TABLE E-1 Level-of-Evidence Grades for Autogenous Bone Graft Recommendations*

Recommendation	Citations	Evidence Grade
Autogenous bone graft is biologically the graft material of choice because it is the only option that includes all three properties necessary for bone healing, and it has complete histocompatibility and a strong history of clinical success.	5,6,9,10	C
Cortical bone graft is best suited for structural defects in which immediate mechanical stability is required for healing.	5,9,10	C
Within the first 6 months after implantation, nonvascularized grafts become progressively weaker secondary to resorption, but regain structural strength within 12 months.	5,9,12	C
The large surface area of cortical grafts leads to rapid remodeling and incorporation, making cancellous graft an excellent option for arthrodesis and nonunion procedures.	13,14,15,16	C
Free vascularized grafts offer the most predictable incorporation and are indicated for larger bone defects (>12 cm^3).	5,9,11,12,19	B
More than 90% of the residual osteocytes can survive, making vascularized graft osteogenic.	5,12,19	B
Open air storage is deleterious, and bone autograft should be harvested for immediate implantation whenever possible.	18,22,23	I
Use of antibiotic powder-impregnated bone graft does not hinder bone union.	24,25,26,27	C
There is significantly greater reduction in infection rate in patients treated with organism-specific antibiotic-impregnated autogenous cancellous bone graft.	26	A
Graft cultured in antibiotics such as clindamycin and cefuroxime have been shown to have time and dose-dependent stimulus effects on osteoblastic proliferation at therapeutic concentrations, but deleterious effects at higher concentrations.	28,29	B
One limitation to iliac crest harvest is limited volume, with an average of 13 cm^3 anteriorly and 30 cm^3 posteriorly.	8,30	B
When larger volumes are needed, yields of 90 cm^3 with use of an acetabular reamer technique have been reported.	8,32	B
The reamer procedure is faster than the traditional techniques, with decreased operative time and lower cost despite large quantities of harvested bone.	3,8	C
Bone graft harvested with the acetabular reamer technique appears to be clinically effective, with union achieved in 33 (97%) of 34 tibial nonunions at an average of 10 weeks.	8	B
Arrington et al., in a large review of 414 cases, found 41 (10.0%) had minor complications (36 superficial hematomas and/or seromas and 5 superficial infections) and 24 (5.8%) had major complications (4 deep hematomas, 2 incisional hernias, 6 neurologic injuries, 3 vascular injuries, 2 iliac wing fractures, and 7 deep infections).	33	B

After ICBG, minor complications occur in 7.1% to 39.0% of patients and major complications occur in 1.8% to 10.0% of patients.	3,33,42,43,44	B
Early pain (occurring within three months after graft harvest) at the ICBG donor site has been reported to occur in 2.8% to 37.9% of patients.	7,43,45,46,47	B
Iliac crest postoperative pain has not been shown to decrease with intraoperative crest reconstruction.	48	I
Intraoperative morphine injection has not been shown to decrease pain at the iliac crest at 24 hours or at 3, 6, or 12 months postoperatively	49	A
At present, there are conflicting Level-I studies regarding the effects of postoperative anesthetic infusion on donor-site pain.	49,50,51,52	I
After ICBG, superficial infections occur in 0.5% to 1.2% of patients, superficial hematomas occur in 1.2% to 3.9%, and superficial seromas occur in up to 4.8%.	3,33,44	B
After ICBG, deep infection occurred in 1.7% to 2.5% of patients.	33,42,43	B
Suction drain at the iliac crest incision has been shown to have no benefit in wound complication and infection rates.	54	A
If ICBG is harvested too far posteriorly, the sacroiliac joint can be inadvertently breached or the posterior sacroiliac ligaments may be compromised, leading to sacroiliac instability, pain, and arthrosis.	7	I
Another complication of crest harvest is gait disturbance, including a Trendelenburg gait that is often associated with hip abductor weakness, which can be avoided by careful reapproximation of abductor fascia and minimal retraction of the abductor muscles.	7	I
Anterior crest harvest site should not be <3 cm posterior to the ASIS to avoid avulsion fracture.	7,32	C
Avulsion has been shown to be more frequent with bicortical and tricortical ASIS grafts than with unicortical grafts; therefore, the surgeon should exercise caution with these harvest techniques.	7	C
The proximal part of the tibia provides an easily accessible source of abundant cancellous, unicortical, or corticocancellous graft, especially in cases in which the ipsilateral limb is the recipient site.	25,56,57,58,59	C
The average volume of cancellous bone graft that can be obtained from the proximal part of the tibia is approximately 25 cm^3, which compares favorably with ICBG; however, we and others have succeeded in harvesting as much as 70 cm^3 of cancellous bone from the proximal part of the tibia in young patients with good bone stock.	25,36,56,60,61,62	C
In the majority of patients who have proximal tibial bone-graft harvest, immediate postoperative weight-bearing as tolerated is allowed; however, when the harvest extends across the midline of the proximal part of the tibia, we recommend protected weight-bearing for 6 to 12 weeks.	25,59,63	I
Numerous techniques, including access from both the medial and	18,20,25,36,56,57,61	C

lateral aspect of the proximal part of the tibia have been described, with no significant differences reported in graft quantity.		
It is recommended that the entry portal into the proximal part of the tibia be circular or have rounded edges in order to prevent stress-risers with possible fracture propagation.	36,56,57	C
During proximal tibial bone-graft closure, any periosteal elevation should be repaired to provide osteoblasts for the reconstitution of bone at the harvest site.	64	I
Whitehouse et al. showed that 20% of patients report mild pain immediately postoperatively, but only 4% report persistent long-term pain.	58	B
The distal radial harvest can be performed via a dorsal or volar approach.	71	C
Injury to the superficial radial nerve can result in pain, sensory loss, or neuroma, so meticulous care with incisions and retraction is necessary to reduce the risk of damage to this nerve.	20	C
Similar to the distal end of the radius, the distal tibial metaphysis can be a source of corticocancellous struts, and is an easily accessed source of small volumes of cancellous bone.	18,74,75	C
The distal end of the tibia is particularly convenient in surgery of the foot and ankle because of the proximity within the operative field and minimal increase in operative blood loss or time.	73	C
Persistent donor-site pain and hematoma at the distal tibial donor site are rare, and infection and fracture have not been reported.	18,74,75	C
The greater trochanter is a useful source of bone graft for surgery of the ipsilateral lower extremity.	32,67,76,77	C
RIA harvest volumes from 30 to 90 cm^3 have been reported, with comparable union rates and lower immediate and chronic pain scores compared with iliac crest bone graft.	30,80,82,83,84	C
On the average, the RIA technique provides approximately 40 cm^3 of bone graft from the femur and 33 cm^3 from the tibia.	30	C
RIA graft is rich in stem cells, osteogenic cells, and growth factors, which are at least equivalent to iliac crest.	30,80,85,86	B
In a series of 21 patients with an average void of 6.6 cm, RIA bone graft resulted in defect consolidation in 85% at 11 months postoperatively.	30	C
One case report showed union of a 14-cm void with internal fixation and RIA graft.	80	I
For RIA harvest, the trochanteric entry point is preferred over the piriformis by many authors in order to avoid damage to the femoral neck.	30	I
The RIA entry angle should be as narrow as possible to minimize eccentric reaming.	82	I
The femora were tested with cyclical loading, and no significant differences ($p = 0.606$) were noted in the mechanical behavior, including load failure with any of the starting points (greater	87	B

trochanter, piriformis fossa, and intercondylar notch).		
Overall, there is a negligible loss of strength when the intramedullary cortices are reamed by ≤2 mm; however, reaming of >2 mm can compromise torsional strength and potentially lead to iatrogenic fracture.	30,84,88,89	B
To preserve strength, the reamer head should not exceed 50% of the periosteal diameter.	84	I
Despite several authors suggesting that walking is well tolerated immediately after RIA harvest, donor-site fracture is well documented and overall there is inconclusive evidence as to fracture risk.	30,87	I
RIA should be considered an option for autogenous graft in patients at risk for infection at other harvest sites, in patients who may have low iliac crest bone stock, in those who have previously had graft harvested, or in patients in whom the volume of bone graft needed exceeds that which is available with traditional techniques.	82	C
To minimize the risk of hemodynamic compromise, the RIA suction should be discontinued and the reamer removed whenever reaming is not in progress, or if the reamer becomes incarcerated in the canal.	82	I
The risk of incarceration can be reduced by reaming no more than 1.0 to 1.5 mm larger than the isthmus.	80	I
Iatrogenic fracture is possible if the reamer follows an eccentric path in the intramedullary canal, and breaching of the anterior or medial cortex results.	82	C
Reaming of the distal cortices should be discontinued once adequate bone graft has been obtained as this is also associated with iatrogenic fracture, especially in osteopenic patients.	82	I
No episodes of superficial or deep hematoma, deep infection, or fat embolism were noted in the RIA group compared with the ICBG group, in which 2.5% (1/40) had hematoma and 7.5% (3/40) had deep infections.	30	C
The induced membranes technique has shown favorable union rates, even in recently radiated and postinfectious tissue beds, and may be a viable option for patients who are poor medical hosts, who are not ideal candidates for other more complex reconstructive options, or who have large bone voids.	93	C
Masquelet and Begue retrospectively reviewed a series of 35 reconstructions of bone defects, ranging from 5 to 24 cm, using the induced membranes technique and observed radiographic healing at 4 months in all cases (100%).	90	C
They found that union with the induced membranes technique was independent of defect length and that all deep bone infections had resolved by 8.5 months.	90,93	C
The induced membrane produces multiple cytokines potentially	93	B

responsible for promoting union and bone graft consolidation, including vascular endothelial growth factor (VEGF), bone morphogenetic protein-2 (BMP-2), and transforming growth factor beta-1 (TGF-β1).		
The pseudomembrane protects the autograft from rapid resorption and promotes graft consolidation.	90,91,93	C
Another adjuvant method combines the induced membranes technique with RIA graft to fill large bone voids.	80,95	C

*This table lists all of the concepts of bone-grafting discussed in the review article, provides citation of references that address that concept, and provides level-of-evidence grades for the citations that address that concept. Grade-A recommendations are based on consistent Level-I studies. Grade-B recommendations are based on consistent Level-II or III evidence. Grade-C recommendations represent either conflicting evidence or are based on Level-IV or V evidence. A grade of I indicates that there is insufficient evidence to make a treatment recommendation. ICBG = iliac crest bone grafting, RIA = reamer-irrigator-aspirator, and ASIS = anterior superior iliac spine.