SPARTAN MEDICAL INC.’S REQUEST FOR LINE ITEM ADDENDUM TO INDEFINITE DELIVERY INDEFINITE QUANTITY CONTRACT FOR BIOLOGICAL IMPLANTS

U.S. Department of Veterans Affairs; OPAL Strategic Acquisition Center

VA AWARD # 36C10G18D0143

QUICKDRAW Bone Harvester

Primary Point of Contact:
Craig Schad, Director of Spinal Technologies
Email: craigscad@spartanmedspine.com

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12200 Tech Road, Suite 120
Silver Spring, MD 20904
Telephone/Facsimile: 1.888.240.8091
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To whom it may concern:

I request usage of the following FDA/AATB approved product(s) under Spartan Medical VA Contract 36C10G18D0143 dated 28 September 2018:

- QUICKDRAW Bone Harvester

The items requested meet clinical needs to improve patient outcomes and have the following unique characteristics:

- Technology must be supplied sterile.
- Technology must be supplied in 10mm and 12mm diameters, short and standard length.
- Technology must harvest autogenous bone graft from the anterior and/or posterior superior iliac spine utilizing a minimally-invasive technique
- Technology must reduce risk factors attributed to donor site pain and morbidity, including but not limited to, pain, infection, hematoma, among others which have been identified in the literature to be due directly to incision size
- Technology must decrease donor site incisions to 1-2cm and permit a muscle splitting approach that reduces scarring, blood loss, muscle loss, nerve impingement
- Vendor must have the capability to track devices.

The QUICKDRAW Bone Harvester is indicated for graft harvesting procedures requiring the collection of morselized bone for the purposes of arthrodesis. These procedures include spinal fusion, reconstructive joint surgery, fracture repair, or any procedure requiring morselized autogenous bone graft.

Date: 31 Jan 2019

Spartan Medical Representation Point of Contact: Craig Schad 703-362-3555
February 7, 2019

Spartan Medical, Inc.
Mr. Vincent Proffitt
12200 Tech Road
Suite 120
Silver Spring, MD 20904

Paradigm BioDevices, Inc.
Garrett deBorst
800 Hingham Street Suite 207S
Rockland, MA 02370

Re: Letter of Commitment for Spartan Medical, Inc.

Dear Mr. Proffitt:

Paradigm BioDevices, Inc. ("Manufacturer") is providing this Letter of Commitment ("LOC") in reference to the offer that Spartan Medical, Inc. ("Spartan") intends to submit in response to Solicitation No. 36C10G18R0003 ("Solicitation"), issued by the Department of Veteran’s Affairs ("Government"), along with any addendum requests.

In the event that Spartan is awarded an Indefinite Delivery Indefinite Quantity ("IDIQ") contract / addendum by the Government under the above-referenced Solicitation, this letter hereby certifies that Spartan Medical, Inc., located in Silver Spring, Maryland, is an authorized Government distributor of the biological implants identified in "Attachment 3" for the entire contract period of performance, including option periods. The Manufacturer hereby affirms that Spartan has an uninterrupted source of supply, with sufficient quantities of product, for the duration of the base contract period and all option years, provided that said Spartan remains in good standing with Manufacturer and adheres to all the Original Equipment Manufacturer Partner Agreements.

The Manufacturer is certifying that Spartan is an authorized Government distributor of the sourced items for the duration of the contract period, including options, if applicable and if exercised. Furthermore, the proposed pricing for the items in "Attachment 3" will be fixed for the life of the contract.

The Manufacturer understands that all products offered must be compliant with the Trade Agreements Act ("TAA"). 19 U.S.C. 2501, et seq. As such, all products supplied by the Manufacturer to Spartan will be TAA compliant. Further, while the Manufacturer understands that responsibility for TAA compliance resides with Spartan, the Manufacturer agrees to cooperate with Spartan in support of TAA compliance for the items proposed on this contract and to provide country of origin information. The Manufacturer will notify Spartan immediately upon discovery of any changes in the country of origin of supplied products.
Spartan is authorized to distribute Manufacturer's products at all VA Medical Centers and associated Clinics. Spartan has the authority to promote, distribute, sell and offer technical assistance for Manufacturer the biological implants identified in Attachment 3.

I hereby certify that I am authorized to make the commitments for Manufacturer.

Sincerely,

[Signature]

Garrett deBorst
Vice President of Sales
781-982-9950
“A Novel Minimally-invasive Technique for Harvesting Iliac Crest Bone Graft”
S. Grewal, M.D., K. Parsa, D.O., S. Pirris, M.D., Mayo Clinic, Jacksonville, FL

- 21 patients underwent lumbar fusion w/ mean F/U of 3 mos.
- 67% of patients undergoing TLIF with MIS bone grafting could not tell they had a bone graft harvest.
- 33% could identify with only 14% being confident.
- 10% of patients had only “mild” pain at F/U.
- No infections at donor site were reported.

The study concluded, “...(we) describe a minimally-invasive procedure to harvest ICBG. Pain at the graft site was either non-existent or mild enough that patients were unable to accurately define their graft site.”

Surgeon Surveys & Testimonials
- 100% of surgeons surveyed witnessed a reduction in incision size & harvest time vs. previous techniques.
- 100% of surgeons surveyed stated Quickdraw was beneficial to them.

“Just wanted to give you an update that as of this AM (24-hr post-op), the patient stated that she has had little to no pain at her graft site. To me, that is impressive since that is usually most patients’ biggest complaint after surgery...”

Unsolicited testimonial from Jodi S., RN 9/18/15
MIS DILATION
• Muscle can be split via percutaneous guidance & dilation techniques.
• Incisions can be reduced 70% to 90%.
• Protects surrounding tissue.

UNIVERSAL INSTRUMENTATION
• Percutaneous & MIS grafting minimizes incision sizes to 1-2 cm.
• Relevant and significant impact on O.R. bone graft expense in orthopedic, spine, and oral-maxillofacial procedures.
• Reduces risk factors contributing to donor site pain & morbidity.
• Superior clinical performance in over 20,000 cases.
• Clinical track record of success & safety.

CANNULA
• Available to control the sterile disposable cutter tip and permit sweeping of the iliac crest.

STERILE & DISPOSABLE
• 10mm and 12mm diameters
• Short & standard lengths
• Completely sterile packaged option
• Sterile cutter with reusable universal instrumentation

www.paradigmbiodevices.com
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Unsolicited testimonial from Jodi S., RN 9/18/15
NEW Disposable MIS Sterile Kit
Catalogue # 988-1000SK

Packaged one (1) per kit

Kit Includes:

- Plunger
- Bone Punch / Guide Wire
- Harvester

Manufactured by:
Paradigm BioDevices, Inc.
800 Hingham St. Ste 207S
Rockland, MA 02370
www.paradigmbiodevices.com
888-698-7778  781-982-9950

ISO 13485 / EN 2012 Certified
Proudly made in the U.S.A.
August 7, 2018

To whom it may concern:

Paradigm BioDevices is the manufacturer of the QuickDraw Bone Harvester™. This device is a Class I manual orthopedic instrument registered with the FDA. The registration can be found on the FDA website under Establishment Registration & Device Listing or by following this link: http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfr/cfrl.cfm?id=459111&lpcd=LXH

Code of Federal Regulations
Title 21, Volume 8
(Revised as of April 1, 2013)

PART 888 -- ORTHOPEDIC DEVICES

Subpart E--Surgical Devices

Sec. 888.4540 Orthopedic manual surgical instrument.

(a) Identification. An orthopedic manual surgical instrument is a nonpowered hand-held device intended for medical purposes to manipulate tissue, or for use with other devices in orthopedic surgery. This generic type of device includes the cerclage applier, awl, bender, drill brace, broach, burr, corkscrew, countersink, pin crimper, wire cutter, prosthesis driver, extractor, file, fork, needle holder, impactor, bending or contouring instrument, compression instrument, passer, socket positioner, probe, femoral neck punch, socket pusher, reamer, rongeur, scissors, screwdriver, bone skid, staple driver, bone screw starter, surgical stripper, tamp, bone tap, trephine, wire twister, and wrench.

(b) Classification. Class I (general controls). The device is exempt from the premarket notification procedures in subpart E of part 807 of this chapter, subject to the limitations in 888.9.

Should you have any additional questions please don’t hesitate to contact me.

Sincerely,

Garrett deBorst
Vice President of Sales
PACKAGE INSERT
QUICKDRAW BONE HARVESTER®
MINIMALLY- INVASIVE GUIDED GRAFT DELIVERY SYSTEM

ENGLISH

PRIOR TO USE SURGEON SHOULD BE FAMILIAR WITH THE SURGICAL PROCEDURES OF AUTOGENOUS BONE GRAFT HARVESTING AND DONOR SITE ANATOMY.

IMPORTANT! Single Patient Use

This pamphlet is designed to assist in the utilization of the QUICKDRAW Bone Harvester®.

PLEASE READ THE FOLLOWING INFORMATION THOROUGHLY PRIOR TO USING PRODUCT.

CAUTION: U.S. Federal law restricts this device to sale by or on the order of a physician.

I. DEVICE DESCRIPTION:

The QUICKDRAW Bone Harvester® is a cylindrical biocompatible polycarbonate cutter shaft with a surgical grade stainless steel cutting tip available in 10 mm and 12 mm diameters. The product is designed to harvest autogenous bone graft from the anterior and/or posterior superior iliac spine, femur, tibia, ulna, and radius through minimally invasive surgical techniques.

QUICKDRAW Bone Harvester® utilizes a guided delivery system that enables the surgeon to harvest bone through a less destructive percutaneous or closed technique. Through a succession of Trocar, Sleeve, Dilator, and Cannulae, the six blade cylindrical cutting tip is delivered to the host graft site with minimal muscle stripping and tissue damage. This contributes to less blood loss, less tissue damage, less incisional scarring, and decreased donor site pain.

Aseptic morselized bone graft is harvested and retrieved as the QUICKDRAW Bone Harvester® cutter shaft is inserted into the donor graft site and turned in a clockwise, counterclockwise, or bi-directional motion.

II. INDICATIONS:

The QUICKDRAW Bone Harvester® is indicated for graft harvesting procedures requiring the collection of morselized bone for the purposes of arthrodesis. These procedures include spinal fusion, reconstructive joint surgery, fracture repair, or any procedure requiring morselized autogenous bone graft.

The QUICKDRAW Bone Harvester is indicated for single use only, and should not be resterilized.

III. CONTRAINDICATIONS INCLUDE:

1. Active infection in or around donor site.
2. Osteoporosis, osteomalacia, or any disorder that diminishes the quality of bone tissue.
3. Previous donor site harvest.

IV. PRECAUTIONS:

1. Surgeon must be trained in bone harvesting techniques. Surgeon must take care to not perforate outside cortical bone to minimize risk of damage to tissue, nerves, and vascular vessels.
2. The patient must be advised of the possible adverse effects of bone harvesting procedures including fracture of the donor site, nerve damage, blood loss, or infection.
3. The patient must also be warned of the surgical risks and advised that non-compliance with postoperative instructions could lead to prolonged donor site morbidity with possible infection, fracture, acute pain, and further surgery.
4. Misuse or improper maintenance of the instrumentation set, or cutter tip, can result in instrumentation malfunction or material failure. The Cutter is indicated for single use only.

V. POTENTIAL ADVERSE EFFECTS:

1. Fracture of donor site bone.
2. Tissue & nerve damage.
3. Allergic reaction to instrumentation material content.
4. Surgical complications including infection, blood loss, pain, discomfort, and possible death.
VI. INSTRUCTIONS FOR USE:

A. Iliac Crest Harvest

A small incision (<2 cm) is made above the desired donor graft site. The surgeon identifies the medial aspect of the anterior or posterior superior iliac spine. A trocar is gently inserted into center of desired graft site area creating a perforation in cortical surface. The sleeve is placed over trocar, then the dilator over the sleeve and Trocar to split muscle and expose the donor site. A cannula is selected and is inserted over the dilator, sleeve and trocar to enlarge incision and provide guidance for the cutter tip. The trocar, sleeve, and dilator are removed to create a working channel for insertion of the 12 mm cutter tip (the dilator is left in the cannula if surgeon desires to use 10 mm cutter). The impactor cap is placed over the cannula and is gently tapped into final position over the donor site. The cutter is inserted and rotated in a clockwise, counterclockwise, or bi-directional motion. Morselized graft is captured in the cylindrical shaft and forced up the bone graft chamber. The cutter is removed from the donor site and bone is pushed with the offset plunger to proximal end of cutter shaft to measure approximate graft volume. For greater quantities of graft, angle the cannula in 5-10 degree increments to harvest additional graft where available. To remove graft, or to insert in vivo, disengage T-handle and plunge bone to desired area. Dispose of cutter assembly. Close donor site incision in normal fashion.

B. Other Donor Sites

For tibia, femur, ulna, or radius harvest, make incision (< 8 mm) over donor site. Insert trocar & tap gently into cortical surface. Insert Obturator, Dilator 1, and Toothed Cannula 2. Remove trocar, Obturator and Dilator. Place Impactor Cap over Toothed Cannula & gently tap into cortical surface. Repeat steps described above.

VII. MANUAL CLEANING INSTRUCTIONS:

1. Immediately after the surgical procedure, remove as much debris as possible from each instrument using a water moistened gauze pad. If the instruments cannot be soaked immediately, wrap them in a moist towel to prevent desiccation.
2. Immerse instruments in a neutral pH enzymatic cleaning solution (eg. Enzol or equivalent) and activate any moving mechanisms a minimum of 5 times, Soak the instruments in the enzymatic solution for a minimum of 10 minutes, Change soak solution as necessary.
3. While in the soak solution, use a soft bristled brush to scrub the instruments to remove all visible soil.
4. After the enzymatic soak, rinse instruments with clean warm water for at least 1 minute.
5. Rinse instruments again in deionized water for at least 1 minute.
6. Dry the instruments with a sterile gauze pad, clean towel or filtered air.
7. Perform a visual inspection of the instruments and verify they are clean. Repeat cleaning steps #2-6 as necessary.
8. Verify instruments are in proper working order prior to sterilization.

VIII. STERILIZATION:

The QUICKDRAW Bone Harvester® cutter is provided sterile for single use. Ensure that the seal on the sterile packaging has not been broken, and that the sterile package has not been damaged during shipment. If contaminated, the cutter should be discarded. Do not attempt to re-sterilize.

The instrumentation kit is provided non-sterile.

1. Remove all packaging and labeling materials prior to sterilization.
2. Recommended sterilization methods include steam autoclaving. The following steam autoclave cycles are recommended, however, sterilization should be in accordance with the institution’s usual and customary procedures for assuring sterility.
3. When sterilizing multiple instruments in one steam sterilization cycle, ensure that the sterilizer manufacturer’s maximum load is not exceeded. Drying times will vary according to the load size and should be increased for larger loads.

<table>
<thead>
<tr>
<th>Sterilization Technique</th>
<th>Method</th>
<th>Cycle</th>
<th>Temperature &amp; Time</th>
<th>Dry Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Steam</td>
<td>Gravity</td>
<td>270° F (132° C) for a minimum of 15 Minutes</td>
<td>Minimum of 15 Minutes</td>
</tr>
<tr>
<td></td>
<td>Steam</td>
<td>Pre-vacuum</td>
<td>270° F (132° C) for a minimum of 4 Minutes</td>
<td>Minimum of 20 Minutes</td>
</tr>
</tbody>
</table>

IX. COMPLAINT REPORTING:

All complaints involving the QUICKDRAW Bone Harvester® should be forwarded to Paradigm BioDevices, Inc via mail, phone, or fax using the information listed below.

Manufactured by:
PARADIGM BioDevices, Inc. 800 Hingham St. Suite 207S, Rockland, MA 02370 781-982-9950 Fax:781-982-9008
Autologous Bone Graft: Properties and Techniques

Article in Journal of orthopaedic trauma · March 2010
DOI: 10.1097/BOT.0b013e3181cec4a1 · Source: PubMed

3 authors, including:

Hans Christoph Pape
University of Zurich
768 PUBLICATIONS 13,648 CITATIONS

Andrew R Evans
University of Pittsburgh
17 PUBLICATIONS 246 CITATIONS

Some of the authors of this publication are also working on these related projects:

Medical Education View project
From Himalayas across Rockies to the Alps: Improvement of Orthopedic Residency Programs and Diversity:Dilemmas and Challenges, an International Perspective. Vom Hindukusch über Rockies in die Alpen: Verbesserung der Facharztausbildung im Bereich Orthopädie und Unfallchirurgie und Integration View project

All content following this page was uploaded by Hans Christoph Pape on 14 July 2014.

The user has requested enhancement of the downloaded file. All in-text references underlined in blue are added to the original document and are linked to publications on ResearchGate, letting you access and read them immediately.
**Summary**: Bone grafting is involved in virtually every procedure in reconstructive orthopaedic surgery. Although autologous bone grafts have excellent biologic and mechanical properties, considerable donor site morbidity and the limited volume available must be taken into consideration. Currently, there are no heterologous or synthetic bone substitutes available that have superior biologic or mechanical properties. This review article summarizes the biologic and mechanical properties of autologous bone grafts, differentiates various autologous bone graft types, and compares them with other bone substitutes.

**Key Words**: autologous bone grafting, tricortical graft, properties of bone, cancellous bone graft

(J Orthop Trauma 2010;24:S36–S40)

**INTRODUCTION**

With more than half a million grafting procedures annually, autologous bone is the second most commonly transplanted tissue in the United States. The success of autografts in the treatment of nonunions is well established. In the tibia, union rates of more than 90% have been reported using iliac crest bone graft in a mechanically stable environment. Similar success rates have been documented in the treatment of diaphyseal nonunions at other sites. In posterior cervical fusions, successful fusions in 92% to 100% of patients have been reported when using autologous iliac graft. In addition, iliac crest bone grafting has been successful in treating recalcitrant and infected nonunions as well as completing the healing at the docking site of nonunions treated with distraction osteogenesis.

In addition to its volume effect, the biologic properties of grafts in terms of new bone formation are essential. Autologous bone graft continues to represent the gold standard for management of bone defects or nonunions. It possesses biologic advantages over heterologous and synthetic bone substitutes as a result of its excellent combination of osteogenic, osteoinductive, and osteoconductive properties. Furthermore, tricortical grafts can be used to improve the immediate strength of constructs (“bioplating”). This combination of biologic and mechanical properties has not yet been achieved by heterologous or synthetic bone substitutes.

**Properties of Autologous Bone Grafts**

**Osteogenic Properties**

In general, osteogenic properties are induced by osteogenic precursor cells and osteoblasts within a graft. In autologous bone, histoincompatibility with cell degeneration is not an issue. Nevertheless, an interindividual variability of the osteogenic potential does exist. Genetic factors may play a role and age of the donor has been identified as an important variant. Furthermore, the osteogenic properties may be compromised by the techniques of graft preparation with osteonecrosis being a major complication. Careful harvesting and implantation techniques are therefore important along with short harvest-to-implant time and adequate interim storage.

**Osteoinductive Properties**

The osteoinductive properties of a graft depend on the availability of growth factors. In fresh autologous grafts, several growth factors are detectable. Among these are members of the transforming growth factor-β (TGF-β) superfamily (e.g., bone morphogenetic protein [BMP]–2, BMP–4), angiogenic factors such as fibroblast growth factor and vascular endothelial growth factor, and platelet-derived growth factor and insulin growth factor 1, which have migratory and differentiating effects on cells. In contrast, in demineralized freeze-dried allografts, neither BMP-2 nor BMP-4 are present.

**Osteoconductive Properties**

Osteoconductive properties depend on the three-dimensional structure of the graft and determine the velocity of osteointegration. This is well illustrated when comparing the osteointegration between dense cortical grafts and highly porous cancellous grafts: the cancellous graft is incorporated much faster.

**Biomechanical Properties (structural use as biologic plate)**

The biomechanical properties of autologous grafts apply for the use of tricortical bone grafts, which commonly are used to improve initial stability. A tricortical graft can be firmly attached to the adjacent bone by using small fragment screws. This applies especially when a unilateral implant is present and support is required on the contralateral side. It is advantageous...
to use these grafts in young patients in whom the strength of the bone adds to the initial stability.

However, when using large tricortical grafts, the risk of significant donor site morbidity is high. Fractures of the anterior iliac spine can occur and carry a high risk of nonunion and prolonged disability. It is therefore important to harvest the graft as far posterior as possible from the anterior–superior iliac spine to reduce the likelihood of a fracture in this region. A vascularized bone graft such as one derived from the fibula may also be used as an isolated strut for mechanical support. Figure 1 demonstrates a free fibula graft in association with a bioplate for a posttraumatic distal femoral defect. Of note, this technique should be reserved for special indications in which bone loss and instability are substantial, usually with periarticular lesions.

**Autologous Bone Graft Types**

Different types of autologous bone grafts have variable properties associated with structural anatomy. Cancellous bone has greater cellular diversity and activity than cortical bone, whereas cortical grafts have enhanced mechanical properties (Table 1). Overall, cancellous bone is eight times as metabolically active as cortical bone and cortical bone is four times as dense as cancellous bone.

**Cancellous Bone Graft**

The trabecular structure of cancellous bone results in a large surface area. This allows for a high number of cellular components (mesenchymal stem cells, immature and mature osteoblasts) to be incorporated and explains its excellent osteogenic and osteoinductive capabilities. In addition, the trabecular structure allows for easy revascularization and rapid incorporation at the host site. In turn, one of the limitations of cancellous bone is its lack of initial mechanical strength. Also, the formation of new bone on a necrotic cellular structure weakens the construct within the first weeks. As a result of the excellent biologic capacity to induce the production of new bone, increased stability is then achieved within months once the graft is incorporated.

Vascularization of cancellous bone grafts begins within 2 days after implantation and is accompanied by infiltration of the marrow spaces by mesenchymal stem cells. The early stage of osteointegration with revascularization is followed by graft remodeling with active bone formation and resorption of necrotic bone after 4 weeks. Histologically, osteoblasts can be found to line the trabecular scaffolds and deposit a seam of osteoid. Remodeling takes several months.

**Cortical Bone Graft**

Cortical bone grafts have a more limited biologic profile as compared with cancellous grafts (Table 1). Cortical bone has fewer osteoblasts and osteocytes, fewer growth factors, and less surface area per unit weight, the structure of which constitutes a barrier to vascular ingrowth and remodeling. However, cortical bone does provide good initial mechanical stability and strength to bony fixation constructs as compared with cancellous bone grafts. Osteoclastic activity with resorption of the dense cortices and bone loss begins 2 weeks after the grafting procedure. This results in transient weakness with reduction of mechanical strength of up to 75%. Differences in graft incorporation between cortical and cancellous grafts become evident during the stage of graft revascularization and remodeling. The process takes longer for cortical bone. Revascularization takes approximately 2 months because of the structure of the cortical graft, which does not allow as large a contact area for vascular penetration between the graft and the host. In contrast to cancellous grafts in which incorporation is initiated by new bone formation, the osteoclasts must first initiate resorption of the dense cortices in cortical grafts to allow revascularization. In dog studies, it has been shown that cortical grafts have significantly decreased strength at 6 weeks that remains low.
through 24 weeks but returns to normal strength by 48 weeks after transplantation.\textsuperscript{25}

**Autologous Bone Marrow Aspirates**

Bone marrow aspirates can be harvested using minimally invasive techniques. Despite the initial enthusiasm surrounding the injection of bone marrow into fractures sites, two major limitations have been observed. First, the number of stem cells harvested in bone marrow aspirate is not as high as previously suspected; it has been estimated that marrow contains one per 50,000 nucleated stem cells in young adults and as few as one per one million in the elderly.\textsuperscript{25} Second, the injected bone marrow tends to move from the insertion site, resulting in higher rates of heterotopic ossification and no observed improvement in fracture healing.\textsuperscript{25} Thus, the clinical value of isolated autologous bone marrow aspirate currently appears to be negligible.

**Vascularized Cortical Bone Graft**

Autologous vascularized cortical bone grafts have favorable biologic attributes as compared with standard autologous nonvascularized cortical grafts. Furthermore, they are mechanically superior during the initial 6 to 12 months postgrafting. Despite their many biologic advantages, their primary limitation is that they are more technically difficult to obtain and implant given that this technique requires orthopaedic and microvascular skill sets.

Vascularized cortical grafts heal quickly at the graft–recipient junction because the remodeling process closely resembles that of normal bone.\textsuperscript{25} It has been suggested that adequate vascular anastomosis and graft stability are achieved, more than 90% of the osteocytes may survive the transplantation.\textsuperscript{28} New bone formation by graft and host can lead to rapid graft incorporation and residual weakness of the construct is minimal.\textsuperscript{26}

**Sites for Bone Graft Harvesting**

Although the biologic advantages of autologous bone grafts are numerous, there remain concerns about the availability of autologous grafts resulting from limited volume and considerable donor-site morbidity.\textsuperscript{29–34} Furthermore, increased surgical time and hospital length of stay with consequent additional costs are described in the literature.\textsuperscript{35}

Although the gold standard for nonvascularized cortical grafts is the iliac crest and for vascularized cortical grafts the fibula, the optimal harvesting site for cancellous grafts is debatable. Cancellous grafts are most commonly harvested from the iliac crest; however, recently, a new method for harvesting cancellous grafts has become available. With the "Reamer Irrigator Aspirator" (RIA) System, large quantities of autologous bone graft can be harvested from the femoral and tibial medullary cavities.

When compared with iliac crest, harvesting cancellous bone with the RIA technique demonstrated several advantages. The volume of bone graft harvested typically exceeds the volume available in the anterior iliac crest.\textsuperscript{19} Furthermore, bone graft harvested from the femoral canal appears to provide a higher concentration of growth factors\textsuperscript{35–38} than that derived from iliac crest.\textsuperscript{19} Other authors describe that the RIA technique is associated with less postsurgical pain,\textsuperscript{36} which may result in a shorter hospital length of stay.

Possible complications of iliac crest harvesting have been extensively discussed in the literature and therefore only possible complications of the RIA technique are further discussed in this review. Critics of reaming suggest that reaming disturbs the endosteal blood flow and thereby increases the risk of infection,\textsuperscript{42,43} although this appears not to have been proven.\textsuperscript{44,45} Another potential risk of the RIA technique is heterotopic ossification, which is a frequent finding after hip arthroplasty and antegrade femoral nailing.\textsuperscript{56} Local risk factors for the induction of heterotopic ossification include surgical soft tissue trauma and spilling of osteogenic substances in the soft tissue during reaming.\textsuperscript{57–59} Both risk factors are usually reduced through proper implementation of the RIA technique using an approach that is minimally traumatic to the soft tissues and continuous suction of the marrow contents to prevent the spillage of osteogenic material. Other issues derive from the sharp reamer head that may cause penetration and resultant weakness of the cortex. In addition, the guidewire has to be appropriately positioned within the

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**TABLE 1. Properties of Different Types of Bone Grafts**

<table>
<thead>
<tr>
<th>Type of graft</th>
<th>Osteogenesis</th>
<th>Osteoinduction</th>
<th>Osteoconduction</th>
<th>Immediate strength</th>
<th>Vascularity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autologous</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bone marrow aspirate</td>
<td>++</td>
<td>+</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cancellous bone</td>
<td>+++++</td>
<td>+++++</td>
<td>+++</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Cortical non-vascularized</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+++</td>
<td>–</td>
</tr>
<tr>
<td>Cortical vascularized</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>+</td>
</tr>
<tr>
<td>Heterologous</td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>cancellous frozen</td>
<td>–</td>
<td>+</td>
<td>++</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>cancellous freeze-dried</td>
<td>–</td>
<td>+</td>
<td>++</td>
<td>–</td>
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<tr>
<td>Cortical freezing-dried</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+++</td>
<td>–</td>
</tr>
<tr>
<td>Cortical freeze-dried</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>–</td>
</tr>
<tr>
<td>Synthetic</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ceramics (TCP, CPC)</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>DBM</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>TCP+BMA composite</td>
<td>++</td>
<td>++</td>
<td>+++</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>TCP+BMP composite</td>
<td>–</td>
<td>+</td>
<td>+++</td>
<td>+</td>
<td>–</td>
</tr>
</tbody>
</table>

Extent of activity (–, +, ++, ++++) from none (–) to maximal (+++).

TCP, tricalcium phosphate; CPC, calcium phosphate cement; DBM, demineralized bone matrix; BMA, bone marrow aspirate; BMP, bone morphogenetic protein.
Comparison of Biologic Properties of Autologous Bone Grafts With Heterologous or Synthetic Bone Substitutes

One of the major downsides of autologous bone grafting is the limited availability. Therefore, some surgeons favor heterologous grafts. However, heterologous grafts carry the potential for disease transmission and may trigger immunogenic reactions.50–53 Therefore, irradiation is required for all heterologous transplants, which in turn reduces their osteogenic and osteoinductive capability54–56 (Table 1).

In comparison, synthetic bone substitutes (eg, tricalcium phosphate, calcium phosphate cement) possess osteoconductive properties and in combination with growth factors (eg, BMPs) may also achieve osteoinductive and osteogenic properties. Such composite grafts are currently being developed and may present an alternative to autologous bone grafts in the future. However, considering that the therapeutic dose of recombinant human BMP-2 for tibia fractures is currently approximately $4000, it is likely that the costs for such implants will be high.57

Currently, autologous bone graft remains the only clinically available graft source that is osteogenic, osteoinductive, osteoconductive, and contains viable precursor cells. Although some of the alternatives listed may have some potential in the future, to date, no other graft source appears to be more effective, or more cost-effective, than autologous grafts in stimulating bone formation10–20. As a result, autologous grafting remains the gold standard for treating nonunions.

CONCLUSION

As a result of its excellent and cost-effective combination of biologic and mechanical properties, autologous bone graft continues to be an important tool in the management of certain bone defects or nonunions. Heterologous grafts lose some of their biologic properties through sterilization and synthetic bone substitutes have only osteoconductive properties if not combined with recombinant human growth factors or autograft. If heterologous or synthetic bone is combined with growth factors, these composite grafts may have equal biologic properties to autologous bone grafts, but further research is required to determine their efficacy and cost–benefit profile.

In clinical practice, the decision as to which type of autologous bone graft should be used must take into account whether the operative site needs metabolic activity (cancellous bone), stability (cortical bone), or both. If the autologous bone graft has to withstand compression and mechanical load, cortical bone may be a way to provide additional support. However, the considerable donor site morbidity has to be considered.

REFERENCES