



Incidence of donor site morbidity following harvesting from iliac crest or RIA graft



G.M. Calori^{a,*}, M. Colombo^a, E.L. Mazza^a, S. Mazzola^a, E. Malagoli^a, G.V. Mineo^b

^a Reparative Orthopaedic Surgery Department, Orthopaedic Institute Gaetano Pini, University of Milan, Italy

^b University Department of Orthopaedic, Orthopaedic Institute Gaetano Pini, University of Milan, Italy

ARTICLE INFO

Keywords:

Reamer irrigator aspirator
Bone graft
Diamond concept
Polytherapy
Iliac crest
Non-union
RIA
Segmental defect
Bone defect

ABSTRACT

Introduction: Clinical management of non-union of long bone fractures and segmental bone defect is a challenge for orthopaedic surgeons. The use of autologous bone graft (ABG) is always considered the gold standard treatment. Traditional techniques for harvesting ABG from iliac crest usually involve several complications, particularly at the donor site. The Reamer–Irrigator–Aspirator (RIA) is an intramedullary reaming system that generates a large volume of cancellous bone material in a single-step reaming process; this bone material can be collected and potentially used as an ABG source. Our interest is to compare the complications associated with the standard technique of harvesting from iliac crest with those of the innovative RIA harvesting device.

Materials and methods: A database of 70 patients with long bone non-unions was studied. The patients were divided into two groups according to the surgical harvesting technique used: RIA system ABG (35 patients) and iliac crest ABG (35 patients).

Results: At the 12-month follow-up, pain at the donor site was reported in no patients in the RIA system ABG group and five of 35 patients (14.28%) in the iliac crest ABG group. Local infections at the donor site were found in no patients in the RIA system ABG group compared with five patients (14.28%) in the iliac crest ABG group. There were no fractures in the RIA system ABG group and one case (2.85%) of anterior superior iliac spine (ASIS) dislocation in the iliac crest ABG group. No systemic infections were detected in either group.

Discussion: We analysed the scientific literature on the use of RIA technique to collect ABG for use in patients with anthropic–oligotrophic non-unions, with a focus on the complications associated with this technique.

Conclusion: RIA bone graft for the treatment of non-unions and segmental bone defect of long bones seems to be a safe and efficient procedure with low donor site morbidity.

© 2014 Elsevier Ltd. All rights reserved.

Introduction

Fracture non-union occurs in 6% of all fractures; the treatment of critical bone defects requires further surgical intervention [1]. Atrophic non-unions are usually associated with a deprived biological substrate; the gold standard treatment is a stable fixation of the non-union site and a simultaneous use of autologous bone graft (ABG). During the last few years, with advances in every

field of medicine, new alternatives are being developed: mesenchymal stem cells (MSCs) [2–4], growth factors (GFs), such as bone morphogenetic proteins [5–10], and scaffold [11–14]. All these elements have been used as monotherapy. The “diamond concept” [15,16] has recently been defined as a new strategy of biological stimulations combined in polytherapy [17–19]: this involves the utilisation and simultaneous implantation of all three fundamental components of the diamond concept: MSCs, GFs and scaffold. The ABG is the only scaffold that possesses all of the three desirable properties of graft materials: osteogenicity, osteoinductivity and osteoconductivity; however, the use of ABG raises some problems. A major difficulty is the limited availability of ABG; a further complication is the associated donor site morbidity (haematoma, seroma, dysaesthesia, paraesthesia, infection, vascular injury and

* Corresponding author at: Reparative Orthopaedic Surgery Department, Orthopaedic Institute Gaetano Pini, University of Milan, P.za Cardinal Ferrari 1, 20122 Milan, Italy. Tel.: +39 0258296904; fax: +39 0258296905.

E-mail address: gmc@studiocalori.it (G.M. Calori).

iliac crest fracture) [20–27]. The development of a new bone-graft harvesting device, the Reamer–Irrigator–Aspirator (RIA; Synthes, Paoli, PA, USA), provides an additional source of bone: this is a novel reaming system that provides continuous irrigation and suction during reaming of a long bone; the volume of available graft is usually 50 cc or more [28–33]. Clinical studies reported in the literature show no critical weakness at the donor bone after harvesting [34–36]. Analysis of the filtered canal aspirates has revealed the presence of substantial amounts of osteoprogenitor cells, and Schmidmaier et al. reported that the quantity of GFs was higher using RIA than with the gold standard of iliac crest bone graft [37–41]. The aim of the present study was to conduct a retrospective evaluation of our clinical experience in the treatment of recalcitrant long bone non-unions with the RIA system, and to compare the results with patients who received the gold standard treatment with implantation of ABG derived from the iliac crest; our interest is to analyse the complications derived from the harvesting procedure.

Materials and methods

Study design

This is a retrospective clinical study conducted in the Orthopaedic Institute G. Pini (University of Milan) based on a database of patients treated for long bone non-union between January 2010 and January 2013. The objective of this clinical study was to determine whether the use of the RIA system may be safer than the gold standard ABG derived from iliac crest by conducting a systematic evaluation of the intra-operative and postoperative complications with these two techniques. All patients underwent follow-up for a minimum of 12 months.

Patients

Patients affected by long bone non-union with critical bone defects and needing ABG were included in the study. Exclusion criteria were as follows: skeletal immaturity, active infection at the non-union site or active systemic infection, insufficient skin to cover the fracture site and insufficient vascularisation in the non-union bone defect site, non-union due to pathological fracture, and diagnosed autoimmune disease.

Standard demographic patient data were collected and the characteristics of each non-union were documented, including localisation, classification according to the Non-Union Scoring System (NUSS) and number of operations preceding graft insertion. A total of 70 patients (44 male and 26 female) with a mean age of 51.9 ± 6.87 years with long bone non-union met the inclusion criteria. Location of the non-unions was as follows: tibia (27 patients), femur (6 patients), humerus (17 patients), ulna (8 patients) and radius (12 patients). The patients were divided into two groups according to the surgical treatment received: RIA system ABG (35 patients; 23 males and 12 females) and iliac crest ABG (35 patients; 21 males and 14 females). The mean age of the RIA system ABG group was 50.17 ± 6.34 years and of the iliac crest ABG group was 53.62 ± 6.95 years. In the RIA system ABG group, there were 14 tibia non-unions, four femur, eight humerus, five ulna and four radius; in the iliac crest ABG group, there were 16 tibia non-unions, three femur, seven humerus, five ulna and four radius. In the group treated with RIA system ABG, the mean NUSS score was 61.37 ± 7.49 points; the non-union persisted for 16.57 ± 5.06 months before administration of the study treatment and the number of surgical interventions conducted previously for the treatment of non-union was 3.42 ± 1.35 . In the group treated with iliac crest ABG, the mean NUSS score was 59.88 ± 6.35 points; the non-union persisted for 17.51 ± 4.98 months before administration of the study treatment

and the number of surgical interventions conducted previously for the treatment of non-union was 3.05 ± 1.16 .

Procedure

All patients in the iliac crest ABG group underwent complete bone debridement of the non-union, followed by implantation of ABG collected from the iliac crest and a stable fixation provided by nails or plates. Twenty-five of the 35 patients in the RIA system ABG group were treated with the Masquelet technique: the first surgical step was characterised by soft tissue and bone debridement and by the placement of antibiotic cement spacer into the bone defect to prevent fibrous tissue ingrowth into the recipient site. Other roles of the cement spacer are to induce a vascularised membrane that protects the bone graft, and to secrete and create a “biological chamber” [42]. After almost two months, the cement spacer is removed and the gap is filled with ABG collected from the femur using the RIA system; the stabilisation of the non-union is provided by plates. The other 10 patients in the RIA system ABG group were treated in one surgical step with bone debridement and implantation of ABG collected from the femur using the RIA device.

Outcome assessments

The study protocol included two different outcomes: the primary endpoint was to compare the complications at the donor site between the RIA system ABG group and the iliac crest ABG group; the secondary endpoint was the evaluation of blood loss with the two different treatments. All patients were evaluated preoperatively, postoperatively and 1, 3, 6 months and 1 year after the surgical intervention using a clinical and radiological assessment; a CT evaluation was performed in selected patients. Pain during follow-up was evaluated using the Visual Analogue Scale (VAS); a value higher than 5/10 points was considered significant. Complications were divided into two groups: local complications (infections, fractures and pain at the donor site) and systemic complications (infections). Haemoglobin levels were measured preoperatively and post-harvesting. Total bone loss and haemoglobin loss during surgery were evaluated.

Results

At the 1-month follow-up, pain at the donor site was reported in 30 of 35 patients (85.7%) in the RIA system ABG group and in 34 of 35 patients (97.14%) in the iliac crest ABG group. Pain at the donor site at the 6-month follow-up was reported in four patients (11.42%) in the RIA system ABG group and 11 patients (31.42%) in the iliac crest ABG group. No patients reported pain at the donor site at the 12-month follow-up in the RIA system ABG group compared with five patients (14.28%) in the iliac crest ABG group. There were no local infections at the donor site in the RIA system ABG group compared with five (14.28%) cases in the iliac crest ABG group. There were no fractures in the RIA system ABG group and one case (2.85%) of anterior superior iliac spine (ASIS) dislocation in the iliac crest ABG group.

A rupture of the RIA device was recorded, specifically a rupture of the cannula that covers the reamer, with relative detachment of the reamer head. Using the olive of the dedicated guide wire, the surgeon was able to remove the residue of the device without complications (Fig. 1). Also observed in the RIA group in a young patient with high bone resistance was the presence of metallic debris at the harvesting site in the femur (Fig. 2A) and at the graft site in the forearm (Fig. 2B). No systemic infections were detected in either group.



Fig. 1. Intraoperative fluoroscopic image showing the rupture of the device.

The mean preoperative and postoperative haemoglobin levels in the RIA system ABG group were 13.78 ± 0.80 g/dl and 12.12 ± 1.30 g/dl, respectively, which is a decrease of 1.66 g/dl. Blood loss during surgery was 572.85 ± 195.66 cc. In the iliac crest ABG group, the mean preoperative and postoperative haemoglobin levels were 13.55 ± 0.83 g/dl and 12.91 ± 0.78 g/dl, respectively, which is a decrease of 0.64 g/dl. Blood loss during surgery was 243.42 ± 132.93 cc.

Discussions

The treatment of bone defects has improved greatly in recent years. When choosing an optimal treatment the surgeon must evaluate the size of bone defect, quality of soft tissue, age of the patient, any comorbidity and the presence or absence of local or systemic infections. The two main types of treatment are bone transport and bone grafting. Bone transport requires considerable surgical experience, is associated with common complications and is a long-lasting therapy. Bone grafting techniques, such as the free vascularised fibula graft procedure, requires a microvascular approach performed by well-trained surgeons and it sacrifices a healthy limb with no certain results. Alternatives are ABG from the iliac crest or from RIA. The choice of the type of graft must be made on the basis of an appropriate preoperative planning and after an appropriate staging and consideration of graft volumes. The gold standard source for ABG is usually the iliac crest, but good clinical results have been shown recently with RIA system ABG. RIA was developed primarily in an attempt to reduce the incidence of fat embolism and thermal necrosis that can complicate reaming/nailing of long-bone fractures. RIA removes marrow contents and reduces intra-medullary pressure whilst operating at decreased reaming temperatures. Another indication of RIA reported by the scientific community is treatment of postoperative osteomyelitis by providing intramedullary debridement and lavage [43,44]. The last indication for the RIA system is the treatment of non-union using aspirated bone fragments as bone graft and harvesting MSCs. Schmidmaier compared quantitative levels of GFs from RIA aspirate, iliac crest bone graft and platelet



Fig. 2. Post-operative X-ray images of the femur (A) and of the forearm (B) showing metallic debris.

preparations; higher levels of five of seven GFs were obtained from intramedullary reaming compared with iliac crest graft [40]. The GFs included fibroblast growth factor (FGF α), platelet-derived growth factor (PDGF), insulin growth factor (IGF-I), bone morphogenetic protein (BMP-2) and transforming growth factor (TGF- β 1).

We analysed the scientific literature on the use of the RIA technique to collect ABG for use in patients with anthropic-oligotrophic non-unions, with a focus on the complications associated with this technique. Various complications may occur, some of which are not related to the harvest technique, including a too medial entry point of the reamer, which may lead to weakening of the femoral neck. Other complications are specific and should be avoided by using a rigorous technique.

Belthur et al. [32] reported a 4.8% complication rate in a retrospective comparative study of 41 patients with an unmatched iliac crest bone graft control group; patients in the femoral RIA harvesting group reported lower overall pain scores than those in the control group during all postoperative periods. There were no documented infections or revision procedures. An anterior distal femoral breach and impending femoral neck fracture were reported.

Newman et al. [28] described the success of this technique in a small series of 10 non-union patients, with 9 of 10 patients achieving union and only one minor complication (asymptomatic hypertrophic scar formation over the donor site incision).

Lowe et al. [45] published a case series of complications related to the RIA technique: acute RIA-associated events that necessitated an additional procedure or altered postoperative rehabilitation were described for two patients, and four patients fractured through their donor site in the early postoperative period.

Finkemeier et al. [46] had one operative revision for infection after RIA in an open tibial fracture, a failed distal tibial non-union and a patient with transient knee pain in a series of 23 procedures.

McCall et al. [47] presented their experience in segmental bone defect treatment with RIA harvested bone graft in 20 patients; there were no complications reported.

Quintero et al. [48] reported 20 consecutive RIA cases for 18 femoral and two tibial non-unions. No significant pain, infection or antalgic gait was reported postoperatively. Although there were no revision surgeries, three intraoperative complications were documented: one breach of the anterior distal femur cortex; an intra-articular medial femoral condyle guide wire penetration and in one patient the reamer became lodged in the isthmus area during a second pass over a pre-bent guide wire.

Stafford et al. [29] performed a retrospective study on 42 patients and there were no intraoperative or postoperative complications identified with the use of the RIA bone graft harvest.

Kanakaris et al. [49] conducted a retrospective study on a group of 18 patients and observed three types of complication: haematomas in two (11%) patients, hardware dismantling in one (5.5%) patient, and persistent non-union in one patient.

Qvich et al. [50] evaluated donor site morbidity and complication rate associated with the RIA system for intramedullary, non-structural autogenous bone graft harvesting: the complication rate in 204 RIA procedures in 184 patients was 1.96% ($N = 4$).

A careful analysis of the complications associated with the RIA technique reported in the literature enables the surgeon to identify some tips and tricks to achieve the best treatment results. The orthopaedic surgeon should carefully evaluate the patient during preoperative planning and by intraoperative fluoroscopic monitoring during the reaming process. A history of osteoporosis or a radiographic appearance of osteopenia could be considered a patient-specific risk factor for subsequent fracture after intramedullary bone graft harvesting. Part of the preoperative plan must include a precise measure of the canal diameter to enable the surgeon to choose the right size of reamer head to collect the required quantity of ABG and to reduce cortical impairment. Also, according to the literature, patients with healthy skeletal systems may sustain an iatrogenic fracture after RIA bone graft harvesting. The current study has several weaknesses, including the small population size, enrolled in a single centre, and the lack of evaluation of the harvested bone quantity, which may influence the complication rate.

Conclusion

The RIA technique seems to be well tolerated and relatively safe. The amount of blood lost during the procedure with the RIA system is higher than with harvesting from the iliac crest, but the resulting anaemia is rarely clinically significant or requires blood transfusion. There are many options for treating non-unions and bone defects: bone transport and free vascularised fibula grafts (both of which require training and expertise), and defect-filling treatment options with ABG, which have shown similar success rates and are technically less demanding for the surgeon and patient. RIA graft has many characteristics that warrant its consideration as a new gold standard for bone defect non-union surgery, particularly its versatility and short learning curve for the surgeon. The reaming debris obtained with RIA has been shown to contain elevated levels of FGF- α , PDGF, IGF-I, TGF- β 1 and BMP-2 and multipotent stem cells; this discovery reduces the need for

utilisation of synthetic and expensive GFs to help the union. The graft materials provided with the RIA technique satisfy all the fundamental properties of graft materials: osteogenicity, osteoconductivity and osteoinduction, but to reach the best results in the treatment of the non-union the appropriate mechanical environment must be provided according with the “diamond concept”. The quality of the bone graft taken with the RIA technique only enables usage as a filler. RIA graft is a cancellous bone and is particularly useful as a filler in large bone defects, applying the principle of the “biological chamber”. If the case requires stability, therefore, a better option is to use a tricortical bone graft. The scientific community is only just starting to use RIA; many more studies must be performed to validate this technique.

Conflict of interest statement

The authors declare that they have no conflicts of interest concerning this article. No financial support has been received by the authors for the preparation of this manuscript.

References

- [1] Tzioupis C, Giannoudis PV. Prevalence of long-bone non-unions. *Injury* 2007;38(Suppl. 2):S3–9.
- [2] Jones E, Yang X. Mesenchymal stem cells and bone regeneration: current status. *Injury* 2011;42:562–8.
- [3] Papathanasopoulos A, Giannoudis PV. Biological considerations of mesenchymal stem cells and endothelial progenitor cells. *Injury* 2008;39(Suppl. 2):S21–32.
- [4] Pountos I, Corscadden D, Emery P, Giannoudis PV. Mesenchymal stem cell tissue engineering: techniques for isolation, expansion and application. *Injury* 2007;38(Suppl. 4):S23–33.
- [5] Kanakaris NK, Calori GM, Verdonk R, Burssens P, De Biase P, Capanna R, et al. Application of BMP-7 to tibial non-unions: a 3-year multicenter experience. *Injury* 2008;39(Suppl. 2):S83–90.
- [6] Kanakaris NK, Lasanianos N, Calori GM, Verdonk R, Blokhuis TJ, Cherubino P, et al. Application of bone morphogenetic proteins to femoral non-unions a 4-year multicentre experience. *Injury* 2009;40(Suppl. 3):S54–61.
- [7] Calori GM, Tagliabue L, Gala L, d'Imporzano M, Peretti G, Albisetti W. Application of rhBMP-7 and platelet-rich plasma in the treatment of long bone non-unions: a prospective randomised clinical study on 120 patients. *Injury* 2008;39:1391–402.
- [8] Moghaddam A, Elleser C, Biglari B, Wentzensen A, Zimmermann G. Clinical application of BMP 7 in long bone non-unions. *Arch Orthop Trauma Surg* 2010;130:71–6.
- [9] Schmidmaier G, Schwabe P, Wildemann B, Haas NP. Use of bone morphogenetic proteins for treatment of non-unions and future perspectives. *Injury* 2007;38(Suppl. 4):S35–41.
- [10] Blokhuis TJ, Calori GM, Schmidmaier G. Autograft versus BMPs for the treatment of non-unions: what is the evidence? *Injury* 2013;44(Suppl. 1):S40–2.
- [11] De Long WG, Einhorn TA, Koval K, McKee M, Smith W, Sanders R, et al. Bone grafts and bone graft substitutes in orthopaedic trauma surgery. A critical analysis. *J Bone Joint Surg Am* 2007;89(3):649–58.
- [12] Giannoudis PV, Chris Arts JJ, Schmidmaier G, Larsson S. What should be the characteristics of the ideal bone graft substitute? *Injury* 2011;42(Suppl. 2):S1–2.
- [13] Calori GM, Mazza E, Colombo M, Ripamonti C. The use of bone-graft substitutes in large bone defects: any specific needs? *Injury* 2011;42(Suppl. 2):S56–63.
- [14] Janicki P, Schmidmaier G. What should be the characteristics of the ideal bone graft substitute? Combining scaffolds with growth factors and/or stem cells. *Injury* 2011;42(Suppl. 2):S77–81.
- [15] Giannoudis PV, Einhorn TA, Marsh D. Fracture healing: the diamond concept. *Injury* 2007;38(Suppl. 4):S3–6.
- [16] Giannoudis PV, Einhorn TA, Schmidmaier G, Marsh D. The diamond concept – open questions. *Injury* 2008;39(Suppl. 2):S5–8.
- [17] Calori GM, Mazza E, Colombo M, Ripamonti C, Tagliabue L. Treatment of long bone non unions with polytherapy: indications and clinical results. *Injury* 2011;42:587–90.
- [18] Calori GM, Colombo M, Ripamonti C, Bucci M, Fadigati P, Mazza E, et al. Polytherapy in bone regeneration: clinical applications and preliminary considerations. *Int J Immunopathol Pharmacol* 2011;24(1):85–9. S2.
- [19] Calori GM, Colombo M, Mazza E, Ripamonti C, Mazzola S, Marelli N, et al. Monotherapy vs. polytherapy in the treatment of forearm non-unions and bone defects. *Injury* 2013;44(Suppl. 1):S63–9.
- [20] Ahlman E, Patzakis M, Roidis N, Shepherd L, Holtom P. Comparison of anterior and posterior iliac crest grafts in terms of harvest-site morbidity and functional outcomes. *J Bone Joint Surg Am* 2002;84-A:716–20.

- [21] Younger EM, Chapman MW. Morbidity at bone graft donor sites. *J Orthop Trauma* 1989;3:192–5.
- [22] Kim DH, Rhim R, Li L, Marthas J, Swaim BH, Banco RJ, et al. Prospective study of iliac crest bone graft harvest site pain and morbidity. *J Spine* 2009;9(11):886–92.
- [23] Banwart JC, Asher MA, Hassanein RS. Iliac crest bone graft harvest donor site morbidity. A statistical evaluation. *Spine (Phila Pa 1976)* 1995;20:1055–60.
- [24] Goulet JA, Senunas LE, De Silva JL, Greenfield ML. Autogenous iliac crest bone graft. Complication and functional assessment. *Clin Orthop Relat Res* 1997;339:76–81.
- [25] Arrington ED, Smith WJ, Chambers HG, Bucknell AK, Davino NA. Complications of iliac crest bone graft harvesting. *Clin Orthop Relat Res* 1996;329:300–9.
- [26] Sen MK, Miclau T. Autologous iliac crest bone graft: should it still be the gold standard for treating nonunions? *Injury* 2007;38(Suppl. 1):S75–80.
- [27] Seiler 3rd JG, Johnson J. Iliac crest autogenous bone grafting: donor site complications. *J South Orthop Assoc* 2000;9:91–7.
- [28] Newman JT, Stahel PF, Smith WR, Resende MD, Hark DJ, Morgan SJ. A new minimally invasive technique for large volume bone graft harvest for treatment of fracture non-unions. *Orthopedics* 2008;31(3):257–61.
- [29] Stafford PR, Norris BL. Reamer-irrigator-aspirator bone graft and bi Masquete technique for segmental bone defect nonunions: a review of 25 cases. *Injury* 2010;41(Suppl. 2):S72–7.
- [30] Cox G, Jones E, McGonagle D, Giannoudis PV. Reamer-irrigator-aspirator indications and clinical results: a systematic review. *Int Orthop* 2011;35(7):951–6.
- [31] Hak DJ, Pittman JL. Biological rationale for the intramedullary canal as a source of autograft material. *Orthop Clin North Am* 2010;41:57–61.
- [32] Belthur MV, Conway JD, Jindal G, Ranade A, Herzenberg JE. Bone graft harvest using a new intramedullary system. *Clin Orthop Relat Res* 2008;466(12):2973–80.
- [33] 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;15:500–6.
- [34] Silva JA, McCormick JJ, Reed MA, Morse AS, Heffernan MJ, Lavado RD, et al. Biomechanical effects of harvesting bone graft with the Reamer/Irrigator/Aspirator on the adult femur: a cadaver study. *Injury* 2010;41(Suppl. 2):S85–9.
- [35] Pratt DJ, Papagiannopoulos G, Rees PH, Quinnell R. The effects of medullary reaming on the torsional strength of the femur. *Injury* 1987;18(3):177–9.
- [36] Finnan RP, Prayson MJ, Goswami T, Miller D. Use of the Reamer-Irrigator-Aspirator for bone graft harvest: a mechanical comparison of three starting points in cadaveric femurs. *J Orthop Trauma* 2010;24(1):36–41.
- [37] Henrich D, Seebach C, Sterlepper E, Tauchmann C, Marzi I, Frank J. RIA reaming and hip aspirate: a comparative evaluation of osteoprogenitor and endothelial progenitor cells. *Injury* 2010;41(Suppl. 2):S62–8.
- [38] Frolke JP, Nulend JK, Semeins CM, Bakker FC, Patka P, Haarman HJ. Viable osteoblastic potential of cortical reamings from intramedullary nailing. *J Orthop Res* 2004;22:1271–5.
- [39] Porter RM, Liu F, Pilapil C, Betz OB, Vrahas MS, Harris MB, et al. Osteogenic potential of a reamer-irrigator-aspirator (RIA) aspirate collected from patients undergoing hip arthroplasty. *J Orthop Res* 2009;27:42–9.
- [40] Schmidmaier G, Herrmann S, Green J, Weber T, Scharfenberger A, Haas NP, et al. Quantitative assessment of growth factors in reaming aspirate, iliac crest, and platelet preparation. *Bone* 2006;39:1156–63.
- [41] Wenisch S, Trinkaus K, Hild A, Hose D, Herde K, Heiss C, et al. Human reaming debris: a source of multipotent stem cells. *Bone* 2005;36:74–83.
- [42] Calori GM, Giannoudis PV. Enhancement of fracture healing with the diamond concept: the role of the biological chamber. *Injury* 2011;42:1191–3.
- [43] Zalavras CG, Singh A, Patzakis MJ. Novel technique for medullary canal debridement in tibia and femur osteomyelitis. *Clin Orthop Relat Res* 2007;461:31–4.
- [44] Bellapianta J, Gerdeman A, Sharan A, Lozman J. Use of the reamer irrigator aspirator for the treatment of a 20-year recurrent osteomyelitis of a healed femur fracture. *J Orthop Trauma* 2007;21(5):343–6.
- [45] Lowe JA, Della Rocca GJ, Murtha Y, Liporace FA, Stover MD, Nork SE, et al. Complications associated with negative pressure reaming for harvesting autologous bone graft: a case series. *J Orthop Trauma* 2010;24(1):46–52.
- [46] Finkemeier CG, Neiman R, Hallare D. RIA: one community's experience. *Orthop Clin North Am* 2010;41:99–103.
- [47] McCall TA, Brokaw DS, Jelen BA, Scheid DK, Scharfenberger AV, Maar DC, et al. Treatment of large segmental bone defects with reamer-irrigator-aspirator bone graft: technique and case series. *Orthop Clin North Am* 2010;41:63–73.
- [48] Quintero AJ, Tarkin ID, Pape HC. Technical tricks when using the reamer-irrigator-aspirator technique for autologous bone graft harvesting. *J Orthop Trauma* 2010;24:42–5.
- [49] Kanakaris NK, Morell D, Gudipati S, Britten S, Giannoudis PV. Reaming-Irrigator-Aspirator system: early experience of its multipurpose use. *Injury* 2011;42(Suppl. 4):S28–34.
- [50] Qvick LM, Ritter CA, Mutty CE, Rohrbacher BJ, Buyea CM, Anders MJ. Donor site morbidity with reamer-irrigator-aspirator (RIA) use for autogenous bone graft harvesting in a single centre 204 case series. *Injury* 2013;4(10):1264–9.