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Introduction

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Bone grafting represents an exciting field of study and a major advance of modern surgery. It is an important tool that allows surgeons to deal with different and difficult situations. Massive tissue loss or impaired bone healing, caused by tumors, trauma, infections or congenital abnormalities, were unsolved problems until the recent development of bone grafting one century ago. Bone graft could be defined as a bone fragment transplanted, whole or in pieces, from one site to another. Bone grafting is the name of the surgical procedure, by which bone graft, or a bone graft substitute, is placed into fractures or bone defects, to aid in healing or to improve strength.

Bone is the second most commonly implanted material in the human body, after blood transfusion, with an estimated 600.000 grafts performed annually only in the USA 1.

Besides its frequent use, bone grafting study is also important because it is used by many specialties of Medicine and Dentistry, like Orthopedics, Traumatology, Neurosurgery, Spinal Surgery, Plastic Surgery, Hand Surgery, Head and Neck Surgery, Otolaryngology, Maxillofacial Surgery and others.

The correct and effective use of bone graft takes not only precise surgical technique skills, to harvest it and to deliver it to host bed, but also a deep theoretical knowledge, to understand its mechanical and biological behavior during graft integration to host tissues.

So, it is important to all surgeons and specialists involved somehow with bone grafting procedures, to have knowledge of some basic principles that will be presented along this and the following chapters. To understand the actual state of the art, it is important to begin by knowing the pioneers that initiate the history of bone grafting.

1.1 History

In the 19th century, three important scientific discoveries stimulated the rapid development of Modern Surgery: the advent of Anesthesia, attributed to William Thomas Green Morton in 1846; the use of asepsis and the development of an antiseptic solution to prevent infection in surgery, by Joseph Lister; the discovery of X-Ray by Wilhelm Conrad Röentegen, which performed the first radiography, taken by the hand of his wife in December 1895. These iscoveries boosted the surgical treatment of fractures during First World War [2].

Parallel to the rapid development of metallurgy, which allowed the rigid fixation of bone fractures with increasingly expensive implants, there was a slowly, but important, understanding of the biology of bone healing.

Although reports of autologous bone grafting date back to the ancient Egypt, the first description of systematic use of autologous bone grafting, with the modern principles and concepts, is attributed to **Fred H. Albee** (1876 – 1945), a North American surgeon that served during the First World War, and published in **1915** a textbook named **"Bone Graft Surgery**". Before Albee, occasional reports described the use of various forms of bone grafts.

In the 17th century, there was an isolated report of a successful bone xenograft, performed by Job van Meekeren, who treated a bone defect in the skull of a Russian soldier with a dog's skull bone. It takes two centuries to appear a new reference about this kind of surgery. In 1881, MacEwen was able to reconstruct the umerus of a child with a cadaveric bone. Barth and Marchand also observed that the bone from autograft, when transplanted to another site, goes to necrosis and are subsequently invaded by host cells that differentiate to bone cells and produce new bone. In that way, those authors demonstrated that a fragment of bone take from one site can substitute bone from another site.

The French surgeon Léopold Ollier (1830-1900), called "The Father of Bone and Joint Surgery" and "The Father of Experimental Surgery", shed a significant light on the function of the periosteum, reflected in his "Traité de Régénération Osseuse Chez L'Animal". He also performed autologous and homologous bone grafting in humans.

Georg Axhausen (1877-1960) and Erich Lexer (1867-1937), German surgeons, and the North American surgeon Dallas B. Phemister (1882-1951), played an important role to make bone grafting recognized as rational and viable. Axhausen and Phemister described the graft incorporation process by the host organism. Lexer published clinical cases of bone allografting with twenty years follow-up, with good results in half of patients [3].

In the 40th decade, Wilson (1947) and Bush (1948) described freezing storage techniques for preserving allografts, giving rise to the era of tissue banking [4,5]. After the end of the Second World War, tissue banks become more complex, with the need to create protocols and rules to control the use and safety of musculoskeletal tissues. The American Association of Tissue Banks (AATB) was founded in 1976 by a group of doctors who had started in 1949 the first full tissue bank of the world, the United States Navy Tissue Bank [6].

Following the creation of AATB, the Asian Pacific Association of Surgical Tissue Banking was done. In a few years after 1949, additional regional tissue banks were established in Europe as well. Those first European regional and national tissue banks were established in the former Czechoslovakia in 1952, the former German Democratic Republic in 1956, in Great Britain 1955 and in Poland in 1962. Only after the end of the "Cold War" and the reunification of Berlin, it was born the European Association of Tissue Banks (EATB), in 1991 [7].

In the 60's decade, Marshall R Urist (1914-2001) established the osteoinductive capacity of Demineralized Bone Matrix (DBM), which leads to the discovering and understanding of a family of proteins called Bone Morphogenetic Proteins (BMPs) [8,9,10,11,12]. Both DBM and BMP are available nowadays to clinical use isolated or in combination with scaffolds. This finding started a new era in bone grafting, leading to the development of graft substitute research.

1.2 General indications for bone grafting

In brief, the major indications to the use of some kind of bone grafting procedure are the following [13]:

- Reconstruction of skeletal defects of multiple etiologies, like tumors, trauma, osteotomies and infections.
- Augmenting fracture healing, in the treatment of delayed-union and non-union, or in the prevention of those problems in patients with risk factors (smoking, diabetes).
- Fusing joints.
- Augmenting joint reconstruction procedures, especially to correct massive bone loss in revision arthroplasties.

1.3 Types of bone grafts

Bone grafts could be classified in different manners, according to its sources (table 1), surgical location (table 2) or time to use (table 3) [14,15].

Autograft	**A graft moved from one site to another within the same individual.**
Allograft	Tissue transferred between two genetically different individuals of the same species.
Xenograft	Tissue from one species into a member of a different species.
Isograft	Tissue from one twin implanted in an identical (monozygotic) twin.

Table 1. Type of bone graft according to its source.

Orthotopic	**Anatomically appropriate site. Ex: delayed union of a bone fracture.**
Heterotopic	Anatomically inappropriate site. Ex: subcutaneous tissue.

Table 2. Type of bone graft according to its surgical location.

Fresh	**Transferred directly from the donor to the recipient site, in the case of autografts, or held for a relatively short time, in culture or storage medium, in the case of allografts (fresh-frozen).**
Preserved	Maintained stored for a relatively long time in a tissue bank, by freezing, freeze-drying, irradiation or chemical treatment.

Table 3. Type of bone graft according to its time until implantation.

Bone grafts could also be classified as cortical, cancellous or corticocancellous, according to the type of bone present in the graft. Cortical bone grafts are used for structural support. Cancellous bone grafts are used for osteogenesis. These properties could be combined in a corticocancellous graft.

Although the name, vascularized bone grafts will not be approached in this chapter, because it is better understand in the field of microsurgical flaps.

1.4 Properties

Bone grafts present mechanical and biological properties. The biological properties are divided in Osteoconduction, Osteoinduction and Osteogenesis.

Osteoconduction is defined as the propertie of bone graft to serve as a framework to cells of the host (mature osteoblasts) that uses it as a porous three-dimensional scaffold to support in-growth. It depends of the host surrounding viable tissue to survive and incorporates. This effect could be exerted by autograft, allograft and bone graft substitutes. Autograft is always the gold-standard procedure; to wich the other must be compared. However, autograft harvest presents a series of complications, like pain, bloody loss, long surgical time, risk of nerve or vascular injurie, and scars. So the use of alternatives is very attractive, principally when the graft indication is for osteoconduction. Several artificial substitutes have been developed [16,17,18,19].

They could be divided in biological or non-biological materials.

Biological:

- Porous coralline ceramics
- Calcium sulfate
- Calcium phosphate
- Type 1 collagen (Col1);
- Numerous commercially available combinations of the above materials.

Non-biological:

- Degradable polymers (polylactic acid and polyglycolic acid);
- Bioactive glasses;
- Ceramics;
- Metals.

Osteoinduction is defined as the enhancement of bone formation, by the stimulation of host osteoprogenitor cells to differentiate to osteoblasts. It is used to enhance bone healing, to treat bone loss from trauma, tumor, osteonecrosis or congenital conditions. The gold-standard procedure is the autograft, but the pursuits of substitutes to avoid harvest complications lead to a significant improve in the understanding of growth factors that mediates bone formation. The most studied is a family of proteins called BMPs (Bone Morphogenetic Proteins).

Osteogenesis is defined as bone formation, from cells that survive in the graft and are capable of produce new bone. When new bone is formed from host cells which penetrate graft from surrounding tissue, this is called osteoinduction. It is indicated when the host conditions are impaired, like in fracture non-unions. Gold-standard procedure is autograft, but beyond the inconvenience of harvest, the limited quantity available is a major concern. With the development of tissue engineering, the combination of a scaffold with growth factors and stem cell derived osteo-progenitor cells has becoming a promissory field to provide large amounts of graft to fill large defects.

Mechanical properties are indicated to support weight-bearing. It could be exerted by autografts, like fibular non-vascularized transfer to support tibia bone loss (figure 1). With the development and expansion of the uses of joint arthroplasties, nowadays it is more common to use structural allografts in revision arthroplasty surgery to deal with large bone defects.

1.5 Sources of autollogous bone grafts

Surgeons must plan carefully any surgical procedure that involves bone grafting. Small amounts of cancellous grafts can be obtained from local sites nearby the surgical region:

- Greater trochanter of the femur for hip surgery;
- Femural condyle for knee surgery;
- Proximal tibial metaphysic for knee surgery;
- Medial malleolus of the tibia for ankle surgery;
- Olecranon for upper extremities;
- Distal radius for wrist surgery;

Large cancellous and corticocancellous grafts can be obtained from the anterosuperior iliac crest and the posterior iliac crest. Cancellous graft can be obtained also from the medular cavity when reaming procedures are performed.

Fig. 1. An example of a structural autograft: after extensive bone loss caused by a high energy trauma, non-vascularized fibular diaphises was transferred to the tibia ("Tibialization of the Fibula") and fixed with plate and screws (pictures kindly provided by dr Bruno Livani).

1.6 Surgical techniques

1.6.1 Anterior iliac bone graft

If the patient is in the supine position for surgery, graft can be obtained from the anterosuperior iliac spine. This is a very dynamic source, as it provides cortical or cancellous grafts as well. If the intention is to use osteogenesis alone, bone chips can be removed. If mechanical support is required, a corticocancellous graft can be obtained with one, two or three cortical walls (figure 2).

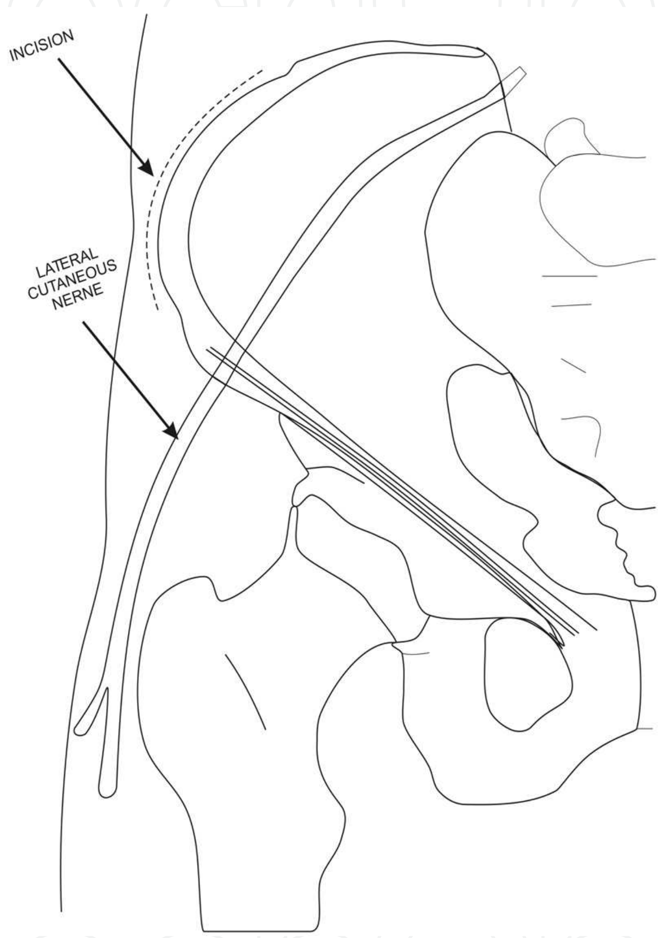

Fig. 2. Autologous bone graft could be obtained from the anterior region of the iliac bone. An oblique incision ("bikini incision") over the crest is performed carefully to avoid damage to the Lateral Thigh Cutaneous Nerve that runs medially to the Antero-Superior Iliac Spine, superficially to the Inguinal Ligament.

1.6.2 Posterior iliac bone graft

If the patient is prone, the posterior third of iliac bone is used. Caution should be taken to avoid Cluneal Nerves lesion, restricting the dissection to a line eight cm length from the posterior superior iliac spine (figure 3).

1.7 Complications of iliac autograft harvesting

- Bleeding and haematoma;

- Infection;
- Inguinal hernia;
- Nerve injury: the lateral femoral cutaneous and ilioinguinal nerves are at risk during anterior procedure. The superior cluneal nerves are at risk in the posterior procedure when dissection is extended beyond 8 cm lateral to posterosuperior iliac spine.
- Arterial injury: Superior gluteal vessels can be damaged by inadvertent retraction against the roof of sciatic notch. Arteriovenous fistula and pseudoaneurysm are less frequent.
- Cosmetic deformity;
- Pelvic fractures;
- Chronic pain;
- Insufficient material to fill the defect.

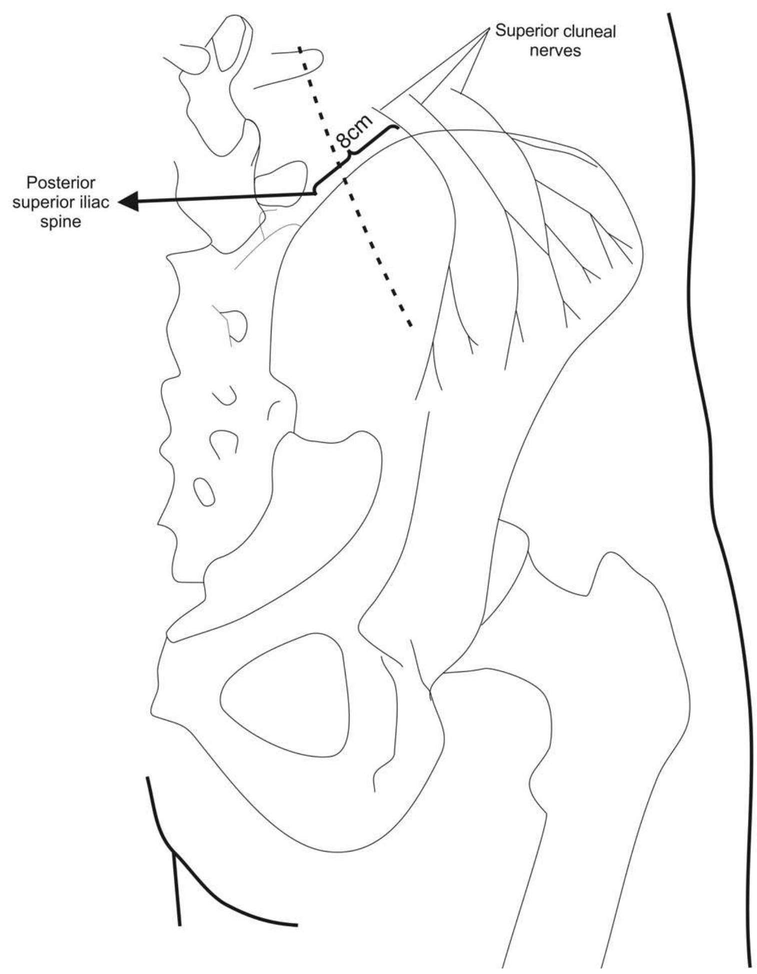

Fig. 3. To take bone from the posterior region of the iliac bone, a longitudinal incision is done crossing the iliac crest in a point between the Postero-Superior Iliac Spine and a point eight centimeters lateral to that, over the iliac crest, to avoid damage to the Cluneal nerves that runs in the subcutaneous tissue.

Nowadays, Autologous Bone Graft is the gold standard procedure. However, to avoid complications related to it, the pursuit of bone graft substitutes is one of the major fields in medical research today. The understanding of graft biology (osteogenesis, osteoinduction, osteoconduction) and integration to host tissue are paramount to the success of new materials. In the future, the developing of graft substitutes could be more safety and less expensive, turning the use of these materials the first choice when dealing with bone loss or fracture non-unions.

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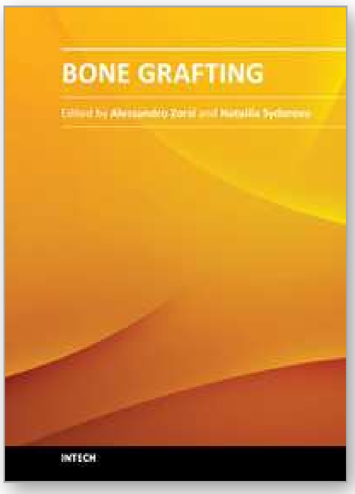

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Bone grafting is the surgical procedure in which new bone (bone graft) or a replacement material (graft substitute), is placed into bone fractures or bone defects to aid in healing. Bone grafting is in the field of interest of many surgical specialties, such as: orthopedics, neurosurgery, dentistry, plastic surgery, head and neck surgery, otolaryngology and others. In common, all these specialties have to handle problems concerning the lack of bone tissue or impaired fracture healing. There is a myriad of surgical techniques nowadays involving some kind of bone graft or bone graft substitute. This book gathers authors from different continents, with different points of view and different experiences with bone grafting. Leading researchers of Asia, America and Europe have contributed as authors. In this book, the reader can find chapters from the ones on basic principles, devoted to students, to the ones on research results and description of new techniques, experts will find very beneficial.