New Approaches in the Treatment of Critical-Size Segmental Defects in Long Bones

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Summary: The treatment of large segmental diaphyseal bone deficiencies presents a formidable challenge. The standard treatment modalities such as cancellous bone grafting, cortical allografts, vascularized bone transfer, or distraction osteogenesis exhibit extremely high complication rates, and can culminate in limb amputation or major functional deficits. Recent efforts to develop new treatment modalities for segmental bone loss have resulted in designing new biodegradable polymeric and metallic mesh implants that can incorporate novel osteogenic, osteoinductive, and/or osteoconductive bone healing augmentation materials. These biologic implant composites are capable of further enhancing the efficacy of the treatment applied. This paper briefly reviews the limitations of the currently applied standard treatment modalities for segmental critical size bone defects, provides insight into the specific treatment challenges, and presents the animal and initial clinical results of new alterative treatment approaches that involve the application of cylindrical mesh implants consisting of biodegradable polylactide membranes or titanium cages as a means of potentiating the efficacy of bone graft.

Keywords: bone defects; bone graft; implants; polylactide membranes; titanium mesh cage

Introduction

Large segmental defects in long bones are prevalent entities in musculoskeletal surgery with etiology that includes high-energy trauma, gunshot injury, deformity correction or iatrogenic resection of infected or neoplastic bone lesions. The treatment of large diaphyseal bone deficiencies presents a formidable challenge, and prior to the advent of complex reconstructive procedures culminated in limb amputation or permanent functional deficits. Among currently applied standard treatment options, none timely and reliably restores skeletal continuity, recovers early limb function, and is well tolerated by the patient.

The objective of this paper is to briefly discuss limitations of the standard treatment modalities for segmental bone defects, provide insight into the specific treatment challenges, and present the authors' animal and initial clinical results with the application of cylindrical hollow mesh implants consisting of biodegradable polylactide membranes or titanium cages as a means potentiating the efficacy of bone grafting in the treatment of critical size segmental bone deficiencies.

Standard Treatment Approaches for Segmental Bone Defects

Autogenous cancellous bone grafting, cortical allografts, vascularized bone transfer, and distraction osteogenesis currently comprise the standard treatment modalities for large segmental defects in long bones. Their success of early defect healing and

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subsequent return of unrestricted limb function is rarely realized, course prolonged, reliability poor, and complication rate high.

Massive cancellous autogenous grafting remains the most common defect treatment procedure.[1] It demonstrates a high incorporation rate, allows for early revascularization, and provides growth factors and to some extent osteogenic cells. However, major shortcomings of cancellous autograft exist, and relate to lack of structural integrity, limited availability, and the morbidity of the donor site. Furthermore, cancellous bone grafting is frequently inefficient for large bone defects (>6 cm in length) due to rapid graft resorption.

Cortical allogeneic bone grafts exhibit excellent structural properties, however due to a high susceptibility to infection are indicated specifically for defects without evidence of contamination, typically post tumor reconstruction.[2,3] Prolonged incorporation of cortical grafts requires an extended period of immobilization, which often leads to disuse osteopenia and muscle atrophy. Vascularized cortical autografts demonstrate good incorporation and necessitates shorter time for defect healing, but donor site morbidity and limited availability are unavoidable.[4] Often lengthy protected weightbearing needs to be maintained until graft hypertrophy occurs. The pedicled graft technique is complex, demanding, and requires sophisticated equipment and extensive clinical experience.

Distraction osteogenesis has recently become a popular treatment modality for large bone defects, infected nonunions, and limb length discrepancy.[5] Although new bone can be generated with this method, bone transport or lengthening is not without numerous problems. The slow rate of bone formation prolongs the treatment, extended fixator presence is cumbersome for patient, and recurrent pin track infection is a frequent complication. Bone transport can be associated with significant pain requiring medication. Upon completion of the transport process, addition surgery is required to debride and graft the docking site. Repeat fixator re-alignments and wire re-tensioning is often necessary, making the treatment amenable only to compliant patients who can interact with the apparatus well.

Biological Treatment Approaches for Segmental Bone Defects

The unsatisfactory results of the standard treatment modalities for segmental bone deficiencies prompted research efforts towards development of more biologically-sound alternatives. Bone graft substitutes with osteogenic, osteoconductive, and osteoinductive properties have recently emerged. Osteogenic options (bone marrow aspirate, plasma concentrate), osteoconductive fillers (ceramics, cements, synthetic or natural polymers), and osteoinductive molecules (growth factors, cytokines) have recently been introduced as biological adjuncts to enhance defect healing. At present, demineralized bone matrix (DBM) and recombinant human bone morphogenetic proteins (rhBMP-2, rhBMP-7) are the most biologically potent osteoinductive adjuncts clinically approved for bone deficiencies.

Although experimentally very promising, the efficacy of the biologic adjuncts in the treatment of large bone defects varies widely. Hence, a routine application of these adjuncts has been hindered by their extremely high concentrations required to produce a clinical effect. The therapeutic cost-effectiveness is, therefore, a concern, and the clinical indications poorly defined. Moreover, the orthopaedic implants currently applied in the treatment of bone defects are not designed to work synergistically with these osteoinductive components in order to realize their full biologic potentials.

Cylindrical Polylactide Mesh Membranes in the Treatment of Bone Defects in Animals

Polylactide membranes in a form of cylinders have been introduced as nonporous or

microporous implants for the treatment of segmental bone defects in rabbits.[6,7] Critical size segmental defects in the rabbit radius wrapped with tubular microporous polylactide membranes healed uneventfully without bone graft. Control defects without membranes did not heal up to 16 weeks, and resulted in atrophic nonunion with a subsequent interposition of the surrounding musculature. Membranes with smaller size pores (range of 0.5–1 μm) resulted in more consistent defect healing.

Subsequently, the efficacy of the polylactide membranes in the treatment of critical-size bone defects was assessed in a sheep model. In a segmental, 4-cm-long osteoperiosteal tibial defect stabilized with a bilateral external fixator, various configurations of polylactide membranes designed as cylindrical microporous or cylindrical mesh implants were applied.[8,9] The designs included single- or double (cylinder-within-cylinder) configurations, with or without autogenous cancellous bone graft augmentation (Figure 1A). All membranes were composed of the same poly(L/DL-lactide) 80/20, and revealed a uniform interconnected microporous structure with pores 50–70 μm in size (Figure 1B). The polylactide mesh membranes had laser-created perforations with a size of 800–900 μm and a density of 16/cm^2 (Figure 1C).

At 16-week followup, radiographic (plain x-ray, computed tomography) and histologic evaluations consistently revealed no evidence of defect healing in groups with single or double microporous or mesh membranes applied without bone graft augmentation (Figure 2). The osseous activity across these defects was marginal and a most of the defect demonstrated a nonmineralized fibrous tissue. Bone healing across the defect occurred only in the groups in which the single or double mesh membranes were augmented with autograft. In the single mesh grafted defects, graft reconstitution was most efficient on the postero-lateral side and resulted in the highly-mineralized new bone defect bridging.

At the antero-medial site of grafted defects, the autograft underwent significant resorption resulting in new bone with a woven structure scattered across the defect

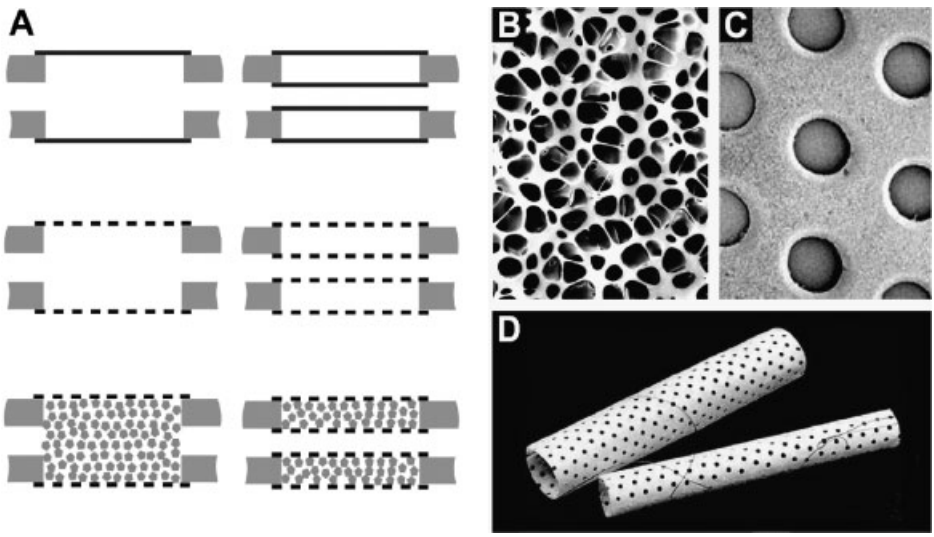

Figure 1.
The experimental design (A) and the structure of polylactide microporous (B) and mesh membranes (C). The membranes were thermoformed into cylinders (D). The single and double cylindrical polylactide mesh constructs accommodated 20 and 12 g of autograft, respectively.

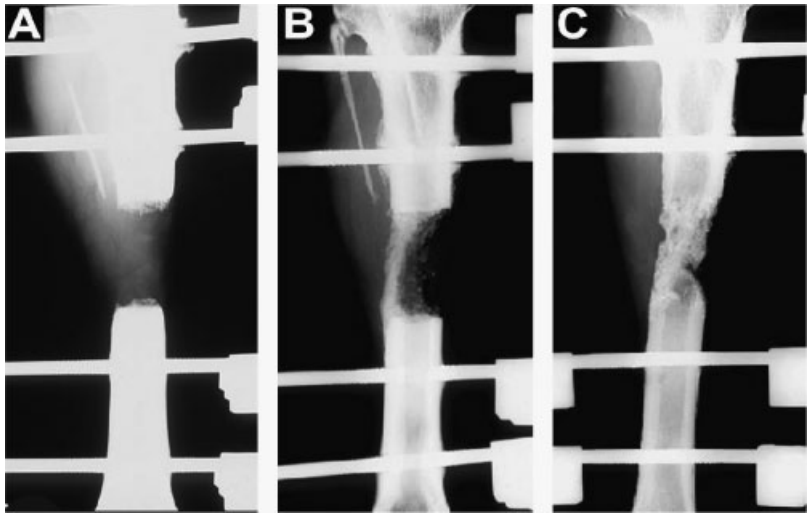

Figure 2.
Plain radiography at 16 weeks revealed no healing of defects treated with single or double polylactide microporous or mesh membranes without bone graft (A). Bone formation bridging the defect occurred only in defects treated with a single polylactide mesh (B) and the double mesh (C), both augmented with autograft. More bone was formed in the latter.

(Figure 3A). The double mesh grafted defects exhibited more bone formation compared to the single mesh due to more uniform graft reconstitution, and new bone was formed within the space between the polylactide mesh (Figure 3). Similarly, the most extensive bone was noted on the postero- lateral aspect of the defect with an abundant soft tissue envelope (Figure 4). The antero-medial graft resorption was also noticed, although much less pronounced than in the singe mesh defects. The pattern of new bone formation in both single mesh and double mesh grafted defects occurred through ''creeping substitution'' and the apposition of new bone layers (Figure 5).

The results of the sheep study elucidated the considerable differences exist in healing potentials of rabbit versus sheep defects treated with polylactide membranes.

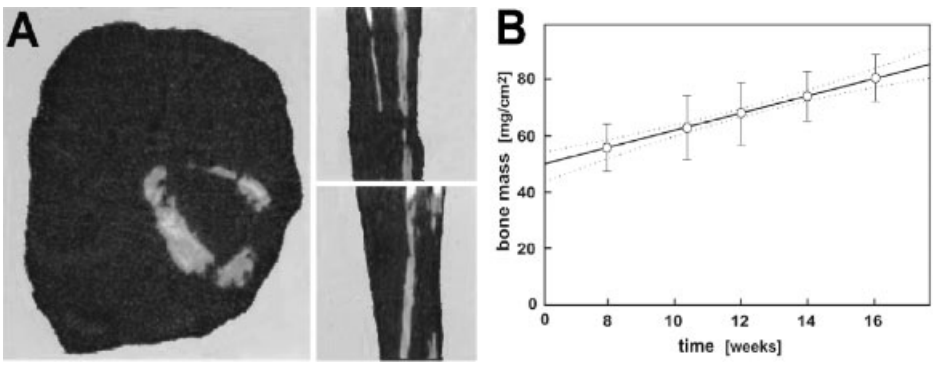

Figure 3.
Axial, coronal, and sagittal CT imaging of the defect treated with the double polylactide mesh membranes and cancellous autograft (A) The graft reconstitution resulted in new bone formation that demonstrated progressive increase in mineral content throughout the experimental followup (B).

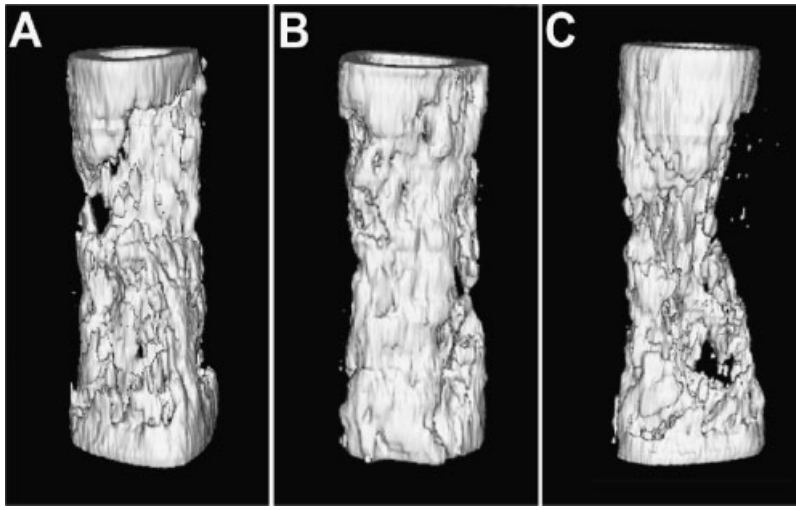

Figure 4.
Three-dimensional CT reconstructions of the anterior (A), posterior (B), and lateral (C) aspects of the defect treated with the double polylactide mesh in combination with cancellous autograft.

Despite relatively comparable sized bone defects and identical microporous membranes, the bone defects in rabbits healed uneventfully without bone grafting while in sheep did not. The location of the defect (tibia versus radius) with tenuous blood supply and higher phylogenetic scale define the critical size bone defect to be proportionally smaller in sheep than in the rabbit model. More pronouced bone formation on postero-lateral site of the defect compared to the antero-medial location unequivocally suggests the contribution of the surrounding soft tissues to the nutrition of bone graft contained by the cylindrical polylactide mesh.

The bone graft interfaces with the adjacent soft tissues through the perforations within the polylactide mesh, and this contact likely determines graft survival and

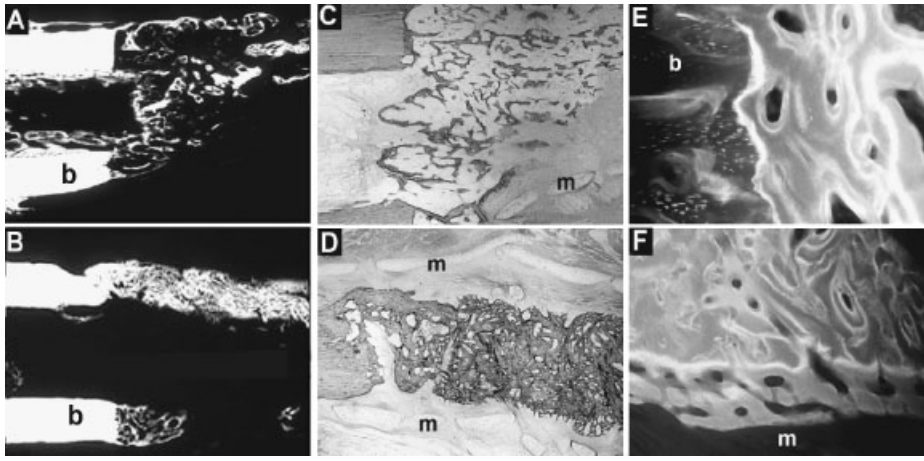

Figure 5.
Histological sections demonstrating the nature and extent of bone healing in the defects treated with a single (top panel) or double (bottom panel) polylactide mesh membranes in combination with autograft. [A,B microradiography; C,D giemsa-eosin; E,F flurochrom labeling; **b**, bone; **m**, polylactide mesh].

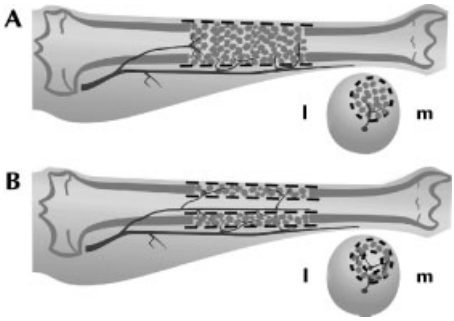

Figure 6.
Hypothetical vascularizaˆtion of the graft in a single (A) and double (B) cylindrical poly-lactide mesh used in the treatment of critical size tibial defects in sheep (**l**, lateral; **m**, medial).

functionality. More efficacious reconstitution of graft contained with double cylindrical polylactide mesh, despite the smaller volume than in the single mesh, suggests the importance of the graft accessibility to nutrients not only from adjacent muscles, but also from the medullary cavity (Figure 6). Moreover, favorable biomechanical conditions may exist for bone graft contained between the double mesh, rather than filling up the whole defect as it is in the single mesh. The enclosed graft is exposed to direct load transferred by the cortices between the double mesh, whereas in the single mesh the central, intramedullary portion of the graft is not loaded. This biomechanical distinction in graft loading may further contribute to more favorable graft reconstitution in defects treated with double cylindrical polylactide mesh.

Cylindrical Titanium Mesh Cages in the Treatment of Bone Defects in Animals

To accentuate the involvement of biomechanical conditions in healing of segmental bone defects treated with cylindrical mesh implants, titanium cages were utilized to treat critical size bone defect in canines.[10] Cylindrical titanium mesh cages, although cleared by the Food and Drug Administration for any osseous reconstruction and/or reinforcement, were used exclusively in the spine to replace and/or fuse vertebral bodies. The design and structural properties of the cylindrical mesh cage permitted application of bone graft and facilitated restoration of spinal alignment and stability. Hence, potential biological and biomechanical advantages of mesh cages were postulated, and were attributed to their hollow and fenestrated nature which could enhance cancellous bone graft reconstitution, permit circumferential healing, and augment the stability of the fixation with minimal stress shielding.

The theoretically favorable characteristics of cylindrical titanium mesh cages in the treatment of long segmental bone defects were validated in canines. The nature and extent of defect healing treated with or without the mesh were compared, and the effects of the intra-versus extramedullary modes of the supplemental internal fixation evaluated. Critical size, 3-cm-long osteo- periosteal segmental defects were reconstructed with a commercially-available titanium cage (DePuy Motech, J&J; Warsaw, IN) with size of 19×40 mm and diamond-shaped fenestrations (Figure 7A, B) The procedure involved packing a standard volume of allograft composite consisting of morselized fresh-frozen canine cancellous bone (Veterinary Transplant Services, Inc., Seattle, WA) and canine demineralized bone matrix (GenSci Regeneration, Ontario, Canada). The defects were stabilized with a statically-locked titanium intramedullary nail (DePuy Ace, J&J; Warsaw, IN) or a 10-hole titanium plate and screws construct (Zimmer, Warsaw, IN) (Figure 7C–E).

At 6-, 12- and 18-week followup, progressive new bone formation about the cage was evident by plain radiography. At 18 weeks, complete defect bridging was consistent for both cage-nail and cage-plate constructs. Defects without the cage demonstrated prominent lucency in the center without bony bridging. Computed tomography corroborated the plain radiography, better visualizing marked progression of new bone formation within and around the cage, throughout the defect, and

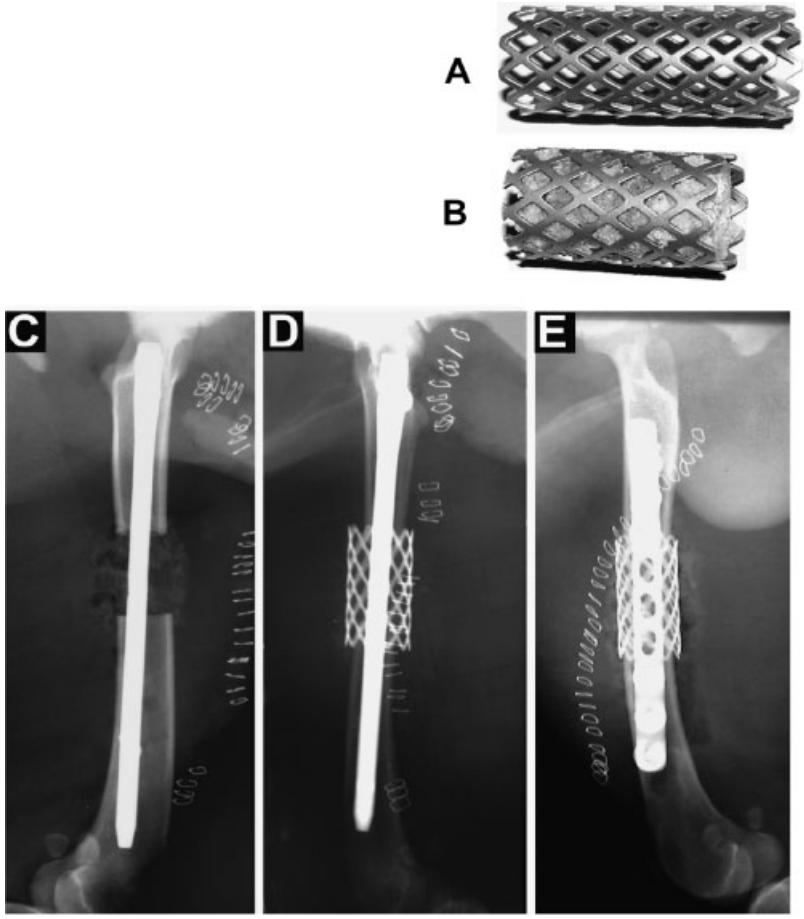

Figure 7.
Cylindrical titanium mesh (A) was trimmed to fit the defect size and packed with allograft prior to implantation (B). Defects treated with allograft alone were stabilized with IM nail (C); defects treated with allograft and mesh were fixed either with IM nail (D) or plate-screws construct (E).

at the host bone-defect junctions (Figure 8). Uniform bone formation occurred in the cage-nail defects, whereas cage-plate defects demonstrated lesser bone formation at the mesh center that its periphery. The extent of new bone formation for both cage-nail and cage-plate defects was significantly greater compared with no cage defects.

The biological activity (Tc^{99m} MDP uptake) of the graft contained in the defects was high and uniform for cage-nail constructs at 6 weeks and subsequently declined at 12 and 18 weeks, persisting preferentially in the defect center (Figure 9). Interestingly, the cage-plate defects remained ''hot'' uniformly within the entire defect up to 18 weeks, resembling the early uptake patterns of cage-nail defects. Defects without cage demonstrated marginal or no radioactive uptake at 18 weeks. Biomechanically, progressive increase in torsional stiffness and strength of the cage-nail construct was observed, and at 18 weeks was 70–80% that of the intact femur (Figure 10). Histologically, the extent and maturation of new bone spanning the defects reconstructed with the cage correlated well with the time of healing. New bone formation progressed inward and outward the mesh, extending onto the margins of the host cortex. At 18 weeks, dense new bone extended outside

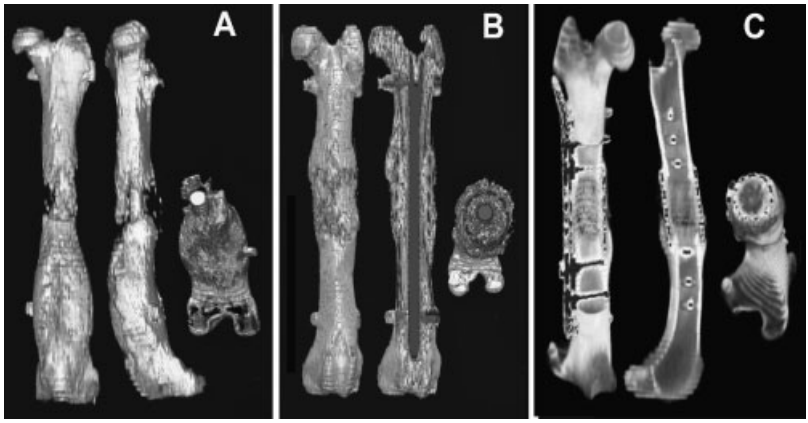

Figure 8.
Three-dimensional CT reconstruction of the canine femur depicting the nature and extent of defect healing 18 weeks post surgery. Defects treated with allograft without the mesh and stabilized with an IM nail cage resulted in nonunion (A). Defects treated with mesh-allograft and stabilized wit IM nail healed forming new bone uniformly distributed within and about the mesh cage (B). Defects treated with allograft-mesh and stabilized with a plate-screws construct also healed, although the central portions of the mesh cage demonstrated radiolucency resulting from resorption of the allograft (C).

and inside the cage seamlessly integrating through its fenestrations. Defects treated with allograft without cage demonstrated a scarce bone within, no defect bridging, and were predominantly filled with fibrous tissue (Figure 11).

Relevance of the Animal Defect Models in Determining the Efficacy of Cylindrical Mesh Implants

Both polylactide mesh membranes and titanium cages were applied as hollow

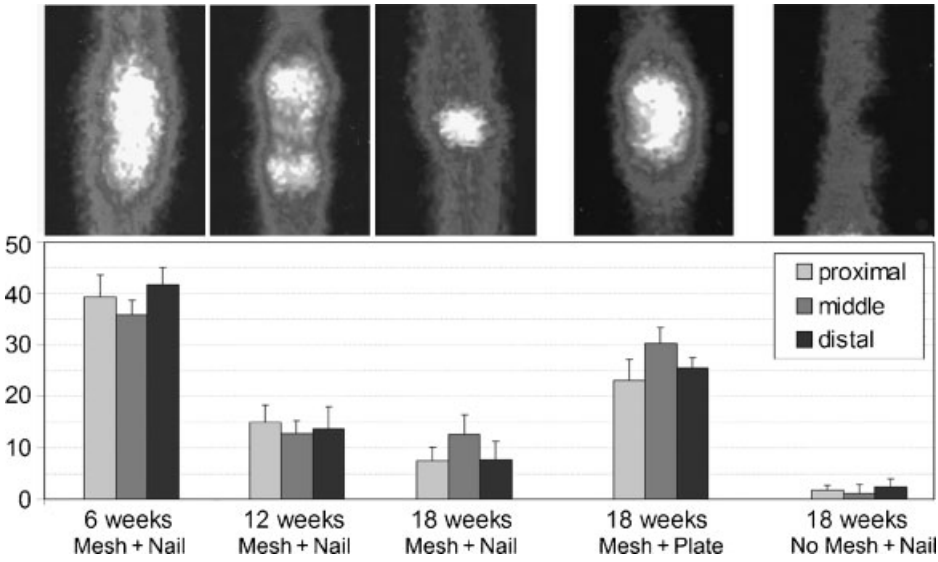

Figure 9.
SPECT visualization and measurements of the radioactive Tc^{m99} MDP uptake within defects treated with an allograft-titanium mesh construct. The uptake was affected by the presence of the mesh as well as by the mode of supplementary defect stabilization.

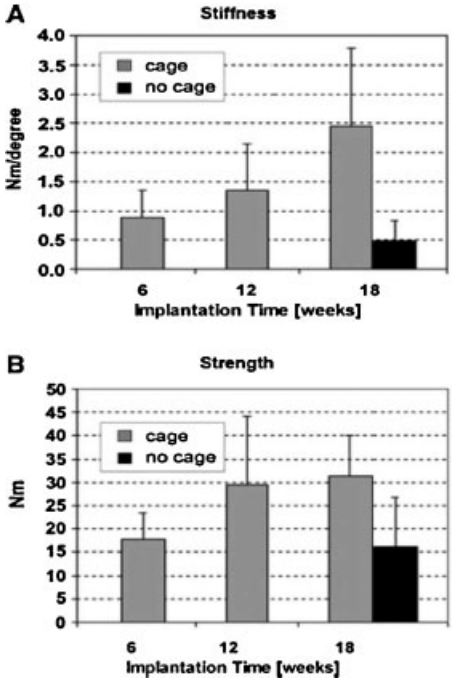

Figure 10.
Torsional stiffness and strength of defects treated with allograft in the absence or presence of titanium mesh and stabilized with an IM nail.

cylindrical implants that could accommodate cancellous bone graft in the treatment of critical-size segmental defects. Both animal models (4 cm in sheep tibia, and 3 cm in canine femur) ultilized defects of critical size, i.e. they did not heal spontaneously, even when augmented with polylactide mesh alone or cancellous bone graft without a mesh.[8–10] Although the minimum size that renders a defect ''critical'' is not well understood, it has been defined as a segmental bone deficiency of a length that exceeds 2-2.5 times the diameter of the affected bone.[11] In the referred animal studies, the sheep defect was approximately 3-times, while the canine 2-times greater that diameter of the corresponding diaphysis. The experimental setting of both animal studies permitted accurate characterization of the extent and nature of the defect healing in presence of cylindrical polylactide or titanium mesh implants that is clinically relevant. Additional advantage of the animal models employed relates to their clinically meaningful anatomical and biomechanical conditions, suitability to accommodate the existing orthopedic implants and/or fixation devices, and the ability of the resume weightbearing after surgery.

Biological Considerations of the Cylindrical Mesh-Graft Constructs in the Treatment of Critical-Size Bone Defects

Although dissimilar in material properties, cylindrical polylactide mesh membranes and titanium cages demonstrate marked similarities in their performances when applied in combination with bone graft for the treatment of segmental long bone defects. Both cylindrical mesh implants are characterized by a number of advantageous biologic properties that promote long bone defect reconstitution. The principal among these is biocompatibility of mesh material, i.e. lactide and/or titanium, as well as their hollow and fenestrated design, and the ability to enclose bone graft. Poly(L/DL-lactide) comprises a biodegradable polymer with an excellent biocompatibility and adequate resorption rate that permits defect restoration entirely with host bone, thereby eliminating issues of a permanent foreign body presence and stress-shielding. Titanium is one of the most biocompatible metals used for orthopaedic implants, demonstrates excellent integration with bone, and has a lower infection susceptibility than other metals. Moreover, the fenestrated nature of both cylindrical implants permits a reduction of mesh material, dedicating most of the defect space to accommodate the bone graft. The hollow geometry of the mesh permits incorporation of various biologically active adjuncts consisting of bone graft or bone graft substitutes to complement the mesh biological efficacy. Hence, the combination of these two components creates an optimal environment for defect healing.

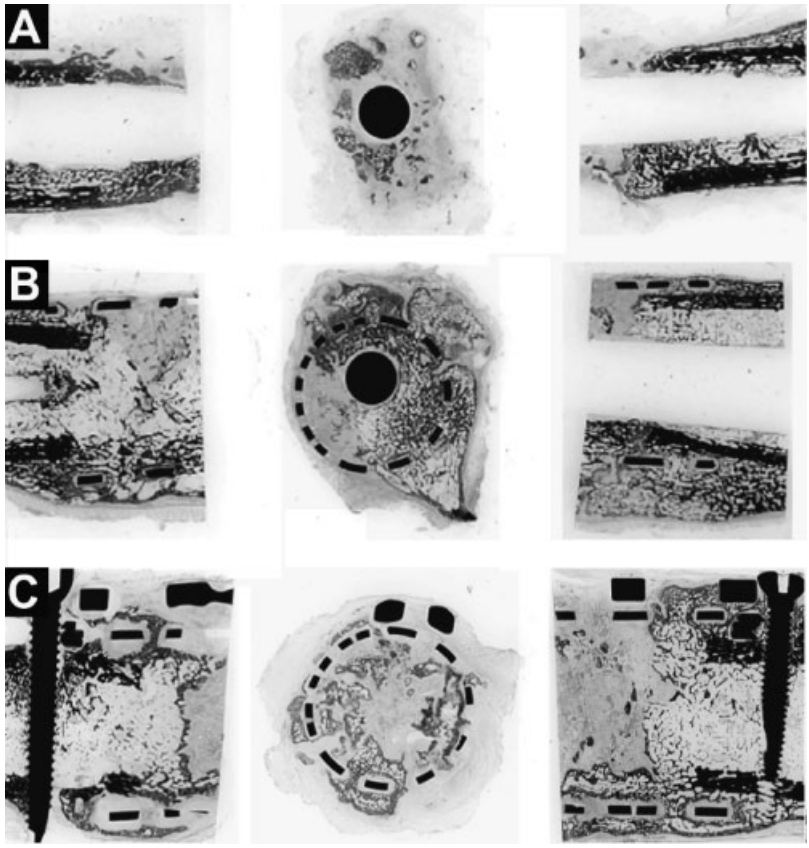

Figure 11.
Histological analysis of new bone formation at 18 weeks in defects treated with allograft and an IM nail (A); allograft-mesh and IM nail (B); and allograft-mesh and plate-screw fixation (C).

The fenestrations both in polylactide mesh membranes as well as in a titanium cage are sufficient in size to permit the diffusion of host nutrients, and can promote the subsequent vascular ingrowth into the defect. This process also stimulates the cage-graft construct integration with the host bone without or minimal presence of the presence of an intervening fibrous capsule. The graft reconstitution with the cylindrical mesh results in meaningful bone healing that is contiguous, and confined to the defect. Both animal experiments demonstrated that the confinement of the graft at the defect site with the mesh is crucial for enhancing its biologic function. They also emphasize the importance of the mesh geometrical design in the enhancement of the graft functionality. The double polylactide mesh and cage in combination with nail fixation accommodated less bone graft than a single polylactide mesh or cage-plate construct, yet the reconstitution of the graft was more efficacious in the former.

The hollow core of the cylindrical titanium mesh cage not only ensures that graft material will be retained in the defect site, but permits the biologic material employed to be osteogenic, osteoinductive, osteoconductive, or osteopromotive (i.e. tissue engineering or gene therapy). The structural integrity of the graft material is not essential; however, the implant's design and the technique of its utilization permits axial load transfer through the graft

material, which can further enhance its biologic activity. The retained loading of the healed construct permits continuous re-modeling over time.

Biomechanical Considerations of the Cylindrical Mesh-Graft Construct in the Treatment of Critical-Size Bone Defects

The cylindrical polylactide and titanium mesh implants demonstrated biomechanical advantages in the treatment of critical-size defects. Both implants separate the defects from the intervening adjacent musculature, ensure retention of the graft at the site, and provide a favorable scaffold for bony restoration. The geometrical structure of the mesh confines and guides the bone healing process to the desired location by providing a latticework for new bone to follow. The presence of fenestrations allows the ingrowth and interdigitation of new bone to occur both inside and outside the mesh, thereby permitting circumferential healing throughout the entire defect length.

The mesh-graft construct immediately restores the defect continuity and limb alignment. The mesh, specifically the titanium cage, is able to significantly enhance the stability of the supplementary internal fixation, thereby permitting immediate unrestricted limb function and weight-bearing. The geometrical double-cylinder design of the lactide mesh or combination of titanium mesh with intramedullary fixation both subject the enclosed graft to mechanical loading and load transfer further enhancing its reconstitution, maturation, and remodelling. Furthermore, the mesh integrity can be reinforced by packing biologically active materials with good structural properties. Both lactide and titanium mesh implants can be custom-contoured to fit the size and geometry of the specific bone defect.

Long-term, the mesh continues to provide an increasingly favorable biomechanical environment for the reconstructed segmental defect to mature and remodel. Polylactide mesh simply degrades, while the minimal amount titanium, owing to the fenestrations and hollow structure, minimizes stress shielding of the reconstructed site. Furthermore, flexible coupling of the mesh-graft construct with various supplemental fixation devices permits the independent fixation device to be removed and or replaced without disrupting the integrity of the mesh with construct.

Clinical Experience with Cylindrical Titanium Mesh in the Treatment of Critical-Size Segmental Bone Defects and Arthrodeses

The cylindrical titanium mesh in combination with allograft was first described by the current authors in 1999.[12] It represents an innovative method of addressing the problems typically confronted in the management of large segmental defects in long bones and joint fusion. Initially reported cases included the titanium mesh-allograft reconstructions of large tibial diaphyseal defects. The results demonstrated that immediate full limb function could be restored and defect healing reliably achieved. The authors' expanding clinical experience with this technique further supports its efficacy in the reconstruction of long bone defects and arthrodeses.[13,14]

Clinical Indications and Surgical Technique for Cylindrical Titanium Mesh-Allograft Reconstruction

The principal indication for long bone application of the cylindrical titanium mesh includes any clinical setting of significant bone deficiency that warrants surgical reconstruction. The mesh technique can be adapted to segmental lesions in the diaphysis, metaphysis-diaphysis segments, or transarticular joint fusion. Prerequisites are an aseptic wound with a healthy soft tissue envelope, sufficient bony quality and anatomy to apply supplemental fixation,

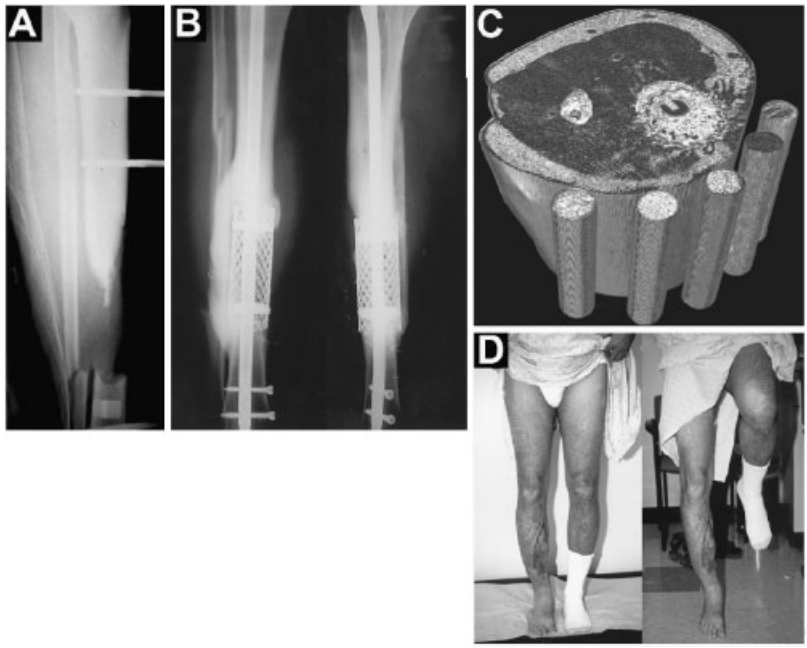

Figure 12.
Grade 3B open tibia fracture with 8.5 cm segmental bone loss in a 34-year-old patient following a motor vehicle accident (A). At 12 months post reconstruction with titanium mesh-allograft, defect healing is evident on plain radiography (B) and axial 3D CT (C). New bone formation occurs inside and outside of the mesh and exhibits

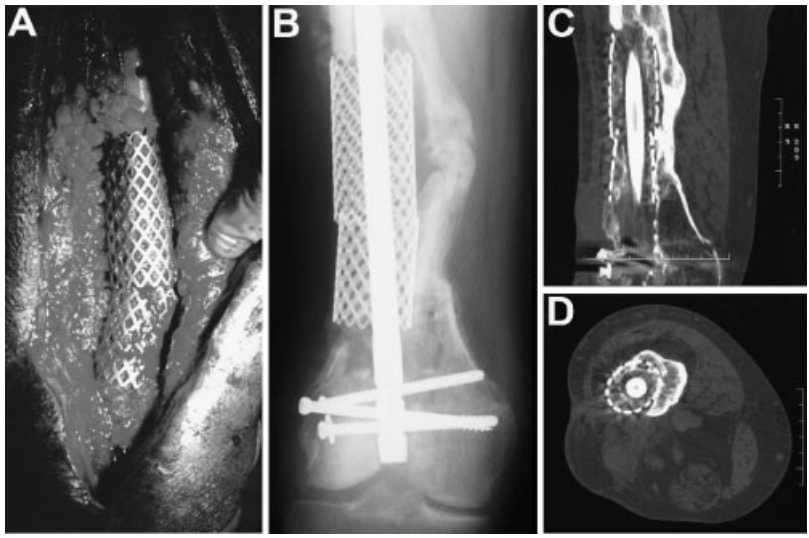

Figure 13.
An intraoperative image of Grade 3B diaphyseal-metaphyseal segmental defect in the distal femur reconstructed with two stacked cages and allograft (A). An AP radiograph depicts defect healing with new bone formation spanning the defect along the medial aspect of the mesh construct (B). At 3 years post surgery, coronal (C) and axial CT (D) confirm complete bone consolidation.

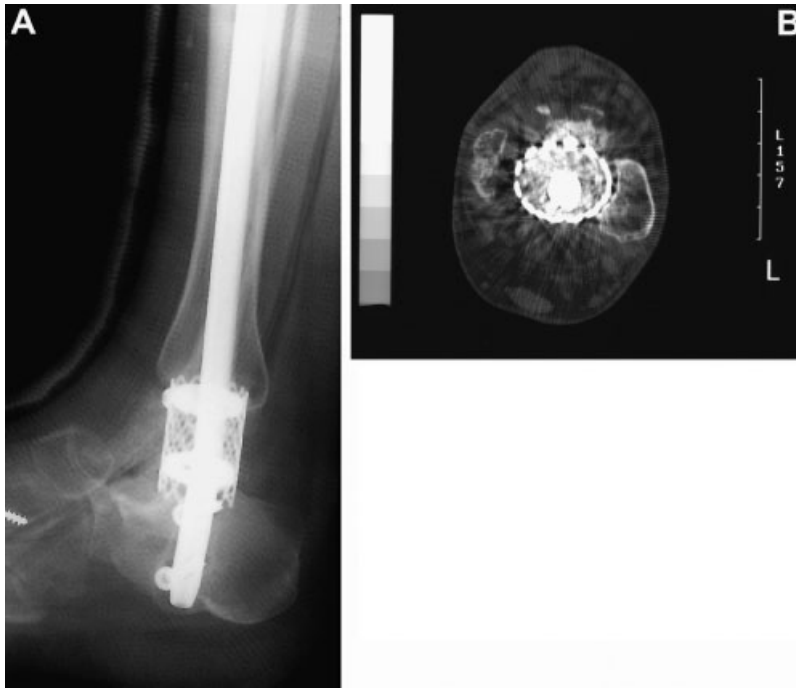

Figure 14.
A lateral radiograph depicting a pantalar fusion using the titanium mesh-allograft and antegrade long tibial nail following talar vascular necrosis (A). An axial CT through the middle of the mesh shows bone consolidation within the cage at 18 months (B).

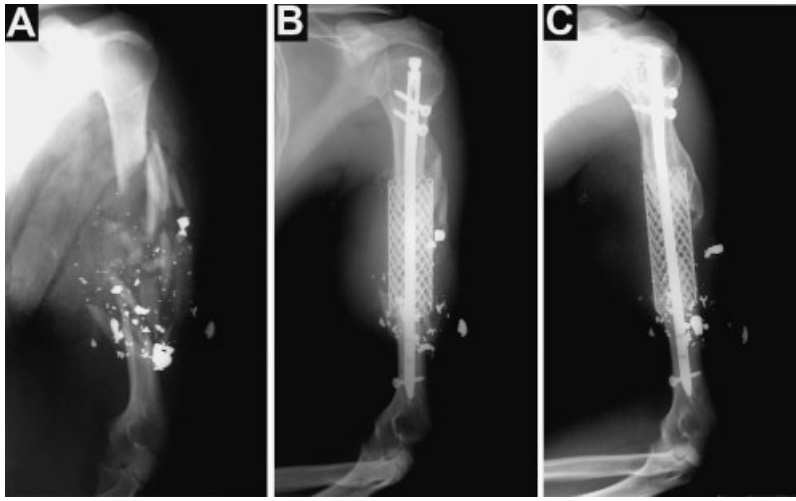

Figure 15.
An AP radiograph of a high-energy gunshot injury to the humerus with an 8-cm-long segmental bone defect (A). The patient was neurovascularly intact. AP radiographs depict the defect immediately post reconstruction (B), and defect healing at 4-year followup (C).

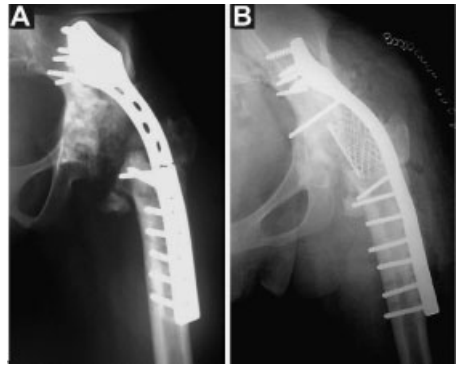

Figure 16.
An AP radiograph of a failed hip fusion with prominent bone deficiency in the proximal femur and breakage of a cobra plate (A). The postoperative salvage reconstruction consisted of repeat cobra plate fixation augmented by a cylindrical titanium mesh (B).

and augmentation of the mesh with bone graft and/or biologic graft substitute. The cylindrical titanium mesh technique is not only a viable alternative to all standard treatment modalities, but it can be a salvage if their failure occurs. It is specifically amenable for patients that cannot tolerate multiple surgical procedures.

To ensure defect suitability for reconstruction, soft tissues surrounding the defect should be meticulously debrided. After an aseptic wound has been achieved, the length and diameter of the bone defect is measured and a titanium mesh cage of an appropriate size of is selected. For diaphyseal reconstructions, the diameter of the mesh cage should be slightly larger than the adjacent cortex to allow the host bone to axially load the graft material contained by the mesh. Metaphyseal and transarticular reconstructions are achieved with the largest diameter cage that can be accommodated at the site. The span of the cage should be equal to the length of the defect in these cases, unlike in the diaphysis where the cage length should be 1–2 cm longer than the defect to allow for overlap with the host bone. The strength of the cage can be increased with rings placed along the inner perimeter of the implant and secured with screws.

After a trial fit of the mesh in the defect confirms its adequate length, the mesh is tightly packed with the graft material. The current authors have used a graft composite consisting of cancellous allograft chips mixed with demineralized bone matrix or rhBMP-2. A guide wire is inserted longitudinally through the middle of the packed cage, and then the construct is reamed sequentially to a diameter permitting the passage of an intramedullary nail. This step is eliminated when supplemental fixation is achieved with a plate or external fixation. When the mesh-allograft construct is in place, under image intensification, a guide wire is passed through the medullary canal, across the cage-allograft, and seated at an appropriate distance within the distal bone fragment. The bone with cage construct is then reamed. Additional bone graft composite is placed along the exterior of the cage adjacent to muscles, and at the cage-host bone junction. A titanium nail of adequate size is inserted in a standard fashion into the medullary canal and across the cage. The host limb is compressed over the cage prior to statically interlocking the nail. The cage-graft construct should also be axially compressed with an application of external fixation or compression plates. Postoperatively, reconstructed extremity is

permitted complete range of motion and weight bearing as tolerated.

Illustrative Clinical Cases

Conclusions

The animal experiments with cylindrical polylactide and titanium mesh implants in combination with bone graft as a treatment of critical-size segmental long bone defects demonstrate several biological and biomechanical advantages. The mesh benefits in the reconstruction of segmental bone defects and joint fusion were corroborated by the authors' initial clinical series. The titanium mesh permits uniform reconstitution of the bone graft and provides initial mechanical stability for defect healing, without restricting the patient's weightbearing. The mesh-graft technique comprised a single-stage surgical procedure, utilizes existing implants, and requires no specialized surgical skills or equipment. It provides immediate restoration of the osseous continuity, early functional limb recovery, and allowes for efficacious defect healing. Cylindrical mesh implants, both composed of polylactide membranes or titanium cages present a viable treatment alternative for critical-size segmental defects in long bones.

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