Vertically bone augmentation procedures—Part I

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Introduction

The success of an implantological procedure largely depends on the alveolar situation and the bone supporting the soft tissues. Until today, complex augmentation procedures pose high demands on the clinician and there is still a great need for research in this field. The following article discusses the basics of implantology relevant to bone augmentation and presents an overview on complex bone augmentation techniques. Part I of this consecutive article series introduces basics in bone morphology, biomaterials and transplants. To be continued in 2014 with issue 1/2014.

Basics

Bone morphology

The histomorphology of bone distinguishes between lamellar bone of complex structure and plexiform bone. Plexiform bone does allow fast healing and growth, but only simple structures of orthogonal primary osteone structure with a mechanical overall weakness of evolutionary relevance in large organisms. It is therefore often found in small mammals like mice, rats, and in part rabbits. Larger mammals including pigs, dogs and humans have a complex lamellar bone structure. Ontogenesis of bone in humans starts with embryonal plexiform bone structures leading to the mature bone structure with secondary osteons (Haversian system). The two morphological forms of bone are cancellous and compact bone. Cancellous bone shows a trabecular structure with an internal lumen containing bone marrow with several function including pluripotent stem cells and vessels. Healing starts in a lamellar fashion from the bone marrow space. Cortical bone is a compact more stiff structure with higher mechanical stability and no internal remodelling capabilities. The internal structure of both bone tissues is lamellar as described above. Osteons with central Haversian canal containing osteocyte and vessels surrounded by mineralised matrix lamellae is the structure principle of compact bone and surrounded by interstitial lamellae (Fig. 1). Osteocytes are connected with each other via gap junctions through the Canaliculi ossei. The bony part of cancellous bone is similar in structure. Periosteum separates bone from surrounding connective tissue and consists of two layers Stratum fibrosum (external) and Stratum osteogenicum (internal) containing nerves, vessels and also osteogenic progenitor cells allowing chemotactic migration during bone healing. Bone tissue consists of cells and matrix (ossein). Ossein contains inorganic minerals, mostly hydroxyl apatite, and organic molecules mostly collagen type I. The organic matrix also contains several other molecules with complex functions including proteoglycans like aggrecan with its glycosaminoglycan arms and multiadhesive proteins but also its hyaluronic acid cores or newly discovered fibrils and other structures under current research.

Bone healing

Healing of augmented bone transplants and biomaterials at the interface site is analogous to defect fracture healing aseptic inflammation and chemotactic cell migration; loose preliminary tissue (soft callus); mineralised immature bone (hard callus); remodelling resulting in full functional bone (Fig. 2). This mode of healing concerns all free avascular transplants including guided bone regeneration (GBR) and block augmentations contact healing is therefore not an issue in all of these augmentations and would require both sides of the healing site to be vasculated vital bone tissue (Fig. 2). The gap healing in bone augmentations includes lamellar healing at the interface site and the periostum.
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with cell recruitment from blood, bone marrow and the periosteum depending on the local anatomy (Fig. 3). This cell recruitment includes local osteoblast progenitors (human trabecular bone derived cells - HTBs), and blood-derived CD-34-positive embryogenic progenitor cells (EPCs). Differentiation of local adult stem cells is not well understood yet. However, the differentiation of EPC follows a stepwise change into an osteoblast while losing pluripotent capabilities from the EPC with high CD34-positive cells, followed by the stage of "circular osteoblast lineage cell" towards the "blood mesenchymal precursor cell" (BMPC) direct differentiation into osteoblasts with continuously rising percentage of stromal cell-derived factor-1 (SDF-1) CXCR4 receptor. Vascular cells in newly formed bone tissue are also derived from EPCs. Osteoclast however are part of the mononuclear phagocyte system and derived syncytiat formations of these cell lineages. Visceral cranial bone of the facial area is mesodermal tissue derived from the branchial arch rather than mesenchymal tissue derived bone in the remaining skeleton. This issue is often not fully considered when discussion bone of the skull.

Cell induction in bone tissue: osteoinduction and neoangiogenesis

The time course of bone healing is influenced by many factors. This includes the stability and morphol-
characterized as: autologous (fresh or frozen), allogeneic (e.g. DBM "demineralized bone matrix"), and xenogeneic. Important material properties concerning bone healing are pore size and interconnectivity, resorbability without severe inflammation and macro stability of particle material. Some of these factors are evaluated scientifically like pore sizes and surface properties, while other factors are mostly clinically bases experiences like macro stability. Materials can be further characterized by their potential to influence bone healing: osteoconductive (promotes bony ingrowth); osteoinductive (induces bone tissue generation by receptor-mediated cell activation); osteogeneic (material contains living bone cells or bone cell precursors). Most common particulate materials are bone chips from the implant site, milled bone blocks, scraped bone chips, mesh grafts with alloplastic materials (Fig. 4). Growth factors and tissue engineering are future options in compromised bone healing and complex reconstructive surgery. Conceptional problems arise, if these novel techniques concerning cost and carcinogenic risks of growth factors are not addressed. Dental implantology therefore offers limited indications for these options.

Donor sites for bone transplants
Choosing the appropriate donor site for bone transplants is the second step after analysis of the defect and augmentation planning. Most common donor sites are:
- Mandible
  - (chin, angle, linea obliqua, corpus mandibulae)
- Maxillary
  - (tuber, spina nasalis, crista zygomaticoalveolaris)
- Calvaria (tabula externa)
- Pelvic rim
- Tibia.

Local donor sites are of special interest for applications in oral and maxillofacial surgery. Intraoral donor sites are shown to be less painful for patients (Fig. 5). Big defects require extraoral donor sites mostly from the pelvic rim region. Quality and healing properties of various bone transplants concern their ontological origin in particular. While local skull bone is branchial tissue of mesektodermal origin, pelvic and most other bone transplants are mesenchymal tissues. Mandibular bone is the most common transplant in dentistry with several donor regions: chin, linea obliqua, angle, corpus mandibulae, lingual exostotic. Bone is harvested as a block for either immediate transplantation or generation of particles in a bone mill or similar device. Using a scraper is a modern way of directly generating bone chips. The chin region bears more donor site morbidity problems due to the mental muscle attachment and should be limited to augmentations in the same region to avoid a second surgery site or other serious indications. The linea obliqua area offers a versatile donor site with limited risks and complications if the anatomy of the alveolar nerve is carefully evaluated. The area of the mandibular angle is another site in the same area and similarly difficult with risks for the local nerve like the lingual exostosis. The maxilla offers only limited amounts of bone material. However, using tuber bone or scraping chips from the anterior wall in combination with sinus lift surgery can be the right option. Harvesting bone from the pelvic rim is the method of choice for most indications requiring large amounts of autologous bone due to limited risks and good approach. There is an anterior and a posterior approach. It is discussed that the rarer posterior approach is offering more bone and less morbidity. Complications of this donor site are pain, bleeding, nerve lesions (N. cutaneus femoris lateralis), and fractures of the pelvic bone.

Editorial note: To be continued in implants 1/2014 with osteotomy and complex bone augmentation techniques. A complete list of references is available from the publisher.

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