Acta Neurochirurgica (2024) 166:43
https://doi.org/10.1007/s00701-024-05918-1

REVIEW ARTICLE

A systematic review and update on diagnosis and treatment of new onset sacroiliac joint dysfunction after lumbar fusion

Helen Karimi[1] · Rahul Rodrigues[1] · Shrey Patel[1] · Jainith Patel[1] · Jacob Kosarchuk[1] · James Kryzanski[1]

Received: 27 August 2023 / Accepted: 20 November 2023

Abstract

Background Sacroiliac joint dysfunction (SIJD) after lumbar/lumbosacral fusion has become increasingly recognized as the utilization of lumbar fusion has grown. Despite the significant morbidity associated with this condition, uncertainty regarding its diagnosis and treatment remains. We aim to update the current knowledge of the etiology, diagnosis, and treatment of post-lumbar surgery SIJD.

Methods PRISMA guidelines were used to search the PubMed/Medline, Web of Science, Cochrane Reviews, Embase, and OVID databases for literature published in the last 10 years. The ROBIS tool was utilized for risk of bias assessment. Statistical analyses were performed using the R foundation. A Fisher's exact test was performed to determine the risk of SIJD based on operative technique, gender, and symptom onset timeline. Odds ratios were reported with 95% confidence intervals. A p-value ≤ 0.05 was considered statistically significant.

Results Seventeen publications were included. The incidence of new onset SIJD was 7.0%. The mean age was 56 years, and the follow-up length was 30 months. SIJD was more common with fixed lumbar fusion vs floating fusion ($OR = 1.48$ [0.92, 2.37], $p = 0.083$), fusion of ≥ 3 segments ($p < 0.05$), and male gender increased incidence of SIJD ($OR = 1.93$ [1.27, 2.98], $p = 0.001$). Intra-articular injection decreased the Visual Analogue Scale (VAS) score by 75%, while radiofrequency ablation (RFA) reduced the score by 90%. An open approach resulted in a 13% reduction in VAS score versus 68 and 29% for SIJ fixation using the iFuse and DIANA approaches, respectively.

Conclusions Lumbar fusion predisposes patients to SIJD, likely through manipulation of the SIJ's biomechanics. Definitive diagnosis of SIJD remains multifaceted and a newer modality such as SPECT/CT may find a future role. When conservative measures are ineffective, RFA and SIJ fixation using the iFuse System yield the greatest improvement VAS and ODI.

Keywords Sacroiliac joint dysfunction · Spinopelvic parameters · Lumbar fusion · Low back pain · SI joint fusion

Abbreviations

SIJ	Sacroiliac joint pain
SIJD	Sacroiliac joint dysfunction
SIJP	Sacroiliac joint pain
VAS	Visual Analogue Scale
ODI	Oswestry Disability Index
SPECT/CT	Single-photon emission computerized tomography
MIS	Minimally invasive
RFA	Radiofrequency ablation
LBP	Low back pain
PT	Pelvic tilt
LL	Lumbar lordosis
SS	Sacral slope
PI	Pelvic incidence

✉ Helen Karimi
helen.karimi@tufts.edu

1 Department of Neurosurgery, Tufts Medical Center, Tufts University School of Medicine, 800 Washington St, Boston, MA 02111, USA

Introduction

Low back pain (LBP) has a lifetime prevalence of 65–80% in adults living in the USA and is a leading cause of disability and lost workdays [10, 39]. Thirty percent of patients with LBP endorse pain originating from the sacroiliac joint (SIJ) [4]. The SIJ is a diarthrodial synovial joint formed by articulations between the ilium and sacrum that reduces the force load exerted by the torso on the lower body [14].

SIJ pain resulting from abnormal motion of the joint is known as SIJ dysfunction (SIJD) and is endorsed by 12%

of patients with new-onset LBP and history of successful lumbar spine fusion [23]. Identifying the source of pain after lumbar fusion is difficult, as pain may relate to pathology of the vertebral column, intervertebral discs, adjacent soft tissue, facet joints, or the SIJ [21]. Given the rise in these procedures over the last two decades, clinicians should expect to increasingly encounter new-onset post-operative SIJD [12, 44]. Accurate diagnosis of the cause of pain not only guides recommended treatment options but is necessary to optimize treatment outcomes. Despite its high prevalence, SIJD is likely underdiagnosed in the outpatient setting and is also resource-intensive, costing the healthcare system an excess of ~ $3000 per patient.

A dedicated review of this topic is warranted as the clinicopathologic features of de novo SIJD and post-operative SIJD differ. SIJD literature is predominantly recent, with most written over the past 10–12 years and lacks primary focus on new onset SIJD related to lumbar surgery. Therefore, the aim of this study is to provide a synthesized and comprehensive update on our understanding of the etiology, pathogenesis, diagnosis, and treatment of post-lumbar fusion SIJD.

Methods

A systematic review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines and structured according to the broad PECO framework [28]: Population: patients who experience SIJD; Exposure: lumbar/lumbosacral surgery; Comparison: consensus based on literature published before 2013; Outcome: improvement in Visual Analog Scale (VAS) and Oswestry Disability Index (ODI) scores.

The following terms were utilized to search the MEDLINE (PubMed and Ovid), EMBASE, Cochrane Library, and Web of Science databases, starting from study conception to February 10, 2023. ("sacroiliac joint" OR "sacroiliac" OR "sacroiliitis" OR "sacroiliac joint dysfunction" OR "SIJ" OR "SIJ dysfunction" OR "SIJD" OR "SI") AND ("low back pain" OR "lumbago" OR "SI joint pain" OR "SIJ pain" OR "sacroiliac pain" OR "lumbar pain" OR "failed back surgery syndrome") AND ("surgical procedures, operative" OR "spinal fusion" OR "lumbar spine surgery" OR "postoperative" OR "post-operative" OR "lumbar fixation" OR "lumbosacral fixation" OR "lumbosacral fusion" OR "laminectomy" OR "discectomy" OR "vertebroplasty" OR "spinal decompression" OR "spinal fixation" OR "spinal arthrodesis" OR "sacroiliac fixation" OR "SIJ fixation").

Literature selection

Studies were uploaded to the Rayyan systematic review interface [27] A de-duplication tool was utilized; studies with exact match title and authors were removed and potential duplicates were reviewed by H. K. The remaining studies were independently reviewed by H. K and R. R; discrepancies were resolved by S. P.

Studies were eligible if they were conducted with human participants, available in English, full-text, and published in 2013 to present. Clinical trials, cross-sectional, longitudinal, observational, cohort, case–control studies, and relevant literature reviews were included. Studies assessing treatment options were included if they improved VAS and ODI scores, suggesting clinical efficacy.

Case reports, cadaveric and animal studies, unpublished manuscripts, abstracts, book chapters, and editorial letters were excluded. Studies were ineligible if participants had diagnoses of ankylosing spondylitis, spondylolisthesis, SIJ infection, pelvic ring fracture, spine malignancy, scoliosis, kyphosis, or Bertolotti's syndrome. Studies with participants experiencing back pain not originating from the SIJ or those without prior lumbar/lumbosacral surgery were excluded.

Data analysis and risk of bias analysis

The following were extracted from each study: publication details, sample size, participant age and gender, operative technique, follow-up length, and spinopelvic parameters [5, 8, 11, 13, 18, 25, 26, 31, 33–36, 43]. Outcomes were incidence and time to onset of SIJD based on the pre-operative diagnosis, number of fused lumbar segments, and fusion to the sacrum. The percent change in VAS or ODI score relative to baseline was calculated. When raw data was available, a Fisher's exact test was performed to compare the risk of SIJD based on operative technique, gender, and time to symptom onset. Odds ratios were calculated and reported with 95% confidence intervals. All statistical analyses were performed using R (*The R Foundation, v 4.1.3, Vienna, Austria)*. A p-value ≤ 0.05 was considered statistically significant. Data was graphically represented using MATLAB. The diagnosis and management flowchart illustrated in Fig. 6 was created using the findings of the included studies and consensus reported in literature.

The risk of bias assessment was conducted using the ROBIS tool and is available upon request [42]. Two potential areas of bias were identified in the second phase of assessment and are addressed in the limitations section of the review.

Results

As illustrated in Fig. 1, the search captured 1040 relevant articles; 361 duplicates were excluded; and the remaining 689 were screened by abstract and title. Eighty-three were included for full-text review and 17 met inclusion criteria. One systematic review was included for background information but not data analysis [9]. The incidence of new-onset SIJP in patients with history of lumbar/lumbosacral fusion was 7.0% (303 of 4329 patients) [7, 8, 15, 18, 23, 26, 37, 38]. This has previously been reported in one retrospective analysis, which had an incidence of 12% from a sample size of 38 patients that had lumbar fusion [23]. The mean follow-up time in the included studies was 30 months, and the mean age was 56 years. The data extracted from easy study is shown in Table 1.

Risk factors

A pre-operative diagnosis of lumbar stenosis resulted in higher incidence rate of SIJD (17%) when compared to lumbar disc herniation (8.8%) and lumbar structural defects/instability (14%) [15, 37]. The incidence of SIJD increases with number of fused segments and is greatest in patients with ≥ 3 fused segments ($p < 0.05$). The incidence of SIJD when stratified by number of fused segments was: 11% with one segment, 19% with two segments, 27% with three segments, and 26% with ≥ 4 segments (Fig. 2) [15, 18, 23, 26, 37, 38]. The average incidence increased with fixed fusion (extended to the sacrum, 18%) when compared to floating (lumbar only, 12%). (Fig. 3) [23, 36–38]. Patients who receive fixed fusion are at increased odds of developing SIJD than those who receive a floating fusion ($OR = 1.48$ [0.92, 2.37], $p = 0.083$). Fixed fusion

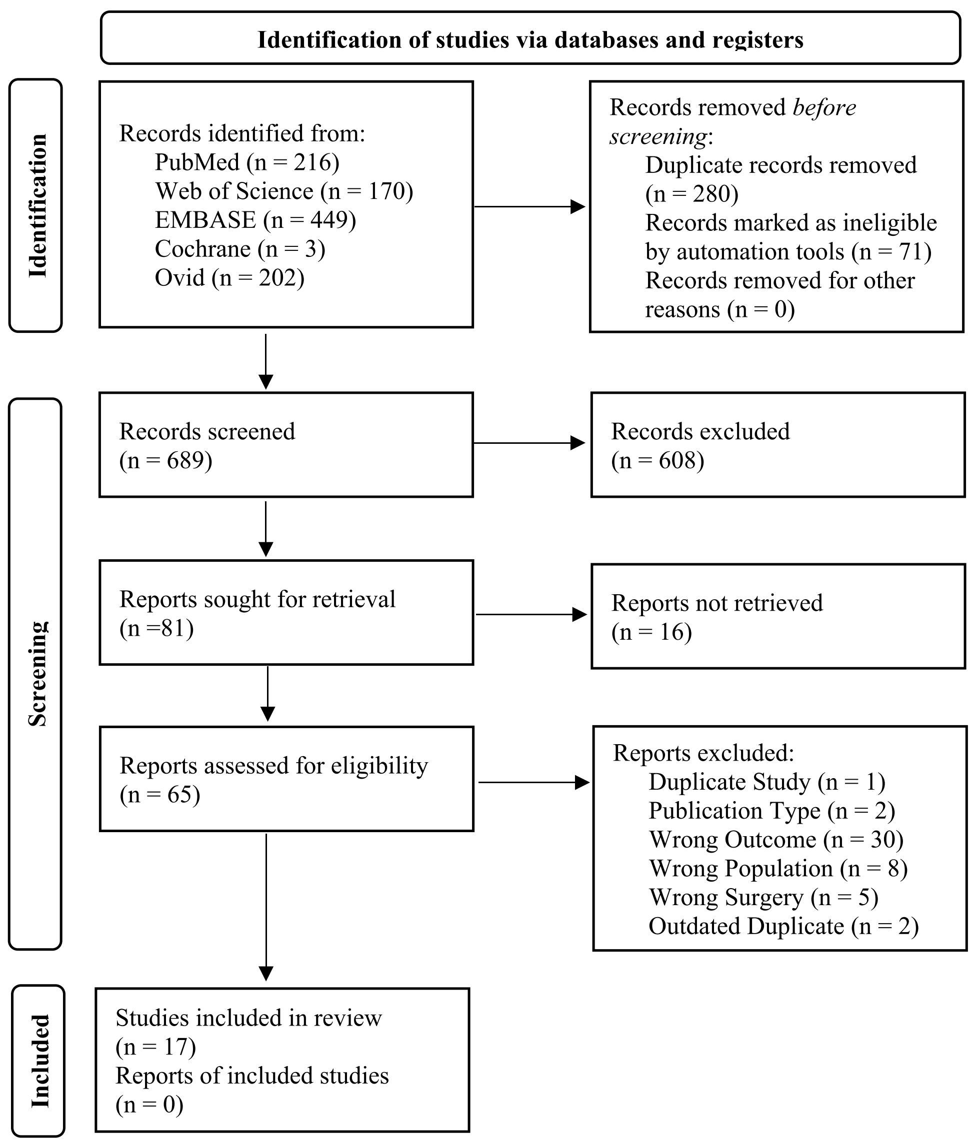

Fig. 1 The PRISMA flowchart outlining the literature search process that was carried out. Figure includes which databases records were identified from, how many records were excluded at each point in the process, and how many studies were included in the review. PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-analyses

Table 1 Characteristics of included studies reporting on the epidemiology and pathogenesis of sacroiliac joint pain after lumbar spine surgery

Study ID (author, year)	Study design	Study aim	Participants (*n*)	Avg. age (years)	Female (%)	Avg. follow-up (months)	Outcomes
Kalidindi et al. (2021)	Retrospective case control	Explore the association between new-onset SI joint pain following TLIF for degenerative spine disorders and changes in spinopelvic parameters	Total (354) Group A (34) Group B (320)	63.2	40.4	At least 6	**Post-operative lumbar lordosis** *Group A* (50.73 ± 11.47); *Group B* (65.86 ± 7.59), *p*-value < 0.001 **Apex migration** *Group A* (30 cephalad, 4 caudal); *Group B* (272 no migration, 4 cephalad, 44 caudal), *p*-value < 0.001 **Post-operative pelvic tilt** *Group A* (24.93 ± 9.02), *Group B* (19.49 ± 6.65), *p*-value < 0.001 **Incidence of SIJP:** 10.6%
Unoki et al. (2016)	Retrospective cohort	To determine the risk factors for sacroiliac joint pain after lumbar or lumbosacral fusion. Specifically, the effect of fusion of multiple segments on the incidence of SIJP after fusion	Total (300) Included (262) Lost to F/U (38)	66.7	61.8	48.5	**Incidence of SIJP (# of fused segments)** *One segment:* 8/137, 5.8% *Two segments:* 6/60, 10.0% *Three segments:* 5/25, 20.0% > *Four segments:* 9/40, 22.5% **Incidence of SIJP (fusion type)** *Fixed:* 8/61, 13.1% *Floating:* 20/201, 10.0%

Table 1 (continued)

Study ID (author, year)	Study design	Study aim	Participants (*n*)	Avg. age (years)	Female (%)	Avg. follow-up (months)	Outcomes
Unoki et al. (2017)	Retrospective cohort	To examine whether SIJP could occur more frequently in patients with two risk factors (multiple-segment fusion to sacrum). SIJP after multiple-segment lumbar fusion was compared between floating fusion (non-fused sacrum) and fixed fusion (fused sacrum) patients	Floating (63) Fixed (28)	Floating (70.0) Fixed (69.6)	Floating (73.0) Fixed (78.6)	Floating (61.2) Fixed (58.0)	**Mean time to onset of SIJP** *Fixed*: 3.78 ± 2.99 months *Floating*: 8.63 ± 4.27 months **Incidence of SIJP (fusion type)** *Fixed:* 9/28, 32.1% *Floating:* 8/63, 12.7%
Guan et al. (2018)	Retrospective Cohort	To clarify the risk factors of post-operative SIJP for posterior open lumbar surgery	Total (599) Included (472) Lost to F/U (129)	42.2	59.5	45.7	**Incidence of SIJP (# fused segments)** *One segment*: 43/322, 13.4% *Two segments:* 15/107, 14.0% *Three segments:* 3/35, 8.6% > *Four segments:* 4/8, 50% **Incidence of SIJP (procedure type)** *Discectomy:* 21/193, 10.9% *Posterior interbody fusion:* 44/279, 15.8% **Incidence of SIJP (pre-op diagnosis)** *Lumbar stenosis*: 29/169, 17.2% *Lumbar disc herniation*: 18/177, 10.2% *Lumbar spondylolisthesis*: 18/126, 14.3%

Table 1 (continued)

Study ID (author, year)	Study design	Study aim	Participants (*n*)	Avg. age (years)	Female (%)	Avg. follow-up (months)	Outcomes
Yao et al. (2022)	Finite element analysis (computer modeling)	To determine the bio-mechanics of a fused lumbosacral spine through three-dimensional modeling using human computed tomography images	1	21	0	Not relevant	**% Increase in stress** *Flexion:* 130% *Extension:* 424% *Bending:* 168% *Axial rotation:* 241% **% Increase in contact pressure** *Flexion:* 170% *Extension:* 676% *Bending:* 199% *Axial rotation:* 203%
Nessim et al. (2021)	Cross-sectional observational cohort study	Determine the incidence and risk factors of SIJD after lumbosacral fusion	Total (2069) + for SIJP (47) Controls (44)	58.4	34	Not relevant	**Post-operative pelvic tilt ($p < 0.05$)** *Controls:* 27.28° ± 2.30° + *for SIJ:* 20.82° ± 2.19° **Post-operative L5 incidence ($p < 0.05$)** *Controls:* 37.11° ± 3.50° + *for SIJ:* 28.64° ± 3.38 **Incidence of SIJ:** 3.9%
Tonosu et al. (2019)	Prospective Cohort	Determine if SIJP following lumbar surgery is associated with changes in spinopelvic parameters	Total (265) + SIJP (8)	66.9	37.5	Not relevant	**Post-operative pelvic tilt ($p = 0.22$)** *Controls:* 20.7 ± 7.9° + *for SIJ:* 24.1 ± 9.1° **Post-operative sacral slope ($p = 0.49$)** *Controls:* 29.5° ± 8.6° + *for SIJ:* 31.6° ± 8.3° **Post-operative lumbar lordosis ($p = 0.6$)** *Controls:* 39.9° ± 12.6° + *for SIJ:* 42.0° ± 11.5° **Post-operative pelvic incidence ($p = 0.01$)** *Controls:* 49.9° ± 10.4° + *for SIJ:* 59.4° ± 11.5° **Incidence of SIJ: 3.0%**

Table 1 (continued)

Study ID (author, year)	Study design	Study aim	Participants (*n*)	Avg. age (years)	Female (%)	Avg. follow-up (months)	Outcomes
Al-Riyami et al. (2017)[a]	Review article	Assessing the utility of SPECT/CT in post-operative imaging of a fused lumbar spine	12	Not relevant			
Lee et al. (2019)	Retrospective cohort	The aim of this study was to identify the incidence of and predisposing factors for new onset SIJ pain following successful lumbar fusion	Total (317) + for SIJ pain (38)	56.7	55.0	Minimum 12	**Incidence of SIJP (# fused segments)** *One segment:* 15/135, 11.1% *Two segments:* 13/108, 12.0% *Three segments:* 4/31, 12.9% > *Four segments:* 6/43, 14.0% **Incidence of SIJP (fusion type)** *Fixed:* 22/174, 12.6% *Floating:* 16/143, 11.2%

SIJD sacroiliac joint dysfunction, *SI* sacroiliac, *SIJP* sacroiliac joint pain, *TLIF* transforaminal lumbar interbody fusion, *SIJ* sacroiliac joint, *SPECT/CT* single-photon emission computerized tomography

[a]The number of studies included in this publication is reported instead of number of human participants. All other data were not calculated as they were not included in the data analysis

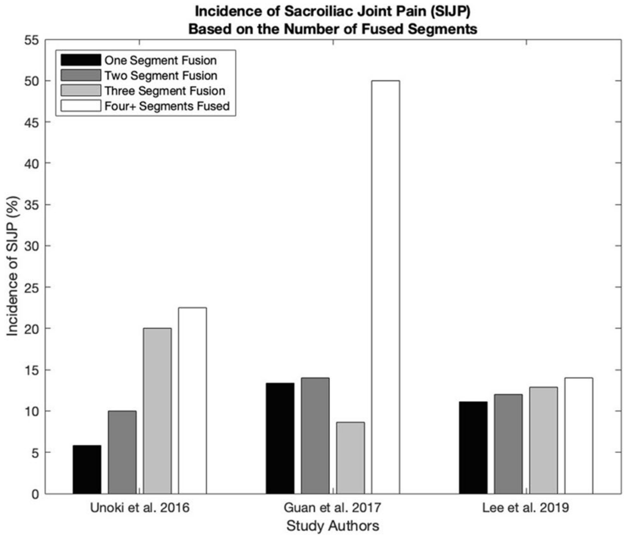

Fig. 2 Incidence of post-operative SIJP based on the number of fused lumbar segments for three different studies. A significant increase in SIJP is observed when comparing single-level fusion to multi-level fusion. SIJP, sacroiliac joint pain

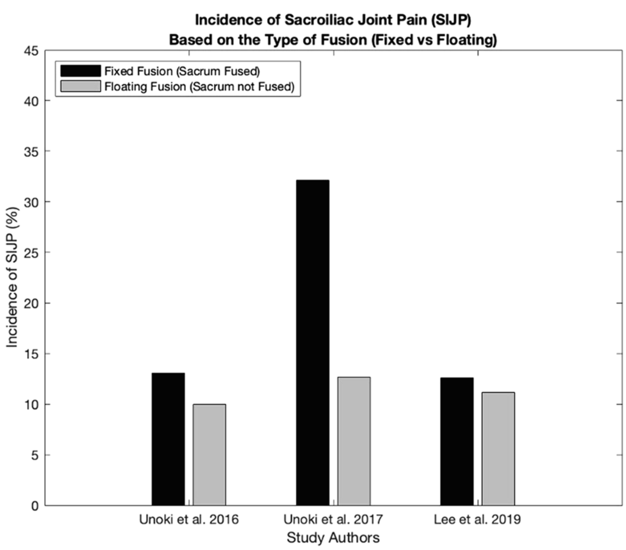

Fig. 3 Incidence of post-operative SIJP based on the type of lumbar fusion (fixed vs floating). A significant increase in SIJP is observed following fixed fusion vs floating (both of which were multilevel fusions). SIJP, sacroiliac joint pain

also significantly shortens the time to onset of SIJD [37, 38]. The mean time to onset in the fixed group was 3.24 ± 2.43 months and 8.29 ± 4.78 months in the floating group ($p = 0.040$). Lastly, 20% of the males in the included studies developed SIJD versus 11% of females [15, 23, 26, 33, 35, 38]. Male gender increased the odds of SIJD development (OR = 1.93 [1.27, 2.98], $p = 0.001$). The data extracted from easy study is shown in Table 1.

Pathophysiology

Lumbar surgery is intended to improve patients' spinopelvic parameters (SPs) including pelvic incidence (PI), pelvic tilt (PT), sacral slope (SS), and lumbar lordosis (LL) [1, 3, 18, 31, 40]. These parameters are interrelated and any change in one results in a compensatory change in the others to maintain sagittal alignment.

The changes in SPs may be influenced by surgical approach. Among the included studies, the incidence of SIJD was 7.0% and was associated with an increase in PT and decrease in PI. When fixation did not include an interbody, the incidence was 4.0% and was associated with a decrease in PT. The change in PT both scenarios differed relative to controls ($p < 0.05$) [20, 21, 23].These findings suggest that use of an interbody may predispose patients to SIJD — yet the exact mechanism relating SIJD and change in SPs has not been uncovered. Other relevant literature indicates that an increase in PT is associated with decreased capacity to compensate for sagittal imbalance, inducing motion of the SIJ, predisposing patients to SIJD [32]. Kalidindi et al. examined SIJD following transforaminal interbody fusion (TLIF), showing that patients with this complication experienced cephalad migration of the lumbar apex, which is linked to a decrease in PI, which, when combined with an increase in PT, results in pelvic retroversion and subsequent hip extension [18, 41]. Yao e al. carried out 3D-modeling of the biomechanics of the SIJ following lumbosacral fusion, reporting an average of 312% increase in stress on the joint [43]. Hip extension was reported to result in the greatest stress relative to flexion, bending, and axial rotation [6, 30]. Together, these studies suggest a model for SIJD following TLIF procedures – limited motion of the lumbar spine decreases PI and SS and increases PT, leading to pelvic retroversion and subsequent motion of the SIJ (Fig. 4). Table 1 reports the data extracted from each included study.

Diagnosis

Studies that reported diagnostic methods of SIJD required patients to present with new onset pain in the lower lumbar/buttocks region that was not due to other lumbar spine diseases. Six studies employed one or more pain provocation tests for diagnosis [5, 23, 31, 34, 37, 38]. Seven studies utilized intra-articular anesthetic block as a confirmatory diagnostic modality with a threshold of 50–70% pain relief [23, 26, 31, 34, 36–38]. One study demonstrated novel usefulness of bone SPECT/CT in diagnostic imaging [2].

Conservative and surgical management

Intra-articular injection of methylprednisone and lidocaine was reported to decrease the VAS and ODI scores by 75%

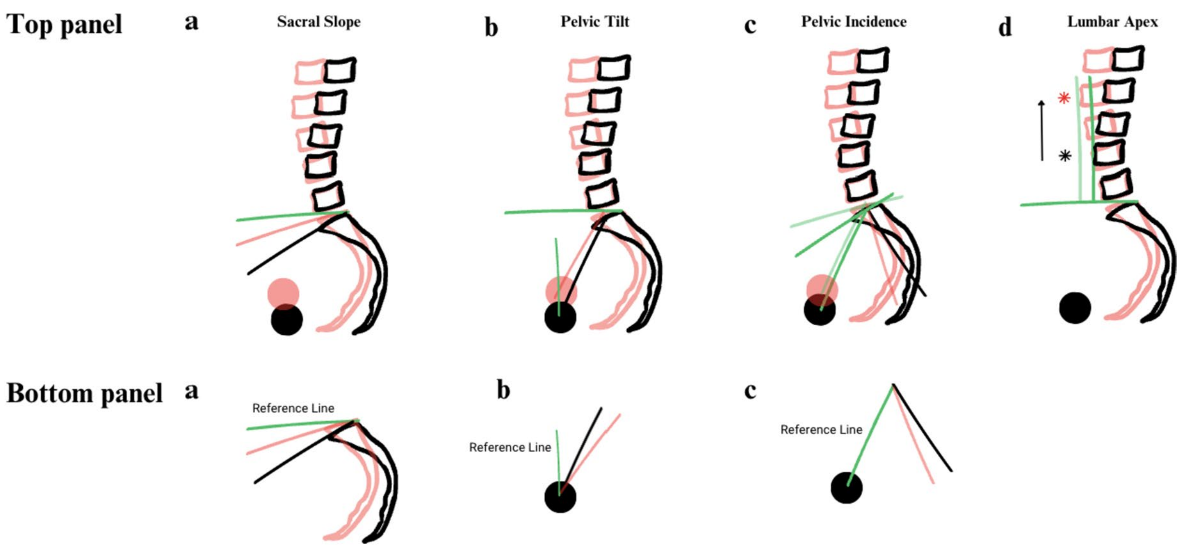

Fig. 4 Illustration of pelvic retroversion due to changes in spinopelvic parameters following transforaminal interbody fusion. (Top panel) Dark black indicates baseline spinal alignment and light red indicates changes to spinal alignment following fusion. Sacral slope (**a**), pelvic tilt (**b**), pelvic incidence (**c**), and cephalad migration of the lumbar apex. (Bottom panel) Demonstration of decrease in sacral slope (**a**), increase in pelvic tilt (**b**), and decrease in pelvic incidence (**c**) relative to the reference line in green. SS, sacral slope; PT, pelvic tilt; PI, pelvic incidence

and 49%, respectively. Patients with prior lumbar surgery required a second injection earlier than those without this history (5.9 vs 11 months) [5]. Radiofrequency ablation (RFA) reduced the VAS and ODI scores by 90% and 60%, respectively [36]. SIJ fusion/fixation is another option for treatment of SIJD. An anterior and posterior open approach resulted in a 13% and 21% improvement in VAS scores, respectively [33]. Patients who underwent an MIS fusion with triangular titanium implants (iFuse Implant System) experienced 68–73% improvement in VAS score and 63–71% improvement in ODI score. The MIS distraction interference arthrodesis neurovascular anticipating (DIANA) method resulted in improvement of 29% and 11.2% in VAS and ODI scores, respectively. These data are reported in Table 2 and illustrated in Fig. 5.

Discussion

Development and diagnosis

Our understanding of post-operative SIJD has progressed recently. Risk factors include spinal stenosis, male gender, and operative technique. The incidence increases when instrumentation is utilized, is highest when ≥ 3 segments are fused, and when fusion extends to the sacrum. The pathophysiology model of this change is defined by biomechanical changes in the spine, similar to proximal junctional degeneration [22]. Fusion limits motion of the lumbar spine which interferes with its capacity for compensatory changes to maintain sagittal balance. Although all lumbar procedures may increase the risk of SIJD, it is likely that each surgical approach is associated with unique changes in the SPs, including anterior (ALIF), lateral (LLIF), posterolateral (PLF), and TLIF procedures. Ahlquist et al. concluded that ALIF and LLIF procedures provided superior sagittal alignment and more drastic SP changes than TLIF and PLF procedures [1]. Furthermore, TLIF procedures increase PT, leading to pelvic retroversion and hip extension, resulting in increased SIJ motion and compressive forces on the joint (Fig. 4) [7, 18]. However, literature linking these unique changes in SPs to risk of SIJD is lacking, warranting further research.

Ultimately, the decision regarding surgical approach for lumbar fusion is multifaceted, requiring consideration of patients' baseline SPs, as these may predispose them to post-operative SIJD, as well as the extent of sagittal alignment that is required to reduce LBP. Taken together, these findings emphasize how critical initial risk assessment and management is to prevention of post-operative SIJD when patients present with LBP.

Diagnosis of SIJD is challenging as pain can mimic other LBP syndromes, potentially resulting in inaccurate diagnoses, unnecessary surgery, and worsening pain. The diagnostic framework of SIJD includes consideration of clinical features, pain provocation tests, nerve block, and more recently imaging, as illustrated in Fig. 6. Pain is typically localized inferior to the posterior superior iliac spine and may be referred to the L5-S1 nerve distribution in a variable pattern among patients [3]. A variety of pain provoking tests are

Table 2 Characteristics of included studies reporting on the treatment of sacroiliac joint pain after lumbar spine surgery

Study ID (author, year)	Study design	Study aim	Participants[a] (%)	Avg. age (years)	Female (%)	Avg. follow-up (months)	PRO change (%)
Buker et al. (2014)[c]	Prospective cohort	Compare the efficacy of steroidal injection for treatment of SIJ pain in patients with and without history of lumbosacral fusion	22/72 (31)	50.3	75.0	17.7	VAS: 75.4 ODI: 48.8
Matsuki et al. (2017)[d]	Case report	Report on success with ultrasound-guided SI block in treatment of SIJ pain	1 (100)	67.0	0	7 days	VAS: 34.0
Tseng et al. (2023)	Technical note	Report on an optimized approach to biportal endoscopic radiofrequency ablation for SIJ pain	7/16 (43)	Not reported	Not reported	12.0	VAS: 90.0 ODI: 60.3
Endres and Ludwig (2013)	Prospective cohort	Assess the efficacy of distraction arthrodesis of the SIJ for patients with history of lumbar/lumbosacral fusion	19 (100)	60.9	26.3	13.2	VAS: 29.4 ODI: 11.1
Smith et al. (2013)[e]	Retrospective cohort	Compare a posterior open SI fusion approach to an MIS alternative for treatment of SIJ pain	Open: 35/149 (24) MIS: 54/114 (48)	Open: 45.8 MIS: 57.4	Open: 69.1 MIS: 71.9	24.0	Open, VAS: 21.4 MIS, VAS 70.5
Slinkard et al. (2013)	Prospective case series	Compare the clinical outcomes of patients with and without history of lumbar fusions who undergo an anterior open SI fusion procedure	12/19 (63)	51.0	75.0	33.0	ODI: 13.4
Cummings and Capobianco (2013)[f]	Prospective cohort	Compare patient-reported outcomes following MIS fusion with triangular titanium implants for treatment of SIJ pain	15/18 (83)	64	67	12	VAS: 73.7 ODI: 71.3
Rainov et al. (2019)[f]	Retrospective case series	Assess clinical outcomes in patients with and without history of lumbar surgery following MIS SI fusion using triangular titanium implants	102/160 (64)	58	68	12	VAS 68.8 ODI 63.7

SIJ sacroiliac joint, *SIJD* sacroiliac joint dysfunction, *MIS* minimally invasive, *VAS* Visual Analogue Score, *ODI* Oswestry Disability Index

[a] *n* is the number of participants with history of lumbar surgery and % refers to the percentage of patients with history of lumbar surgery out of the total number of patients (including controls)

[b] A total of 39 patients were originally included, but only 31 had a 10-year follow-up; all the data except sex demographics were reported for the final analyzed cohort

[c] Total number of females reported for the entire cohort only as sub-population demographics were not available

[d] Authors state that the patient was seen in clinic 7 days after treatment and subsequently every 2 weeks; however, it is unclear what the length of long-term follow-up was

[e] Average age and total number of females reported only for the entire cohort; sub-population demographics were not available

[f] VAS and ODI scores before and after treatment were reported for the entire cohort; scores for the sub-population of patients with history of lumbar surgery was not available

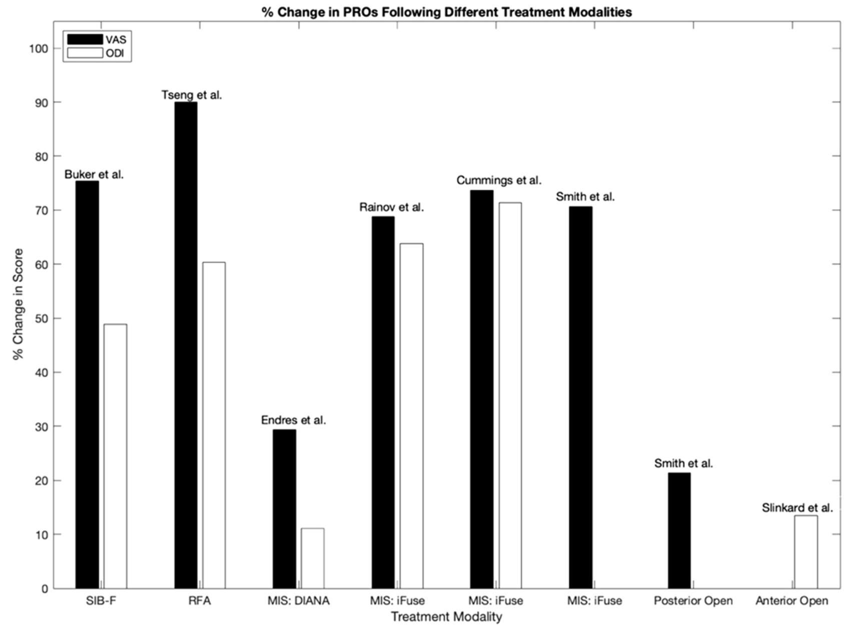

Fig. 5 Percent decrease in ODI and VAS for different treatment modalities in studies that reported each score pre- and post-treatment. ODI, Oswestry Disability Index; VAS, Visual Analogue Score

performed including the FABER, posterior shear, Gaenslen, compression, distraction, and Yeoman tests [4]. Isolation of pain originating from the SIJ requires a positive result in at least two of these maneuvers. The diagnostic modality that is most indicative of SIJD is an image-guided intra-articular anesthetic block into the joint. The image-guided aspect is crucial, as "blind" injections are reportedly accurate only 22% of the time [17]. There is uncertainty regarding the degree of pain relief that is required for a positive response, ~75% relief is most common [36, 37]. Until recently, imaging techniques were used solely to rule out other sources of pain. Typical CT findings consistent with (but not diagnostic of) SIJD include sclerosis, erosion, osteophyte formation, joint space narrowing, and/or intraarticular bone fragments [13]. However, Al-Riyami et al. recently demonstrated the utility of bone SPECT/CT in diagnostic imaging for SIJD, a finding that should be considered by clinicians who frequently treat patients with post-lumbar surgery SIJD [2]. A major benefit of this modality is the ability to assess increased stress on the SIJ, as indicated by increased tracer uptake, and the capability of correlating changes in osteoblast activity to the degenerative changes in the SIJ [2, 16].

Treatment and risk management

Though evidence is mixed, conservative treatments such as physiotherapy and anti-inflammatory medications should be first-line and provide relief in most patients. When conservative measures are ineffective, less-invasive endoscopic approaches may be utilized. While nerve block was equally efficacious for patients with and without history of lumbar surgery, patients with such history required a second injection earlier. Furthermore, multiple RFA approaches are available, including cooled, thermal, pulsed and monopolar, and bipolar techniques. However, consensus regarding which technique offers the greatest benefit needs further exploration [20]. In general, the success rate of RFA is variable, 32–89% experience at least 50% pain relief for 6 months and 11–44% achieve full relief for 6 months [24]. Thus, randomized controlled trials comparing these RFA approaches for patients with SIJD following lumbar surgery are necessary to elongate the pain-free period and identify patients who may benefit from alternative treatment options.

Surgical alternatives for patients who do not benefit from RFA include open or minimally invasive (MIS) SIJ fixation to minimize motion of the SIJ. An anterior open approach is cited as superior to a posterior approach, as it allows for direct visualization of the synovial portion of the joint without risking injury to the stabilizing ligaments [9]. The studies included in this review endorse non-inferiority of an MIS to an open approach, and in some instances, its superiority. This is an important finding for patients requiring re-operation, as an MIS approach is associated with reduced surgical morbidity and length of hospitalization and increased quality of life [29]. Two MIS approaches exist: iFuse Implant System and the distraction interference arthrodesis neurovascular anticipating (DIANA) method. The DIANA method restores the SIJ space using a single implant, eliminating the need for traditional screw-based fusion while maintaining comparable fusion rates, decreasing rate of infection and neurovascular injury [13]. While the DIANA treatment was found to result in a less drastic decrease in VAS and ODI relative to the traditional iFuse method, it is unclear what change in VAS and ODI is necessary for clinically

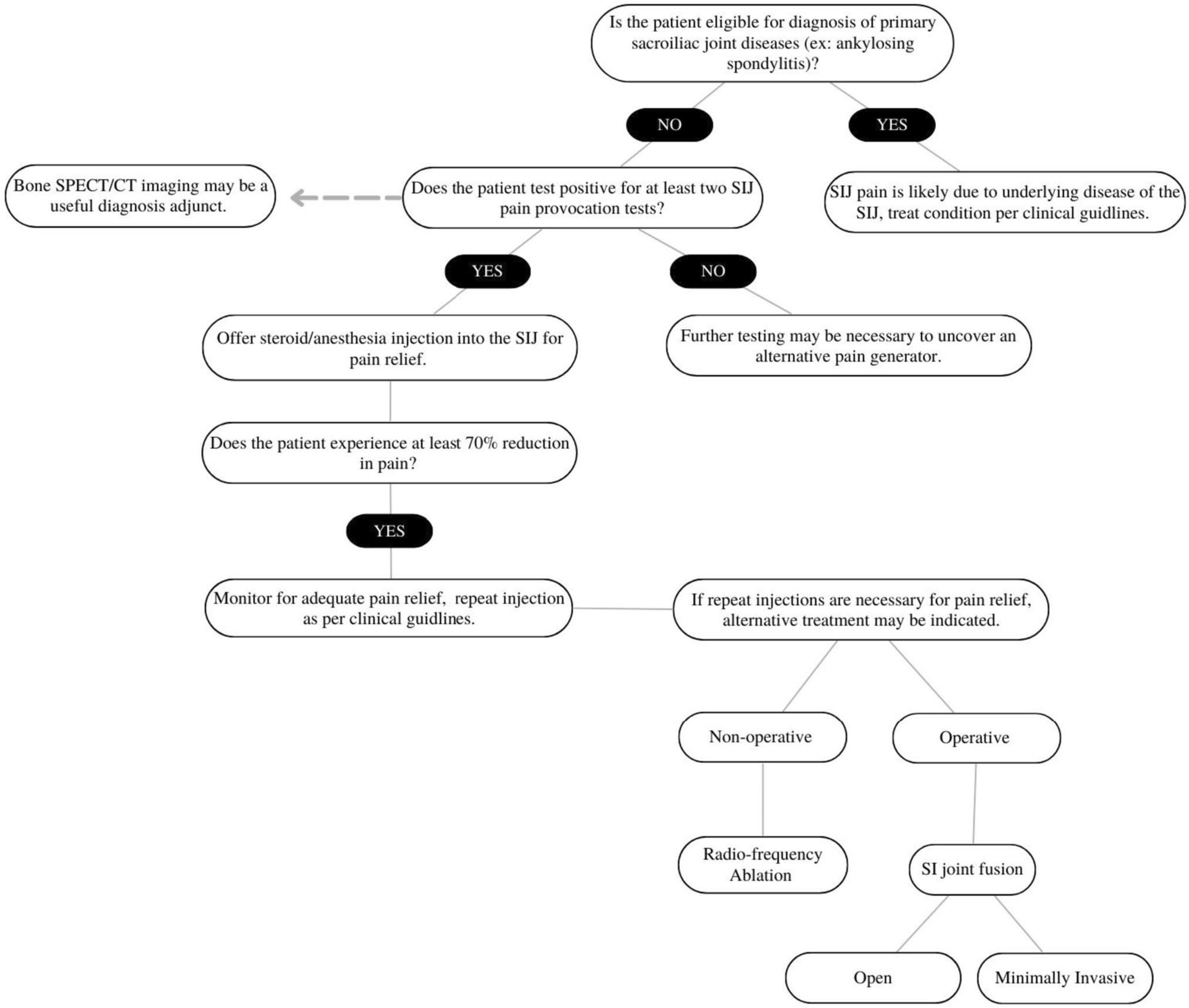

Fig. 6 Flowchart of important initial and subsequent considerations when diagnosing and treating patients with sacroiliac joint dysfunction following lumbar surgery

significant patient satisfaction. It may be possible that patients who undergo the DIANA method for SIJ fixation express similar rates of satisfaction as those receiving the iFuse method and would benefit from the method's potentially superior control of common post-operative complications; however, more research in this field is necessary. This diagnostic and management framework is illustrated in Fig. 6.

Strengths and limitations

Strengths of this review include its adherence to the PRISMA guidelines, blinded review of literature, and focused selection of studies.

This review should be interpreted considering the following limitations. The authors conducted the search on a limited number of databases and restricted publications to those available in the English language, potentially and inadvertently missing novel findings. The search also did not uncover randomized controlled studies, limiting the level of evidence of the included studies. However, this limitation further reinforces the need for more research in this field. Second, the bias of individual studies was not specifically assessed, which may have a negative effect on the reliability of the results. However, the limitations of each individual study were heavily considered when analyzing their findings. Lastly, it is important to note that the authors of the studies reporting the utility of iFuse SIJ fusion method are either paid consultants or employees of the manufacturing company of this implant system.

Future directions and outlook

The profile of SP changes in post-operative SIJD may be unique to the kind of lumbar procedures patients undergo. If further research can establish concrete guidelines on changes associated with each procedure, it may be possible to incorporate assessment of post-operative SPs into the diagnostic framework of post-lumbar fusion SIJD.

It is possible that the complex pathophysiology of SIJD will remain a barrier to its accurate and timely diagnosis and treatment. Thus, it may be necessary to shift focus to risk mitigation and consider which patients are true candidates for lumbar fusion and who may benefit from concurrent SIJ fixation. Some researchers have proposed that patients who develop post-lumbar surgery SIJD were likely misdiagnosed and should have received SIJ fixation instead [23]. Overall, adequate patient counseling and monitoring is necessary for patients who undergo lumbar surgery.

Conclusions

Sacroiliac joint dysfunction following lumbar fusion is an increasingly pertinent topic due to a sharp uptick in lumbar fusion procedures in the recent past. This review supports the consensus that history of lumbar fusion predisposes patients to post-operative SIJD and suggests that this risk occurs due to changes in the biomechanics of the SIJ. Unlike other papers addressing this growing issue, this review synthesizes multiple aspects of SIJD and presents them in one place. Specifically for pathophysiology, this review consolidates incomplete information and provides a more holistic view of the new development of post-operative SIJD. Risk factors, provided with odds ratios that have not previously been reported in the literature, include pre-operative diagnosis of spinal stenosis, male gender, utilization of instrumentation in surgery (e.g., interbody), fusion of ≥ 3 segments, and fusion extending to the sacrum. The exact pathophysiology of SIJD development may be unique among various surgical approaches. TLIF procedures may increase PT resulting in pelvic retroversion and increased SIJ motion. Definitive diagnosis of SIJD remains challenging, with a multifaceted approach including pain provocation tests and intra-articular block being standard while newer modalities such as SPECT/CT may find a future role. When conservative measures are ineffective, RFA and MIS SIJ fixation, using the iFuse System, result in greatest improvement in patient-reported outcomes.

Author contribution All the authors contributed to the study conception and design. HK and RR performed an independent blinded review of publications for inclusion. SP resolved any discrepancies as a third blinded reviewer. All the authors participated in the construction and revision of the manuscript, and all provided the final approval for submission.

Data availability This systematic review was not registered; however, a review protocol and data are available upon request.

Code availability Not applicable.

Declarations

Ethics approval The manuscript does not contain clinical studies or patient data.

Consent to participate The manuscript does not contain clinical studies or patient data.

Consent for publication The manuscript does not contain clinical studies or patient data.

Conflicts of interest The authors declare no competing interests.

References

1. Ahlquist S, Park HY, Gatto J, Shamie AN, Park DY (2018) Does approach matter? A comparative radiographic analysis of spinopelvic parameters in single-level lumbar fusion. Spine J 18(11):1999–2008. https://doi.org/10.1016/j.spinee.2018.03.014
2. Al-Riyami K, Gnanasegaran G, Van den Wyngaert T, Bomanji J (2017) Bone SPECT/CT in the postoperative spine: a focus on spinal fusion. Eur J Nucl Med Mol Imaging 44(12):2094–2104. https://doi.org/10.1007/s00259-017-3765-6
3. Barros G, McGrath L, Gelfenbeyn M (2019) Sacroiliac joint dysfunction in patients with low back pain. Fed Pract 36(8):370–375
4. Buchanan P, Vodapally S, Lee DW, Hagedorn JM, Bovinet C, Strand N, Sayed D, Deer T (2021) Successful diagnosis of sacroiliac joint dysfunction. J Pain Res 14:3135–3143. https://doi.org/10.2147/JPR.S327351
5. Büker N, Akkaya S, Gökalp O, Kıtış A, Savkın R, Kıter AE (2014) Middle-term therapeutic effect of the sacroiliac joint blockade in patients with lumbosacral fusion-related sacroiliac pain. Acta Orthop Traumatol Turc 48(1):61–66. https://doi.org/10.3944/AOTT.2014.3190
6. Cheung JPY (2020) The importance of sagittal balance in adult scoliosis surgery. Ann Transl Med 8(2):35–35. https://doi.org/10.21037/atm.2019.10.19
7. Cho D-Y, Shin M-H, Hur J-W, Ryu K-S, Park C-K (2013) Sagittal sacropelvic morphology and balance in patients with sacroiliac joint pain following lumbar fusion surgery. J Korean Neurosurg Soc 54(3):201–206. https://doi.org/10.3340/jkns.2013.54.3.201
8. Ciarpaglini R, Maestretti G (2014) Sacroiliac Joint Syndrome 10 Years after Lumbar Arthroplasty: The Importance of Spinopelvic Alignment. Glob Spine J 23(6):720–724. https://doi.org/10.1007/s00586-014-3547-9
9. Colò G, Cavagnaro L, Alessio-Mazzola M, Zanirato A, Felli L, Formica M (2020) Incidence, diagnosis and management of sacroiliitis after spinal surgery: a systematic review of the literature. Musculoskelet Surg 104(2):111–123. https://doi.org/10.1007/s12306-019-00607-0
10. Crow WT, Willis DR (2009) Estimating cost of care for patients with acute low back pain: a retrospective review of patient records. J Am Osteopath Assoc 109(4):229–233. https://doi.org/10.7556/jaoa.2009.109.4.229

11. Cummings J, Capobianco RA (2013) Minimally invasive sacroiliac joint fusion: one-year outcomes in 18 patients. Ann Surg Innov Res 7(12):1–7. https://doi.org/10.1186/1750-1164-7-12
12. Deng H, Yue JK, Ordaz A, Suen CG, Sing DC (2021) Elective lumbar fusion in the United States: national trends in inpatient complications and cost from 2002–2014. J Neurosurg Sci 65(5):503–512. https://doi.org/10.23736/S0390-5616.19.04647-2
13. Endres S, Ludwig E (2013) Outcome of distraction interference arthrodesis of the sacroiliac joint for sacroiliac arthritis. Indian J Orthop 47(5):437–442. https://doi.org/10.4103/0019-5413.118197
14. Gartenberg A, Nessim A, Cho W (2021) Sacroiliac joint dysfunction: pathophysiology, diagnosis, and treatment. Eur Spine J 30(10):2936–2943. https://doi.org/10.1007/s00586-021-06927-9
15. Guan F, Sun Y, Zhu L, Guan G, Chen M, Chi Z, Tian D, Gu J, Yu Z (2018) Risk factors of postoperative sacroiliac joint pain for posterior lumbar surgery: ≥2-year follow-up retrospective study. World Neurosurg 110:546–551. https://doi.org/10.1016/j.wneu.2017.11.053
16. Hudyana H, Maes A, Vandenberghe T, Fidlers L, Sathekge M, Nicolai D, Van de Wiele C (2016) Accuracy of bone SPECT/CT for identifying hardware loosening in patients who underwent lumbar fusion with pedicle screws. Eur J Nucl Med Mol Imaging 43(2):349–354. https://doi.org/10.1007/s00259-015-3158-7
17. Jung MW, Schellhas K, Johnson B (2020) Use of diagnostic injections to evaluate sacroiliac joint pain. Int J Spine Surg 14(1):30–34. https://doi.org/10.14444/6081
18. Kalidindi KKV, Bansal K, Vishwakarma G, Chhabra HS (2021) New onset sacroiliac joint pain after transforaminal interbody fusion: what are the culprits? Glob Spine J 13(3):677–682. https://doi.org/10.1177/21925682211003852
19. Kim HS, Kim SH, Ju CI, Kim SW, Lee SM, Shin H (2010) The role of bone cement augmentation in the treatment of chronic symptomatic osteoporotic compression fracture. J Korean Neurosurg Soc 48(6):490–495
20. King W, Ahmed SU, Baisden J, Patel N, Kennedy DJ, MacVicar J, Duszynski B (2015) Diagnosis and treatment of posterior sacroiliac complex pain: a systematic review with comprehensive analysis of the published data. Pain Med 16(2):257–265
21. Knezevic NN, Candido KD, Vlaeyen JWS, Van Zundert J, Cohen SP (2021) Low back pain. Lancet Lond Engl 398(10294):78–92
22. Le Huec JC, Tsoupras A, Leglise A, Heraudet P, Celarier G, Sturesson B (2019) The sacro-iliac joint: a potentially painful enigma. Update on the diagnosis and treatment of pain from micro-trauma. Orthop Traumatol Surg Res 105(1, Supplement):S31–S42
23. Lee YC, Lee R, Harman C (2019) The incidence of new onset sacroiliac joint pain following lumbar fusion. J Spine Surg Hong Kong 5(3):310–314
24. Loh E, Agur AM, Burnham RS (2022) Ultrasound-guided radiofrequency ablation for SI joint pain: an observational study. Interv Pain Med 1(3):100118
25. Matsuki Y, Mizogami M, Shigemi K (2017) Successful treatment of failed back surgery syndrome with an ultrasound-guided sacroiliac joint block: a report of two cases. Anaesth. Pain Intensive Care 21(4):479–481
26. Nessim A, Cho W, Yang XA, Applebaum A, Sekerak R, Brill S, Kim SY (2021) Infra-adjacent segment disease after lumbar fusion: an analysis of pelvic parameters. Spine 46(16):E888–E892
27. Ouzzani M, Hammady H, Fedorowicz Z, Elmagarmid A (2016) Rayyan—a web and mobile app for systematic reviews. Syst Rev. https://doi.org/10.1186/s13643-016-0384-4
28. Page MJ, McKenzie JE, Bossuyt PM et al (2021) The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 372:n71
29. Park J, Ham D-W, Kwon B-T, Park S-M, Kim H-J, Yeom JS (2020) Minimally invasive spine surgery: techniques, technologies, and indications. Asian Spine J 14(5):694–701
30. Pizones J, García-Rey E (2020) Pelvic motion the key to understanding spine–hip interaction. EFORT Open Rev 5(9):522–533
31. Rainov NG, Schneiderhan R, Heidecke V (2019) Triangular titanium implants for sacroiliac joint fusion. Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 28(4):727–734
32. Savarese LG, Menezes-Reis R, Bonugli GP, da Herrero CFPS, Defino HLA, Nogueira-Barbosa MH (2020) Spinopelvic sagittal balance: what does the radiologist need to know? Radiol Bras 53(3):175–184
33. Slinkard N, Agel J, Swiontkowski MF (2013) Documentation of outcomes for sacroiliac joint fusion: does prior spinal fusion influence the outcome? Eur Spine J Off Publ Eur Spine Soc Eur Spinal Deform Soc Eur Sect Cerv Spine Res Soc 22(10):2318–2324
34. Smith AG, Capobianco R, Cher D, Rudolf L, Sachs D, Gundanna M, Kleiner J, Mody MG, Shamie AN (2013) Open versus minimally invasive sacroiliac joint fusion: a multi-center comparison of perioperative measures and clinical outcomes. Ann Surg Innov Res 7(1):14
35. Tonosu J, Kurosawa D, Nishi T, Ito K, Morimoto D, Musha Y, Ozawa H, Murakami E (2019) The association between sacroiliac joint-related pain following lumbar spine surgery and spinopelvic parameters: a prospective multicenter study. Eur Spine J 28(7):1603–1609
36. Tseng C, Chen K-T, Fong Y-C, Lin C-W, Sun L-W, Chen C-M, Wang G-C (2023) Biportal endoscopic radiofrequency ablation of the sacroiliac joint complex in the treatment of chronic low back pain: a technical note with 1-year follow-up. Diagn Basel Switz 13(2):229
37. Unoki E, Abe E, Murai H, Kobayashi T, Abe T (2016) Fusion of multiple segments can increase the incidence of sacroiliac joint pain after lumbar or lumbosacral fusion. Spine 41(12):999–1005
38. Unoki E, Miyakoshi N, Abe E, Kobayashi T, Abe T, Shimada Y (2017) Sacroiliac joint pain after multiple-segment lumbar fusion: a long-term observational study-non-fused sacrum vs. fused sacrum. Spine Surg Relat Res 1(2):90–95
39. Urits I, Burshtein A, Sharma M et al (2019) Low back pain, a comprehensive review: pathophysiology, diagnosis, and treatment. Curr Pain Headache Rep 23(3):23
40. Vleeming A, Schuenke MD, Masi AT, Carreiro JE, Danneels L, Willard FH (2012) The sacroiliac joint: an overview of its anatomy, function and potential clinical implications. J Anat 221(6):537–567
41. Wang J, Zhang Q, Liu F, Yuan H, Zhang Y, Wang X, Li J (2022) Predicting the ideal apex of lumbar lordosis based on individual pelvic incidence and inflection point in asymptomatic adults. Front Surg 9:912357
42. Whiting P, Savović J, Higgins JPT, Caldwell DM, Reeves BC, Shea B, Davies P, Kleijnen J, Churchill R (2016) ROBIS: a new tool to assess risk of bias in systematic reviews was developed. J Clin Epidemiol 69:225–234
43. Yao Z, Li L, Zhang P, Yang L, Bai X, Peng S, Lai Y (2022) Biomechanics evaluation of sacroiliac joint pain after lumbosacral fusion: a finite element analysis. J Orthop Res Off Publ Orthop Res Soc. https://doi.org/10.1002/jor.25411
44. Yoshihara H (2012) Sacroiliac joint pain after lumbar/lumbosacral fusion: current knowledge. Eur Spine J 21(9):1788–1796