iliac sacroiliac joint fusion using triangular titanium implants. *Med Devices Evid Res*. 2018;11:113-121. doi:10.2147/MDER.S160989

62. PainTEQ Begins Novel Biomechanical Study on SI Joint Fusion.

63. PainTEQ LinQ[TM] System: An Effective Treatment for SI Joint Pain.

64. CornerLoc[TM] Case Series Released at NY&NJSIPP - CornerLoc.

65. 12 Month Retrospective Patient Study Presented at ASPN Meeting - CornerLoc.

66. Chin KR, Pencle F, Seale J. Pull-out performance of SacroFuse Sacroiliac Joint Fusion Implant vs. SI-Bone Triangular Trans-Articular Peg.

67. Vanaclocha V, Herrera JM, Sáiz-Sapena N, Rivera-Paz M, Verdú-López F. Minimally invasive sacroiliac joint fusion, radiofrequency denervation, and conservative management for sacroiliac joint pain: 6-Year comparative case series. *Neurosurgery*. 2018;82(1):48-55. doi:10.1093/neuros/nyx185

68. Zaidi HA, Montoure AJ, Dickman CA. Surgical and clinical efficacy of sacroiliac joint fusion: A systematic review of the literature. *J Neurosurg Spine*. 2015;23(1):59-66. doi:10.3171/2014.10.SPINE14516

69. Shamrock AG, Patel A, Alam M, Shamrock KH, Al Maaieh M. The Safety Profile of Percutaneous Minimally Invasive Sacroiliac Joint Fusion. *Glob Spine J*. 2019;9(8):874-880. doi:10.1177/2192568218816981

70. Shaydakov ME, Tuma F. Operative Risk. In: StatPearls Publishing; 2018.

71. Soriano-Baron H, Lindsey DP, Rodriguez-Martinez N, et al. The Effect of Implant Placement on Sacroiliac Joint Range of Motion. *Spine*. 2015;40(9):E525-E530. doi:10.1097/BRS.0000000000000839

72. Cross WW, Berven SH, Slater N, Lehrman JN, Newcomb AGUS, Kelly BP. In vitro biomechanical evaluation of a novel, minimally invasive, sacroiliac joint fixation device. *Int J Spine Surg*. 2018;12(5):603-610. doi:10.14444/5072