Sacroiliac joint pain following iliac-bone marrow aspiration and biopsy: a cohort study

Carlos J Roldan^{*,1,2}, Billy K Huh¹, Thomas Chai¹, Larry C Driver¹, Juhee Song³ & Siddarth Thakur¹

¹Department of Pain Medicine, The University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA

²McGovern Medical School at the University of Texas Health Science Center at Houston (UTHealth), Houston, TX 77030, USA

³Department of Biostatistics, The University of Texas MD Anderson Cancer Center, Houston, TX 77030, USA

*Author for correspondence: croltan@mdanderson.org

Background: Sacroiliac joint (SIJ) pain is a common source of lower back pain; the factors associated have not been studied in cancer patients. Observing patients with bone marrow aspiration and biopsy (BMAB) who subsequently developed SIJ-pain led to this investigation. **Aim:** To investigate this possible relationship. **Methods:** A cohort study of cancer patients diagnosed with SIJ pain. The association of BMAB with SIJ pain was evaluated, as were variables that differed between the groups. **Results:** The prevalence of SIJ pain was 4.95% (231/4669). Among 231 patients with SIJ pain, 34% (78/231) did not have prior history of lower back pain and had undergone BMAB prior to their diagnosis of SIJ pain. A statistically significant association between BMAB–SIJ-pain was found ($p < 0.01$). **Conclusion:** We found linear correlation between BMAB and subsequent SIJ pain.

First draft submitted: 8 November 2018; Accepted for publication: 19 December 2018; Published online: 29 May 2019

Keywords: bone marrow aspiration and biopsy • lower back pain • pain • sacroiliac joint

The sacroiliac joint (SIJ) is a common, yet underappreciated, source of pain in the general population in up to 30% of patients with chronic lower back pain [1]. The SIJ is a diarthrodial structure with two surfaces joined by synovial fluid in a fibrous capsule. Multiple ligaments and muscles support the SIJ, and there is a limited amount of motion in the joint during normal body movement. Presumably, the SIJ can become painful when the integrity of the supporting structures is disrupted or when the supporting ligaments become too lax or tight. The pain usually starts in the paramedian lower back and buttocks and radiates above and below. Multiple referred pain patterns occur with SIJ pain which is thought to be due to converging patterns among nociceptive afferent neurons originating in the joint and second-order spinal neurons receiving sensory input from the lower extremities [2–6]. The referred pain might differ from typical radicular limb pain by not displaying a specific dermatomal distribution and may present different distribution patterns over other areas of the legs [7,8]. Some reports describe patients with SIJ pain with referred pain in anatomic areas, such as the medial gluteal region or the groin that can be predictive of pain relief after intra-articular SIJ injection [2,9]. Although SIJ pain is typically ipsilateral to the compromised joint, it can occur on both sides, especially with the compensatory antalgic use of the contralateral limb. SIJ pain can arise when movement in the pelvis is asymmetric (e.g., asymmetry in length or function of the lower limbs) or in the presence of painful acute or chronic pathology of the hip or knee (e.g., degenerative arthritis). Other risk factors include older age, pregnancy, systemic inflammatory arthritis, previous spine surgery or other iatrogenic causes related to medical procedures. SIJ pain can be a very painful condition, and many cancer patients cannot undergo SIJ injections and physical therapy as part of the conventional treatment, which results in disabling consequences. Additional factors might contribute to the development of SIJ pain. Among them, invasion of the sacroiliac area by tumor cells in either primary [10] or metastatic [11] disease and treatment-related complications [12] have been well recognized; however, bone marrow aspiration and biopsy (BMAB) of the iliac bone as a possible risk factor has received little attention [13,14].

Patients undergo BMAB for evaluation of hematologic malignancies (e.g., leukemia, lymphoma or myeloma), blood cell dyscrasias (i.e., hemophilia, anemia and thrombocytopenia), or prognostic staging (i.e., micrometastasis

Future
Medicine

detection in breast cancer patients). According to the Leukemia & Lymphoma Society (www.LLS.org) [15], hematologic malignancies accounted for approximately 10.2% of the 1,685,210 new cancer cases diagnosed in the USA in the year 2016. Therefore, this procedure is performed relatively frequently in the cancer population.

The BMAB procedure usually entails the insertion of an 11-gauge hollow needle in the superior ridge of the posterior iliac crest, where a small amount of marrow fluid and bone is collected for analysis. This may be followed by the use of a larger needle, specially designed to collect a core (a cylindrical sample) of bone marrow (harvesting) for stem cell transplantation. The procedure does not require imaging guidance; therefore, local bone trauma or inadvertent injury to adjacent structures during needle positioning may be overlooked [16–20].

The SIJ is one structure adjacent to the posterior ilium that is susceptible to injury during BMAB. The extent of these complications can range from local (i.e., sacroiliitis) to systemic (i.e., sepsis), as recently reported in a case of an uneventful bone marrow biopsy [13]. Additional studies have also demonstrated the vulnerability of the SIJ during BMAB; an anatomic study of bone marrow biopsies showed that after cortical bone entry at the posterior superior iliac spine, the SIJ could be encountered if needle advancement was perpendicular to the coronal plane [21].

BMAB is an ambulatory procedure typically performed by primary cancer providers and trained assistants at the bedside or in an ambulatory procedures suite. The procedure is commonly done under local anesthesia and sometimes under moderate sedation. In most cases, no imaging is used to guide the needle placement. The success of the procedure is measured by obtaining a representative sample of the bone marrow. More than one attempt and redirection of the needle is not unusual in order to complete the procedure. After the procedure, patients are advised to return to normal activity as soon as possible and to take common analgesics such as acetaminophen. The standard instructions given do not include preemptive physical therapy or postprocedural follow-up.

Although the described factors may potentially contribute to SIJ pain after BMAB, to our knowledge, its incidence has not been formally evaluated. In our clinical setting, we have seen many patients with worsening of chronic lower back pain or new onset of SIJ pain after BMAB. Therefore, the purpose of our study was to examine the potential association between BMAB and the development of SIJ pain.

Methods

Study setting & population

Our study was performed at a large, academic, comprehensive cancer center where longitudinal data are regularly collected from patients receiving cancer treatment. The study population was selected from the database of patients followed by the Pain Medicine Department. This data bank contains demographic and clinical data regarding comorbid diseases and cancer treatment, including all visits, diagnoses and procedures performed. This protocol was reviewed and approved by our institutional review board (IRB protocol number PA16-0167). Direct patient participation was not necessary, and informed consent was not obtained due to the retrospective nature of the study.

In our practice, the diagnosis of SIJ pain is based on a rigorous clinical evaluation. That includes a complete history and physical exam with at least three positive provocative maneuvers including distraction, thigh thrust, FABER (flexion, abduction and external rotation), compression and Gaenslen's (hip joint is flexed maximally on one side and the opposite hip joint is extended, stressing both sacroiliac joints simultaneously). The gold standard is a diagnostic block but unfortunately in this population is not always feasible.

Selection of cases

We identified participants by searching the billing codes in the pain medicine clinic database for pain along the anatomical area of the SIJ. We used the following search terms under ICD-9 and ICD-10 codes entered as the primary complaint in the pain medicine charting: sacroiliitis, sacroiliac dysfunction, sacroiliac joint pain, also BMAB. We used the search terms 'sacroiliitis' and 'sacroiliac dysfunction' as proxies for SIJ pain, as they are the most commonly used billing codes in our clinic for SIJ pain.

Patients were under the care of various oncology subspecialists. No cancer type, stage or therapeutic approach was excluded except those with cancer in pelvic and sacral bones which might have confounded the results by the location of the pain. Our study population consisted of a subgroup of individuals seen in the outpatient pain management clinic, which averages 5000 patients per year. Of those, we selected patients who had received a clinical diagnosis of SIJ pain between 30 September 2014 and 30 September 2015. A total of 231 cases with diagnosis of SIJ pain were found. From this group, 146 had not undergone BMAB during the study period. The other 85 patients had similar demographics and clinical background; the screening undergone was under the same diagnosis

Figure 1. Flowchart.

BMAB: Bone marrow aspiration and biopsy; SIJ: Sacroiliac joint.

codes. For variable control, we also excluded those patients that underwent BMAB and had prior history of lower back pain (Figure 1).

Variables studied

The following data were collected through medical record review: patient demographics, including sex, age, weight and height; cancer diagnosis; cancer treatment (i.e., chemotherapy, radiation, surgery); and cancer status (i.e., active or in remission). Also recorded were lower limb pathology (i.e., peripheral neuropathy, vascular disease, amputation), body mechanics abnormalities (i.e., wheelchair dependence, scoliosis, other), history of lower back pain or SIJ pain before BMAB, date of the BMAB(s), date of diagnosis of SIJ pain, duration of the symptoms, SIJ pain laterality and associated treatment for the SIJ pain (i.e., SIJ injection, pharmacotherapy, physical therapy).

Statistical analysis

Continuous variables and categorical variables were summarized with means (standard deviations, medians and ranges) and counts (percentages), respectively. The prevalence of SIJ pain and 95% CI was estimated for all patients seen in the pain medicine clinic during 30 September 2014 and 30 September 2015. The association between BMAB and SIJ pain was assessed by χ^2 test. Data for patients with SIJ pain were grouped by whether they had had BMAB, and the groups were compared for each demographic and clinical characteristic.

The two-sample t-test or Wilcoxon rank-sum test was used for continuous variables and χ^2 or Fisher's exact test was used for categorical variables. A p-value of less than 0.05 indicated statistical significance. SAS version 9.4 (SAS Institute, Inc., NC, USA) was used for data analysis.

Results

Characteristics of patients with sacroiliac joint pain

A total of 4669 patients were seen in our clinic during the year of study. Of these, 231 had SIJ pain. The median time frame between the BMAB and the duration of the SIJ pain before diagnosis was 3.5 (2–6.5) weeks; this information was available in 61/78 charts. As shown in Table 1, the majority of the sample was middle-aged (mean $\pm$ SD: 60.43 years $\pm$ 13.92; range: 22–93 years), predominately female (71%), had a history of a solid

Table 1. Demographic and clinical characteristics of patients with sacroiliac joint pain.

Demographics	Patients with sacroiliac joint pain
Age: mean ($\pm$ SD), years	60.43 ($\pm$ 13.92)
BMI: mean ($\pm$ SD), g/m ²	29.83 ($\pm$ 7.43)
Sex:	
– Female (n, %)	165 (71.4%)
– Male (n, %)	66 (28.6%)
Cancer diagnosis:	
– Hematological (n, %)	86 (37.2%)
– Solid tumor (n, %)	145 (62.8%)
Cancer status [†] :	
– Active (n, %)	124 (56.4%)
– Remission (n, %)	96 (43.6%)

n = 231.
[†]Data for cancer status (at the time of sacroiliac joint pain diagnosis) were available for 220 patients.
 BMI: Body mass index; SD: Standard deviation.

Table 2. Clinical characteristics for patients with sacroiliac joint pain with and without BMAB.

Clinical variables	BMAB (n = 85)	No BMAB (n = 146)	p-value
Age: mean ($\pm$ SD), in years	63.17 ($\pm$ 14.84)	59.04 ($\pm$ 13.25)	0.03
BMI: mean ($\pm$ SD), in g/m ²	29.72 ($\pm$ 7.33)	29.89 ($\pm$ 7.51)	0.09
Sex:			<0.01
– Female (n, %)	51 (60.3%)	112 (77.1%)	–
– Male (n, %)	34 (39.7%)	34 (22.9%)	–
Presence of lower limb pathology:			<0.01
– No (n, %)	10 (11.7%)	22 (15.2%)	–
– Yes (n, %)	75 (88.3%)	124 (84.8%)	–
– Peripheral neuropathy of lower limb	29 (40.8%)	42 (33.8%)	–
– Osteoarthritis of lower limb	26 (36.6%)	28 (22.6%)	–
– Peripheral vascular disease	3 (4.2%)	15 (12.1%)	–
– Cancer on lower limb	4 (5.6%)	16 (12.3%)	–
– Amputation in lower limb	4 (5.6%)	13 (10.5%)	–
– Fracture of hip or lower limb	2 (2.8%)	9 (7.3%)	–
– Other	7 (9.3%)	1 (0.8%)	–
History of prior lower back pain:			<0.01
– Yes (n, %)	7 (8.2%)	15 (9.8%)	–
– No (n, %)	78 (91.8%)	131 (90.2%)	–

Data were available for 85 patients who underwent BMAB and 146 patients who did not undergo BMAB. Detailed data were not collected for patients without SIJ pain.
 BMAB: Bone marrow aspiration and biopsy; BMI: Body mass index; SD: Standard deviation.

tumor (62.8%) and had active disease at the time of SIJ pain (56.4%). As shown in [Table 2](#), a large majority of patients had no prior history of lower back pain (83%).

Characteristics of patients with & without SIJ pain & BMAB

[Table 3](#) represents the prevalence of BMAB among patients with and without SIJ pain. Among the 4669 patients seen in the pain clinic during the study period, the prevalence of SIJ pain was 4.95% (n = 231). Of 231 patients with SIJ pain, slightly more than a third (n = 85; 33.8%) had had a previous BMAB, whereas the remaining patients (n = 146; 66.2%) did not. Of those with prior BMAB, seven had history of chronic lower back pain prior to the study timeframe. Among the rest of the population (n = 4438) of patients who did not have SIJ pain, only one had had previous BMAB (0.02%). Fisher's exact test revealed a statistical association between SIJ pain and prior BMAB (p < 0.01).

Table 3. Prevalence of SIJ pain in patients with and without BMAB.

BMAB	SIJ pain		Total	p-value
	Yes	No		
Yes	85 36.8%	1 0.02%	86	–
No	146 63.2%	4437 99.98%	4590	–
Total	231	4438	4669	0.0001

BMAB: Bone marrow aspiration and biopsy; SIJ: Sacroiliac joint.

Clinical characteristics were compared between patients with SIJ pain who had undergone BMAB and those who had not (Table 2). Analyses revealed statistical differences in age and gender. Patients who developed SIJ pain after BMAB had older mean age ($p = 0.03$), were more often female ($p < 0.01$). No significant difference in BMI or in the history of lower limb pathology (e.g., peripheral neuropathy, peripheral vascular disease, amputation; $p < 0.01$) was observed between groups. This variable outline supports the correlation of BMAB and the development of subsequent SIJ pain.

The treatment of the SIJ pain included: opiates 65 (83.3%), nonsteroidal anti-inflammatory drugs 14 (18%), gabapentinoids 32 (41.1%), muscle relaxants 10 (12.8%), lidocaine patch 4 (5.1%), physical therapy 48 (61.5%) and SIJ blocks 58 (74.4%), with the SIJ blocks being a diagnostic and therapeutic tool. SIJ blocks were not performed in patients with neutropenia, thrombocytopenia, febrile conditions, therapeutic anticoagulation, contraindications for the use of steroids or per patient's request.

Discussion

The International Association for the Study of Pain defines SIJ pain as pain that arises from the anatomical area of the SIJ [22]. In the general population, up to 25% of patients with persistent mechanical lower back pain below L5 have the diagnosis of SIJ pathology [23]. In the cancer population, the incidence is unknown.

Several studies have suggested that diagnosis of SIJ pain is not reliably confirmed on the basis of physical exam, provocative maneuvers or conventional imaging [2,24]. However, in the oncologic patient, diagnostic imaging should be included to rule out cancer-related complications. Although challenged by some experts, the gold standard in the diagnosis of SIJ pain is the injection of local anesthetics into the joint [25,26]. This procedure is done under imaging guidance (fluoroscopy or ultrasound). When performed with the proper technique, the result is considered positive for pain from SIJ etiology when at least 75% of the pain is relieved [27]. Unfortunately, in the cancer population, the SIJ pain diagnosis is even less clear-cut, owing to the tumor-related and cancer treatment-related pain. With this limitation, there is a possibility that patients with pain from the SIJ are instead coded as lower back pain. With this rationale, we excluded those patients with SIJ pain after BMAB with prior history of lower back pain. The contraindications for the procedure include immunosuppression, thrombocytopenia, active radiation therapy at the SIJ area and ongoing immunotherapy.

Due to the challenges encountered in the diagnosis of SIJ pain in the cancer patient, to our knowledge, this is the first study to evaluate the relationship between BMAB and the subsequent development of SIJ pain. Our findings indicate that a substantial proportion of patients who sought care in our outpatient pain clinic experienced SIJ pain (4.95%). In our study, BMAB was associated with the increased incidence of developing SIJ pain in patients with cancer. Indeed, it was unlikely to see a post-BMAB patient without subsequent SIJ pain (1/79 patients, 1.2%). The period between the BMAB and the development of the SIJ pain suggests a linear relationship of cause. In addition, the time that elapsed between the BMAB and development of SIJ pain of 3.5 (2–6.5) weeks is clearly outside the realm of expected postprocedural inflammation or recovery.

Many potential mechanisms could have contributed to the development of SIJ pain in patients who underwent BMAB in our cohort. BMAB is a traumatic event with disruption of the overlying soft tissue, connective tissue, periosteum and bone cortex. The path of the biopsy needle is frequently close to numerous ligamentous and neurovascular structures, and injury to these structures might be unavoidable. Furthermore, pain can result from disruption of ligamentous structures surrounding the SIJ, resulting in hypermobility, as these structures function primarily to limit motion and provide stability. In such cases, not only can the initial injury to the ligamentous structures of the joint be problematic, but also the biomechanical compensation may contribute to the problem; for example, an altered pattern of lumbopelvic muscle recruitment might occur in patients suffering from SIJ pain [28].

In addition, iatrogenic injury to bone may trigger localized bleeding, with the accumulation of pro-inflammatory mediators. This mechanism is described in the orthopedic literature, with the concept of early fracture hematoma, where genes involved in immunoregulation are up-regulated, and there is an increase in pro-inflammatory cytokines, chemokines and leukocytes [29]. Furthermore, one animal study found that bleeding around neural tissue might result in nerve inflammation and myelin damage [30]. Perineural inflammation is particularly important for SIJ pain, due to a rich innervation of the SIJ by the lateral branches of the dorsal rami of the L4-S3 nerves. Inflammatory changes identified in the network of muscles supporting the SIJ have been reported after BMAB [13]. In combination with the contributions of direct disruption and biomechanical changes, inflammation can promote the development of SIJ pain in patients who undergo BMAB.

In addition to the association between BMAB and SIJ pain, patients with a history of lower back pain often have poor truncal and pelvic stability from weakness and poor motor control, compared with those without pain [31]. Similarly, lower limb anatomical and functional pathology, defined in our study as the presence of peripheral neuropathy, peripheral vascular disease or cancer in the lower extremities or limb amputation (Table 2), likely contributes to the development of SIJ pain. For instance, pain and decreased proprioception and balance alter a patient's gait and have been described in chemotherapy-induced peripheral neuropathy [32], diabetic neuropathy [33], peripheral vascular disease [34] and amputation [35].

Changes in overall gait biomechanics with lower limb pathology increases stress on the major joints, including the SIJ. For these patients, an additional potentially painful procedure, such as BMAB, may 'tip the scale' toward SIJ dysfunction and pain. However, the presence of lower limb pathology was very similar in our study groups (with BMAB and no BMAB) and therefore we did not consider it a determinant differentiating factor in the observed outcome.

Presence of SIJ pain increases morbidity, suffering and cost of care for the cancer patient. Severe cases can be associated with significant disability. The treatment of this pathology includes the use of local and systemic analgesics, physical therapy and interventional procedures such joint injections, radiofrequency denervation and other modalities. Our experience with treating SIJ pain in cancer patients suggests a potential role of preventative interventions after BMAB, which may include postprocedural follow-up, the establishment of pre-emptive home-based physical therapy and early use of analgesics. These efforts will be better evaluated in a prospective study.

Study limitations

This study had several limitations. The single-center and retrospective study design limited the interpretation and generalizability of the data. The risk of selection bias was also present. In addition, there is limited reliance on ICD coding evaluating the association between two variables. Last, in some of our patients, the presence of contraindications to undergo diagnostic SIJ injections limited our diagnostic accuracy and the internal validity of our findings.

Conclusion

BMAB, a commonly performed procedure in the cancer population, may contribute to the development of SIJ pain in these patients. Patient evaluation immediately following the procedure and timely management may help mitigate unnecessary suffering. Further prospective study is necessary.

Future perspective

In the cancer population, a correlation between BMAB and the development of SIJ pain suggests a necessity to perform this procedure under imaging guidance in order to minimize inadvertent violation of the joint and adjacent structures. Similarly, we foresee the routinely implementation of preventative interventions after BMAB, which may include postprocedural follow-up, the establishment of pre-emptive home-based physical therapy and the early use of analgesics. We expect that prospective studies will clearly elucidate this.

Author contributions

Authors had full access to all the data in the study and took responsibility for the integrity of the data and the accuracy of the data analysis. C Roldan designed the protocol of the study. C Roldan, B Huh, T Chai and L Driver reviewed the charts and collected the data, also participated on the manuscript writing. S Thakur participated on manuscript writing. J Song participated as biostatistician and processed the data collected. C Roldan provided revision for intellectual content and final approval of the manuscript.

Financial & competing interests disclosure

The authors have no relevant affiliations or financial involvement with any organization or entity with a financial interest in or financial conflict with the subject matter or materials discussed in the manuscript. This includes employment, consultancies, honoraria, stock ownership or options, expert testimony, grants or patents received or pending, or royalties.

No writing assistance was utilized in the production of this manuscript.

Ethical consent disclosure

Direct patient participation was not necessary, and informed consent was not obtained due to the retrospective nature of the study.

Summary points

- The sacroiliac joint (SIJ) has multiple referred pain patterns due to converging nociceptive afferent neurons originating in the joint and second-order spinal neurons receiving sensory input from the lower extremities.
- Although challenged by some experts, the gold standard in the diagnosis of SIJ pain is the injection of local anesthetics into the joint.
- In the oncologic patient, the diagnosis of SIJ pain should include imaging to rule out organic causes or cancer-related complications.
- Bone marrow aspiration and biopsy (BMAB) is a traumatic event, the path of the biopsy needle is frequently close to numerous ligamentous and neurovascular structures and injury to these structures might be unavoidable.
- In this study, the prevalence of SIJ pain was 4.95%; the external validity is to be determined.
- Statistical analyses revealed higher incidence of patients who developed SIJ pain after BMAB in older age, and in female gender.

References

Papers of special note have been highlighted as: ● of interest; ●● of considerable interest

1. Cohen SP, Chen Y, Neufeld NJ. Sacroiliac joint pain: a comprehensive review of epidemiology, diagnosis and treatment. *Expert Rev. Neurother.* 13(1), 99–116 (2013).
- **Epidemiology of sacroiliac joint pain (SIJ).**
2. Schwarzer AC, Aprill CN, Bogduk N. The sacroiliac joint in chronic low back pain. *Spine* 20(1), 31–37 (1995).
3. Sembrano JN, Polly DW Jr. How often is low back pain not coming from the back? *Spine* 34(1), E27–E32 (2009).
4. Bogduk N. On the definitions and physiology of back pain, referred pain, and radicular pain. *Pain* 147(1–3), 17–19 (2009).
5. Fortin JD, Aprill CN, Ponthieux B, Pier J. Sacroiliac joint: pain referral maps upon applying a new injection/arthrography technique: part II: clinical evaluation. *Spine* 19(13), 1483–1488 (1994).
6. Slipman CW, Jackson HB, Lipetz JS, Chan KT, Lenrow D, Vresilovic EJ. Sacroiliac joint pain referral zones. *Arch. Phys. Med. Rehabil.* 81(3), 334–338 (2000).
7. Kurosawa D, Murakami E, Aizawa T. Referred pain location depends on the affected section of the sacroiliac joint. *Eur. Spine J.* 24(3), 521–527 (2015).
8. Dengler J, Stuessen B, Kools D *et al.* Referred leg pain originating from the sacroiliac joint: 6-month outcomes from the prospective randomized controlled iMIA trial. *Acta Neurochir. (Wien)* 158(11), 2219–2224 (2016).
- **Complexity of the patterns of pain referral from sacroiliac joint.**
9. Van der Wurff P, Buijs EJ, Groen GJ. Intensity mapping of pain referral areas in sacroiliac joint pain patients. *J. Manipulative Physiol. Ther.* 29(3), 190–195 (2006).
10. Domovitev SV, Chandhanayingyong C, Boland PJ, McKeown DG, Healey JH. Conservative surgery in the treatment of giant cell tumor of the sacrum: 35 years' experience. *J. Neurosurg. Spine* 24(2), 228–240 (2016).
11. Manghani M, Loneragan R, Barnsley L. Metastatic prostatic carcinoma mimicking a unilateral sacroiliitis. *Australas. Radiol.* 51, B92–B94 (2007).
12. Bernini L, Manzini CU, Giuggioli D, Sebastiani M, Ferri C. Reactive arthritis induced by intravesical BCG therapy for bladder cancer: our clinical experience and systematic review of the literature. *Autoimmun. Rev.* 12(12), 1150–1159 (2013).
13. Morotti A, Barozzino MC, Guerrasio A. Rare bone marrow biopsy complication: a challenging case of sacroiliitis and *Staphylococcus aureus* sepsis. *Clin. Pract.* 6(1), 823 (2016).
14. Bain BJ. Bone marrow biopsy morbidity and mortality: 2002 data. *Clin. Lab. Hematol.* 26(5), 315–318 (2004).
15. Leukemia & Lymphoma Society. www.lls.org

16. Salem P, Wolverson MK, Reimers HJ, Kudva GC. Complications of bone marrow biopsy. *Br. J. Hematol.* 121(6), 821–821 (2003).
17. Lowenthal R, Taylor B, Jones R, Beasley A. Severe persistent sciatic pain and weakness due to a gluteal artery pseudoaneurysm as a complication of bone marrow biopsy. *J. Clin. Neurosci.* 13(3), 384–385 (2006).
18. McGoldrick NP, Green C, Connolly P. Gluteal compartment syndrome following bone marrow biopsy: a case report. *Acta Orthop. Belg.* 78(4), 548–551 (2012).
- **Outlines one of the suspected mechanisms of SIJ pain after bone marrow aspiration and biopsy.**
19. Neesse A, Kalinowski M, Walther EM, Görg C, Neubauer A. Clinical management of massive retroperitoneal hemorrhage after bone marrow biopsy. *Leuk. Lymphoma* 50(3), 475–477 (2009).
20. Bain B. Bone marrow biopsy morbidity: review of 2003. *J. Clin. Pathol.* 58(4), 406–408 (2005).
21. Konda B, Pathak S, Edwin I *et al.* Safe and successful bone marrow biopsy: an anatomical and CT-based cadaver study. *Am. J. Hematol.* 89, 943–946 (2014).
- **Outlines one of the suspected mechanisms of SIJ pain after bone marrow aspiration and biopsy.**
22. Task Force on Taxonomy of the International Association for the Study of Pain. *Classification of Chronic Pain: Descriptions of Chronic Pain Syndromes and Definitions of Pain Terms.* Merskey H, Bogduk N (Eds). IASP Press, WA, USA (1994).
- **International accepted definitions.**
23. Simopoulos TT, Manchikanti L, Singh V *et al.* A systematic evaluation of prevalence and diagnostic accuracy of sacroiliac joint interventions. *Pain Physician* 15(3), E305–E344 (2012).
24. Slipman CW, Sterenfeld EB, Chou LH, Herzog R, Vresilovic E. The predictive value of provocative sacroiliac joint stress maneuvers in the diagnosis of sacroiliac joint syndrome. *Arch. Phys. Med. Rehabil.* 79, 288–292 (1998).
25. Berthelot JM, Labat JJ, Le Goff B, Gouin F, Maugars Y. Provocative sacroiliac joint maneuvers and sacroiliac joint block are unreliable for diagnosing sacroiliac joint pain. *Joint Bone Spine* 73(1), 17–23 (2006).
- **Gold standard diagnosis of SIJ pain.**
26. Szadek KM, van der Wurff P, van Tulder MW, Zuurmond WW, Perez RS. Diagnostic validity of criteria for sacroiliac joint pain: a systematic review. *J. Pain* 10(4), 354–68 (2009).
- **Gold standard diagnosis of SIJ pain.**
27. King W, Ahmed SU, Baisden J *et al.* Diagnosis and treatment of posterior sacroiliac complex pain: a systematic review with comprehensive analysis of the published data. *Pain Med.* 16(2), 257–265 (2015).
28. Hungerford B, Gilleard W, Hodges P. Evidence of altered lumbopelvic muscle recruitment in the presence of sacroiliac joint pain. *Spine* 28(14), 1593–1600 (2003).
29. Kolar P, Gaber T, Perka C, Duda GN, Buttgerit F. Human early fracture hematoma is characterized by inflammation and hypoxia. *Clin. Orthop. Relat. Res.* 469(11), 3118–3126 (2011).
30. Steinfeldt T, Wiesmann T, Nimphius W *et al.* Perineural hematoma may result in nerve inflammation and myelin damage. *Reg. Anesth. Pain Med.* 39(6), 513–519 (2014).
31. Kim J-W, Kwon O-Y, Kim T-H, An DH, Oh JS. Effects of external pelvic compression on trunk and hip muscle EMG activity during prone hip extension in females with chronic low back pain. *Man. Ther.* 19(5), 467–471 (2014).
32. Miaskowski C, Mastick J, Paul SM *et al.* Chemotherapy-induced neuropathy in cancer survivors. *J. Pain Symptom. Manage.* 54(2), 204–218 (2017).
33. Karmakar S, Rashidian H, Chan C, Liu C, Toth C. Investigating the role of neuropathic pain relief in decreasing gait variability in diabetes mellitus patients with neuropathic pain: a randomized, double-blind crossover trial. *J. Neuroeng. Rehabil.* 11, 125 (2014).
34. Myers SA, Johanning JM, Stergiou N, Celis RI, Robinson L, Pipinos II. Gait variability is altered in patients with peripheral arterial disease. *J. Vasc. Surg.* 49(4), 924–931 (2009).
35. Hendershot BD, Wolf EJ. Persons with unilateral transfemoral amputation have altered lumbosacral kinetics during sitting and standing movements. *Gait Posture* 42(2), 204–209 (2015).