Prospective Observational Study of Donor-Site Morbidity Following Anterior Iliac Crest Bone-Grafting in Orthopaedic Trauma Reconstruction Patients

Bryan J. Loeffler, MD, James F. Kellam, MD, Stephen H. Sims, MD, and Michael J. Bosse, MD

Investigation performed at the Department of Orthopaedic Surgery, Orthopaedic Clinical Research, Carolinas Medical Center, Charlotte, North Carolina

Background: Complications associated with iliac crest bone-graft donor sites have been reported. This prospective study was conducted to determine the prevalence of pain and complications at the iliac crest donor site in patients undergoing treatment of fracture nonunion.

Methods: Ninety-two patients undergoing anterior iliac crest bone-grafting for nonunion or delayed union of a long-bone fracture were prospectively enrolled. Twenty-seven patients undergoing an alternative surgical treatment were enrolled as a control group. Questionnaires including pain on a visual analog scale (0 to 10) at the donor site were completed by patients at two weeks, six weeks, three months, and one year postoperatively. Short Form-36 (SF-36) forms were completed at enrollment and at the time of final follow-up.

Results: The mean pain on the visual analog scale at the donor site was 3.9 at two weeks but rapidly decreased to 1.4 at six weeks and reached 0.3 at one year or more postoperatively (p < 0.001). Only two patients (2%) reported a pain value of >3 at one year or more postoperatively. There were three deep infections (3%) at the donor site, and no patients had a permanent sensory deficit in the lateral femoral cutaneous nerve distribution. At the time of final follow-up (mean, twenty-two months), scores for the SF-36 bodily pain subscale were significantly higher in the iliac crest group than in the control group, indicating a greater improvement in overall bodily pain in the iliac crest group.

Conclusions: Anterior iliac crest bone-grafting for nonunion was a well-tolerated procedure. Substantial, persistent pain at the iliac crest donor site occurred in 2% of patients. Iliac crest bone-grafting did not appear to impair function or well-being compared with alternative treatments.

Level of Evidence: Therapeutic Level II. See Instructions for Authors for a complete description of levels of evidence.

Autologous bone graft, allograft, or bone-graft substitutes are frequently helpful in the treatment of orthopaedic trauma patients[1-3]. Approximately 500,000 bone grafts are performed annually in the United States[4]. Indications applicable to orthopaedic trauma surgery include bone loss, delayed bone-healing, and posttraumatic arthritis. Autogenous

JBJS | *Express*

This article was chosen to appear electronically on August 8, 2012, in advance of publication in a regularly scheduled issue.

A commentary by Thomas A. DeCoster, MD, is linked to the online version of this article at jbjs.org.

TABLE I Demographics of the Iliac Crest and Control Groups*

	Mean Age *(yr)*	Males *(no. [%])*	Diabetics *(no. [%])*	Smokers *(no. [%])*	Mean BMI *(kg/m²)*
ICBG (n = 92)	41	61 (66)	5 (5)	27 (29)	27.5
Control (n = 27)	44	20 (74)	3 (11)	7 (26)	26.1
P value	0.22	0.12	0.49	0.56	0.23

*ICBG = iliac crest bone graft, and BMI = body mass index.

bone is considered the "gold standard" treatment compared with other options because it has osteogenic, osteoconductive, and osteoinductive properties; it is nonimmunogenic; and it does not confer the risk of spreading transmissible infections. The complications reported with autogenous bone-graft harvest sites[1-3,5-18] as well as the availability and reported efficacy of bone-graft substitutes and recombinant bone morphogenetic proteins (BMPs)[19,20] have influenced the choice of graft source for many surgeons.

The existing literature may be difficult to apply to the treatment of orthopaedic trauma patients because of differences in harvest sites, techniques, and volumes of bone graft harvested for a variety of indications[3,6,7,10,12]. The prevalence of complications associated with iliac crest bone-graft donor sites has varied widely and has been reported to be as high as 49%[10]. To our knowledge, a large prospective study of orthopaedic trauma reconstruction patients undergoing anterior iliac crest bone-graft harvesting has not been reported, and data regarding the effects of such harvesting on functional outcomes and general health status are limited[2,9].

The present prospective study was conducted to determine the prevalence of pain and other complications at the iliac crest donor site in orthopaedic trauma reconstruction patients. Donor-site pain scores following two surgical techniques for harvesting iliac crest bone were compared. Additionally, the effect of donor-site harvesting on outcomes was assessed by comparing functional outcome and quality-of-life measures with those of a control group of patients who underwent similar operative procedures without autogenous iliac crest bone-graft harvesting. The study hypotheses were that (1) the prevalence of chronic pain at the iliac crest donor site is lower than the previously reported 25%[10], (2) the overall complication rate at the iliac crest donor site in this population is lower than previously reported, (3) the surgical technique affects postoperative pain scores at the iliac crest donor site, and (4) functional outcomes and quality of life are similar between patients undergoing iliac crest bone-grafting compared with other treatments for fracture nonunion.

Materials and Methods

Ninety-two consecutive orthopaedic trauma reconstruction patients undergoing bone-graft harvesting from the anterior iliac crest for nonunion or delayed union of a long-bone fracture at a single center between January 1, 2007, and October 30, 2009, were prospectively enrolled in an institutional review board-approved study. All patients were eighteen years of age or older. Patients were excluded if they had had a prior iliac crest bone graft or if there were multiple sites of graft harvesting. Twenty-seven consecutive patients un-

dergoing surgical treatment of nonunion without iliac crest bone-grafting were also prospectively enrolled and followed over the same time period.

Patients

Sixty-one of the ninety-two patients in the iliac crest bone graft group were male and thirty-one were female. The mean age was forty-one years (range, eighteen to seventy-one years). Five patients (5%) were diabetic and twenty-seven (29%) smoked. The mean body mass index (BMI) was 28 kg/m² (range, 16 to 43 kg/m²). The demographics of the control group were similar to those of the iliac crest group (Table I). The decision regarding the method of nonunion treatment (iliac crest bone graft, BMP, or another method) was made at the surgeon's discretion.

Operative Techniques

All autografts were cancellous or corticocancellous; there were no structural tricortical grafts. Autograft was harvested from the anterior iliac crest either by a trap door method (n = 55)[11] or by removing a window of cortical bone from the inner table of the ilium (n = 37). In the trap door method, two small vertical osteotomies are connected by a horizontal osteotomy just lateral to the intact medial soft-tissue hinge; the periosteum and fascial attachments of the abdominal wall muscles and iliacus are left intact. The crest is then hinged open like a trap door to access the cancellous bone between the inner and outer tables of the ilium (see Appendix). The trap door is sutured closed after the desired graft has been harvested. When using the inner table harvesting technique, the interval between the abductors and abdominal muscles is entered, and careful elevation of the abdominal wall muscles off the iliac crest and of the iliacus muscle off the inner table of the ilium is performed. A window of cortical bone is then removed in strips from the inner table with an osteotome to access the cancellous bone of the ilium (see Appendix). The incision is closed in layers. With both techniques, the incision is started 1 to 2 cm posterior to the anterior superior iliac spine, to avoid the lateral femoral cutaneous nerve, and is extended along the crest.

Follow-up

Information from the operative record, including the technique of bone graft harvesting, was prospectively entered into a database. All complications related to the donor site were recorded prospectively.

Questionnaires containing visual analog scale (VAS) measures of pain at the donor site and of satisfaction with the cosmesis of the donor site were completed by patients during follow-up visits at two weeks, six weeks, three months, and one year or more postoperatively. VAS pain responses were recorded on a scale of 0 to 10, with a score of 0 representing no pain and 10 indicating the worst pain possible. A score of 0 to 3 was considered to represent mild pain; >3 to 7, moderate pain; and >7, severe pain[21]. VAS cosmesis scores were also recorded on a scale of 0 to 10, with 0 indicating complete dissatisfaction with the scar appearance and 10 indicating complete satisfaction. The questionnaires also asked patients to record any sensory changes at the donor site and surrounding area with use of a diagram. Patients in both groups completed the Short Form-36 (SF-36) questionnaire[22] at enrollment and at the time of final follow-up, one year or more postoperatively. Patients who did not return for follow-up as scheduled were mailed the questionnaires or were interviewed by telephone.

TABLE II Questionnaire Results According to Time*

	Two Weeks	Six Weeks	Three Months	≥1 Year	P Value	95% CI of Change
VAS pain, 0 = no pain†	3.9 ± 2.8	1.4 ± 2.0	0.87 ± 1.6	0.25 ± 1.0	<0.001	−3.3, −3.9
Percentage of patients with moderate or severe pain (VAS > 3)	61.9%	30.4%	14.8%	2.2%	<0.001	
Percentage of patients reporting sensory changes at the donor site	52.8%	27.8%	23.7%	10.3%	<0.001	
VAS cosmesis satisfaction, 10 = completely satisfied†	7.6 ± 2.6	8.0 ± 2.5	8.1 ± 2.4	9.1 ± 1.5	<0.001	0.8, 2.2

*CI = confidence interval, and VAS = visual analog scale. †Values are given as the mean and the standard deviation. Responses were on a scale of 0 to 10.

In the iliac crest group, follow-up data were obtained for eighty-three patients (90%) at two weeks postoperatively, seventy-six (83%) at six weeks, eighty-three (90%) at three months, and seventy-five (82%) at the time of final follow-up, which occurred at a mean of twenty-two months (range, twelve to forty-eight months) after the iliac crest bone-grafting was performed. Attrition analyses demonstrated that there were no significant differences in measured baseline characteristics between the patients who completed the follow-up and those who were lost to follow-up.

The SF-36 is a commonly used measure of self-reported general health status and assessment of function. It allows for comparison between individuals with the same condition as well as comparison with the general population. Subscale scores measure various domains of health and quality of life, and the physical and mental component summary scores represent the primary dimensions of health. The physical and mental component summary scores can range from 0 to 100 points and are standardized to population norms, with the mean score in the general population equaling 50 points and one standard deviation equaling 10 points[22]. A higher score indicates better function. The SF-36 questionnaire was completed at the time of enrollment by seventy-six patients in the iliac crest group and twenty-four in the control group. The SF-36 questionnaire was then completed again at the time of final follow-up by fifty-four patients (71% of those who completed the SF-36 at enrollment) in the iliac crest group and twenty-two (92%) in the control group (overall SF-36 follow-up, 76%).

A VAS instrument is commonly used to assess pain, and both the SF-36 and VAS pain have been used as outcome measures in trauma reconstruction patients[23]. The SF-36 is a general measure of health-related quality of life, and its sensitivity to detect small functional differences in this population has not been proven. Nevertheless, the SF-36 is a valuable tool for assessing general health and overall quality-of-life outcomes.

Statistical Analysis
Repeated-measures analysis of variance and Cochran Q tests were used to determine whether VAS and percentage values, respectively, differed among the four time points. The Student t test was used to compare demographics, SF-36 scores, and donor-site pain scores according to surgical technique at each time interval.

Source of Funding

Results
Pain
The mean VAS pain score at the iliac crest harvest site declined significantly over the follow-up period to 0.3 (on a scale of 0 to 10) at the time of final follow-up (p < 0.001). The percentage of patients with a score of >3 (at least a moderate level of pain) also decreased over time (p < 0.001) (Table II). By three months postoperatively, only one patient (1%) had a VAS pain score of >5 on a scale of 0 to 10, and the mean score was 0.9. We were unable to detect a significant difference in the VAS pain score between the two surgical techniques at any time interval (see Appendix).

Infection
There were three deep donor-site infections (3%), which were successfully treated with irrigation, debridement, and antibiotic treatment. All three of these patients had known risk factors for wound complications[24-27]. One patient was diabetic and had a BMI of 35 kg/m², the second was a smoker and had a BMI of 45 kg/m², and the third was a smoker and had not received preoperative intravenous antibiotics. The latter patient had a history of an infected nonunion, and antibiotics were delayed to reduce the chance of obtaining a false-negative culture at the recipient nonunion site. Cultures of tissue from the recipient site at the time of bone-grafting were negative, and the microorganism previously identified at the site of the nonunion was a coagulase-negative Staphylococcus, which was different from the bacterium involved in the iliac crest infection.

The infection was caused by methicillin-sensitive Staphylococcus aureus (MSSA) in two patients and by methicillin-resistant Staphylococcus aureus (MRSA) in the remaining patient (see Appendix). A single irrigation and debridement of the wound was performed in two patients, and a planned second irrigation was performed two days after the initial debridement in the remaining patient. A six to ten-week course of intravenous antibiotics was administered through a peripherally inserted central catheter (PICC) line, and one patient received oral antibiotics for an additional four months. There were no signs of persistent infection at the time of final follow-up. The final outcomes for these three patients were not statistically different from those of the patients whose course was not complicated by infection. No cases of superficial infection were reported.

Sensory Changes
No patients had documented permanent loss of sensation in the lateral femoral cutaneous nerve distribution. Seven patients

(8%) had some alteration of sensation in the lateral femoral cutaneous nerve distribution at the initial postoperative visit, which resolved completely by three months postoperatively in six patients. The remaining patient was lost to follow-up. In addition, the percentage of patients with any type of sensory changes at the site of the incision decreased from 53% at two weeks postoperatively to 10% at one year after surgery (p < 0.001) (Table II).

Miscellaneous Complications

No arterial injury, herniation, pelvic instability, fracture, or other complications occurred at the donor site.

Functional Health and Well-Being

SF-36 scores in the iliac crest group improved significantly from the time of enrollment until the final follow-up visit for seven of the eight subscales and both of the summary scores; there was no significant difference for the general health subscale. SF-36 scores in the control group improved significantly for three of the eight subscales and the physical component summary score (see Appendix). Although none of the SF-36 subscales or summary scores had differed significantly between the iliac crest and control groups at the time of enrollment, the score on the bodily pain subscale was significantly higher (better) in the iliac crest group than in the control group at the time of final follow-up (p = 0.020) (see Appendix). The effect of the bone-graft harvesting procedure on function and overall well-being was also assessed by comparing the SF-36 scores between the subset of patients in each group who achieved union. The postoperative SF-36 scores in these patients did not differ significantly between the iliac crest and control groups (see Appendix).

Discussion

I liac crest bone graft has traditionally been recognized as the gold standard among bone-graft options for the treatment of fracture nonunion. It is osteogenic, osteoinductive, osteoconductive, and confers no risk of immunogenicity or infection transmission. Despite these advantages over alternative graft options, concerns regarding donor-site morbidity may influence the decision to obtain bone graft from the iliac crest.

Summers and Eisenstein reported a 25% prevalence of substantial, chronic donor-site pain in a retrospective series of patients undergoing lumbar fusion in which large blocks of corticocancellous bone were harvested as structural grafts[10]. However, complication data for this type of bone graft may not be applicable to patients undergoing treatment of fracture nonunion with a cancellous or corticocancellous graft. In addition, it may be difficult to differentiate donor-site from recipient-site pain in patients undergoing lumbar spine fusion because of the proximity of the donor and recipient sites[28]. Several other retrospective studies have evaluated iliac crest donor-site morbidity[1,5-8,10,29]. The most frequently cited paper in the history of the *Journal of Orthopaedic Trauma* is a retrospective review of 243 autogenous bone grafts performed with a variety of donor sites in a heterogeneous patient population by many surgeons from multiple specialties[30]. In this oft-cited article, the overall major complication rate was reported to be 8.6%, and the minor complication rate was 20.6%. The present study contributes prospectively acquired data on morbidity at the donor site in orthopaedic trauma reconstruction patients undergoing anterior iliac crest bone-grafting.

The reported prevalence of pain lasting more than three months following anterior iliac crest bone-grafting has been variable. DeOrio and Farber reported that four (3%) of 128 patients in their retrospective survey had pain for more than seven months[5]. Silber et al. performed a retrospective survey involving mailed questionnaires and telephone interviews. Thirty-five (26%) of 134 patients in their series reported pain at the donor site, with a mean VAS score of 3.8 (on a scale of 0 to 10) in these patients at a mean of four years postoperatively[8]. Ahlmann et al. sent a questionnaire asking patients to retrospectively grade the severity of donor-site pain. Transient pain was reported by 5% of patients, and only one patient (2%) reported residual pain lasting more than six months after anterior iliac crest bone-grafting[6]. Westrich et al. reported a 2% prevalence of moderate pain in a series of 170 patients undergoing harvesting of tricortical corticocancellous grafts or grafts obtained by a trap door technique[1]. Summers and Eisenstein reported substantial chronic pain in 25% of patients and an acceptable amount of pain in an additional 24%[10]. In the present series, moderate donor-site pain was present in only two patients (2%) at twelve months or more postoperatively. A comparison of our two harvesting techniques did not demonstrate a significant effect on the VAS pain score.

The reported prevalence of deep infection following harvesting of iliac crest bone graft has varied from 0% to 7.5%[1,5,6,29]. In the present series, the prevalence of deep infection requiring irrigation, debridement, and antibiotics was 3%, which was within the range of previously reported values. All three deep infections in the present series occurred in patients with known risk factors for wound complications[24-27]. These infections were all successfully treated with surgical debridement and a course of antibiotics, with no effect on long-term results.

Sensory changes may occur after harvesting of iliac crest bone graft. An anterior approach may result in lateral femoral cutaneous nerve symptoms[7,10,11], whereas a posterior approach is associated with potential injury to the superior cluneal nerves[12]. Ahlmann et al. reported that 8% of patients had transient sensory disturbances in the lateral femoral cutaneous nerve distribution, and 5% had residual symptoms persisting for six months or more postoperatively[6]. Use of an anterior approach in the present series resulted in an 8% prevalence of transient paresthesias in the lateral femoral cutaneous nerve distribution, which resolved by three months postoperatively. In addition, one of the most common complications after iliac crest bone harvesting is chronic alteration in skin sensation over the incision[7]. Silber et al. reported that twenty-one patients (16%) had abnormal sensations at the donor site and 5% reported discomfort with clothing[8]. Only 10% of patients in the present series reported any degree of alteration in skin sensation at the iliac crest incision at one year postoperatively.

Satisfaction with donor-site cosmesis was high in the present series. The mean VAS score for donor-site cosmesis was >9 on a scale of 0 to 10 at the most recent follow-up, indicating a high degree of satisfaction. This score also increased significantly over the duration of the study. Silber et al. reported a 93% satisfaction with the cosmetic result[8]. Cosmetic defects are likely more commonly related to the harvest of structural grafts that involve removal of the superior pelvic brim. The additional scar associated with harvesting of a nonstructural autograft from the anterior iliac crest appears to be well tolerated.

Several rare but severe complications have also been reported after iliac crest bone graft harvesting. These include arterial injury[15], abdominal herniation[17], pelvic instability[14], and fracture[6,13,16]. These complications are more often reported following the harvesting of large structural grafts. None of these rare complications occurred in the present series.

Although the iliac crest and control groups were not randomized, the SF-36 scores and other demographics at the time of enrollment were similar. The number of SF-36 subscale scores that had improved significantly at more than one year postoperatively was greater in the iliac crest group than in the control group. The SF-36 bodily pain subscale score at the time of final follow-up was significantly higher (indicating a lower level of overall bodily pain) in the iliac crest group than in the control group. The data indicated that harvesting bone graft from the anterior iliac crest did not negatively impact functional outcomes compared with alternative treatments.

The findings of this study are limited to patients undergoing anterior iliac crest bone-grafting using either a trap door technique or a technique utilizing a cortical window in the inner table of the ilium. Donor-site morbidity may vary depending on the harvest site, technique, and volume of bone graft harvested, so the findings are not universally applicable to patients undergoing autogenous bone-grafting. Although the

SF-36 and VAS pain are validated outcome measures, the SF-36 is a general measure of health-related quality of life, and its sensitivity to detect small functional differences in this population has not been proven. The effects of both the bone-graft harvesting and the nonunion being treated contributed to the final outcome measured by the SF-36. The present study included no attempt to measure the efficacy of iliac crest bone-grafting compared with other treatments for nonunion. Finally, the clinical importance of pain in the early postoperative period (as reflected in the mean VAS pain score of 4 at two weeks) is not known.

In conclusion, substantial persistent pain at the iliac crest donor site was rare, and iliac crest bone-grafting did not appear to impair general well-being compared with alternative treatments for long-bone fracture nonunion.

Appendix

Tables showing VAS pain levels according to surgical technique, characteristics of the three patients with deep infection at the donor site, SF-36 scores according to time, and SF-36 scores of patients who achieved fracture union as well as figures showing the two surgical techniques and SF-36 scores at the time of final follow-up are available with the online version of this article as a data supplement at jbjs.org. ∎

Bryan J. Loeffler, MD
James F. Kellam, MD
Stephen H. Sims, MD
Michael J. Bosse, MD
Department of Orthopaedic Surgery, Orthopaedic Clinical Research, Carolinas Medical Center, 1320 Scott Avenue, Charlotte, NC 28204.
E-mail address for B.J. Loeffler: bloeffler20@gmail.com

References

1. Westrich GH, Geller DS, O'Malley MJ, Deland JT, Helfet DL. Anterior iliac crest bone graft harvesting using the corticocancellous reamer system. J Orthop Trauma. 2001 Sep-Oct;15(7):500-6.

2. Singh JR, Nwosu U, Egol KA. Long-term functional outcome and donor-site morbidity associated with autogenous iliac crest bone grafts utilizing a modified anterior approach. Bull NYU Hosp Jt Dis. 2009;67(4):347-51.

3. Younger EM, Chapman MW. Morbidity at bone graft donor sites. J Orthop Trauma. 1989;3(3):192-5.

4. Greenwald AS, Boden SD, Goldberg VM, Khan Y, Laurencin CT, Rosier RN; American Academy of Orthopaedic Surgeons. The Committee on Biological Implants. Bone-graft substitutes: facts, fictions, and applications. J Bone Joint Surg Am. 2001;83-A Suppl 2 Pt 2:98-103.

5. DeOrio JK, Farber DC. Morbidity associated with anterior iliac crest bone grafting in foot and ankle surgery. Foot Ankle Int. 2005 Feb;26(2):147-51.

6. Ahlmann E, Patzakis M, Roidis N, Shepherd L, Holtom P. Comparison of anterior and posterior iliac crest bone grafts in terms of harvest-site morbidity and functional outcomes. J Bone Joint Surg Am. 2002 May;84-A(5):716-20.

7. Banwart JC, Asher MA, Hassanein RS. Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. Spine (Phila Pa 1976). 1995 May 1;20(9): 1055-60.

8. Silber JS, Anderson DG, Daffner SD, Brislin BT, Leland JM, Hilibrand AS, Vaccaro AR, Albert TJ. Donor site morbidity after anterior iliac crest bone harvest for single-level anterior cervical discectomy and fusion. Spine (Phila Pa 1976). 2003 Jan 15;28(2):134-9.

9. Goulet JA, Senunas LE, DeSilva GL, Greenfield ML. Autogenous iliac crest bone graft. Complications and functional assessment. Clin Orthop Relat Res. 1997 Jun;(339):76-81.

10. Summers BN, Eisenstein SM. Donor site pain from the ilium. A complication of lumbar spine fusion. J Bone Joint Surg Br. 1989 Aug;71(4):677-80.

11. Kurz LT, Garfin SR, Booth RE Jr. Harvesting autogenous iliac bone grafts. A review of complications and techniques. Spine (Phila Pa 1976). 1989 Dec;14(12): 1324-31.

12. Fernyhough JC, Schimandle JJ, Weigel MC, Edwards CC, Levine AM. Chronic donor site pain complicating bone graft harvesting from the posterior iliac crest for spinal fusion. Spine (Phila Pa 1976). 1992 Dec;17(12):1474-80.

13. Arrington ED, Smith WJ, Chambers HG, Bucknell AL, Davino NA. Complications of iliac crest bone graft harvesting. Clin Orthop Relat Res. 1996 Aug;(329):300-9.

14. Coventry MB, Tapper EM. Pelvic instability: a consequence of removing iliac bone for grafting. J Bone Joint Surg Am. 1972 Jan;54(1):83-101.

15. Escalas F, DeWald RL. Combined traumatic arteriovenous fistula and ureteral injury: a complication of iliac bone-grafting. J Bone Joint Surg Am. 1977 Mar;59(2):270-1.

16. Porchet F, Jaques B. Unusual complications at iliac crest bone graft donor site: experience with two cases. Neurosurgery. 1996 Oct;39(4):856-9.

17. Reid RL. Hernia through an iliac bone-graft donor site. A case report. J Bone Joint Surg Am. 1968 Jun;50(4):757-60.

18. Keller EE, Triplett WW. Iliac bone grafting: review of 160 consecutive cases. J Oral Maxillofac Surg. 1987 Jan;45(1):11-4.

19. Jones AL, Bucholz RW, Bosse MJ, Mirza SK, Lyon TR, Webb LX, Pollak AN, Golden JD, Valentin-Opran A; BMP-2 Evaluation in Surgery for Tibial Trauma-Allgraft (BESTT-ALL) Study Group. Recombinant human BMP-2 and allograft compared with autogenous bone graft for reconstruction of diaphyseal tibial fractures with cortical defects. A randomized, controlled trial. J Bone Joint Surg Am. 2006 Jul;88(7):1431-41.

20. Friedlaender GE, Perry CR, Cole JD, Cook SD, Cierny G, Muschler GF, Zych GA, Calhoun JH, LaForte AJ, Yin S. Osteogenic protein-1 (bone morphogenetic protein-7) in the treatment of tibial nonunions. J Bone Joint Surg Am. 2001;83-A Suppl 1(Pt 2):S151-8.

21. Collins SL, Moore RA, McQuay HJ. The visual analogue pain intensity scale: what is moderate pain in millimetres? Pain. 1997 Aug;72(1-2):95-7.

22. Ware JE Jr, Gandek B. Overview of the SF-36 Health Survey and the International Quality of Life Assessment (IQOLA) Project. J Clin Epidemiol. 1998 Nov;51(11):903-12.

23. Buijze GA, Richardson S, Jupiter JB. Successful reconstruction for complex malunions and nonunions of the tibia and femur. J Bone Joint Surg Am. 2011 Mar 2;93(5):485-92.

24. Lübbeke A, Moons KG, Garavaglia G, Hoffmeyer P. Outcomes of obese and nonobese patients undergoing revision total hip arthroplasty. Arthritis Rheum. 2008 May 15;59(5):738-45.

25. Namba RS, Paxton L, Fithian DC, Stone ML. Obesity and perioperative morbidity in total hip and total knee arthroplasty patients. J Arthroplasty. 2005 Oct;20(7 Suppl 3):46-50.

26. Olsen MA, Nepple JJ, Riew KD, Lenke LG, Bridwell KH, Mayfield J, Fraser VJ. Risk factors for surgical site infection following orthopaedic spinal operations. J Bone Joint Surg Am. 2008 Jan;90(1):62-9.

27. Møller AM, Pedersen T, Villebro N, Munksgaard A. Effect of smoking on early complications after elective orthopaedic surgery. J Bone Joint Surg Br. 2003 Mar;85(2):178-81.

28. Howard JM, Glassman SD, Carreon LY. Posterior iliac crest pain after posterolateral fusion with or without iliac crest graft harvest. Spine J. 2011 Jun;11(6):534-7. Epub 2010 Oct 14.

29. Belthur MV, Conway JD, Jindal G, Ranade A, Herzenberg JE. Bone graft harvest using a new intramedullary system. Clin Orthop Relat Res. 2008 Dec;466(12):2973-80. Epub 2008 Oct 8.

30. Lefaivre KA, Guy P, O'Brien PJ, Blachut PA, Shadgan B, Broekhuyse HM. Leading 20 at 20: top cited articles and authors in the Journal of Orthopaedic Trauma, 1987-2007. J Orthop Trauma. 2010 Jan;24(1):53-8.