Biomaterials in Periarticular Comminuted Fractures

ADRIAN BADILA[1], RADU RADULESCU[1], CRISTIAN NINULESCU[11], ALEXANDRA BOLOCAN[2]*, SORIN CONSTANTINESCU[3], DAN NICOLAE PĂDURARU[2]

[1] "Carol Davila" University of Medicine and Pharmacy Bucharest, Orthopedics and Traumatology Clinic of the Emergency Universitary Hospital, 169 Splaiul Independentei, 050098, Bucharest, Romania

[2] "Carol Davila" University of Medicine and Pharmacy Bucharest, General Surgery Clinic of the Emergency Universitary Hospital, 169 Splaiul Independentei, 050098, Bucharest, Romania

[3] Radiology Clinic of the Emergency Universitary Hospital, Bucharest, Romania

The paper refers to the new approach in bone grafting: biomaterials. Many artificial bone substitute materials are currently available for use in orthopaedic trauma surgery. The selection of these materials is more and more difficult as many bone substitute products are now available for use and this method led to a new approach, although the autologus bone grafting still represents the "gold standard" in bone reconstruction surgery.

Keywords: bone grafting, biomaterials, reconstruction, fracture

Bone reconstruction is a continuous challenge in trauma surgery.

Worldwide, the second most commonly transplanted tissue is the bone, with blood being number one. Approximately 10% of all skeletal reconstructive surgical interventions (mostly trauma related) require bone grafting.

Autologus bone grafting was considered the main source in bone reconstruction surgery and it still represents the "gold standard", whether it is from the iliac crest, the femur, the tibia, the fibula or the ribs. Nevertheless, the development of biomaterials and bone substitutes led to a new approach and made them more and more popular. This happened because the autologus bone grafting has the disadvantage of adding a second surgical procedure in order to perform the graft harvesting with its potential of both short and long term morbidity. Its most frequent complications include pain, infection, gait abnormalities and neurovascular damage. Many artificial bone substitute materials are currently available for use in orthopaedic trauma surgery. Tens of bone substitute products are now registered for use in orthopaedic trauma surgery. Their different composition, characteristics, appearances, and delivery forms make the selection of the product more and more difficult, as we are trying to find the one that mimics the bone the best, both in structure and biomechanical characteristics.

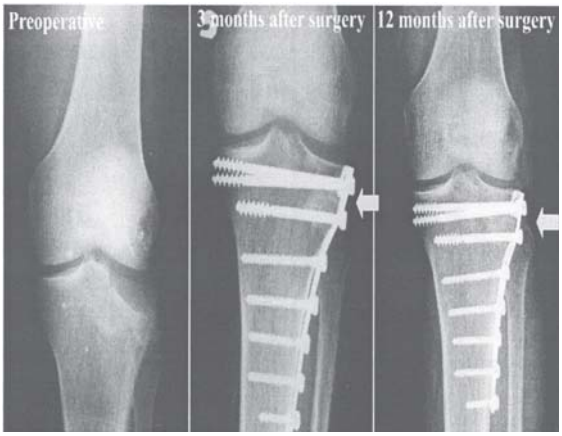

Fig. 1. Tibial plateau fracture – reduction and reconstruction with bone autograft from iliac crest and osteosynthesis with plate and screws

The study aims to compare the clinical and radiological results in comminuted fractures treated with osseous autograft versus bone substitute and internal fixation.

Experimental part

Materials and methods

In the last 5 years, we used bone substitutes in 48 patients with comminuted fractures (femur, tibia and calcaneus). For each patient treated by open reduction, grafting with bone substitute and osteosynthesis (plate and screws or screws only)(Group 1), we allocated 2 patients with similar fractures treated with grafting with bone autografts (Group 2 – 96 patients). The patients in Group 2 were randomly chosen from those operated in the same month as those in Group 1. The mean follow-up was 37 months (extremes: 14 - 72 months). The sex ratio, age distribution, body mass index and the fracture types were similar in the two groups. The bone autograft was harvested from the iliac crest in all cases.

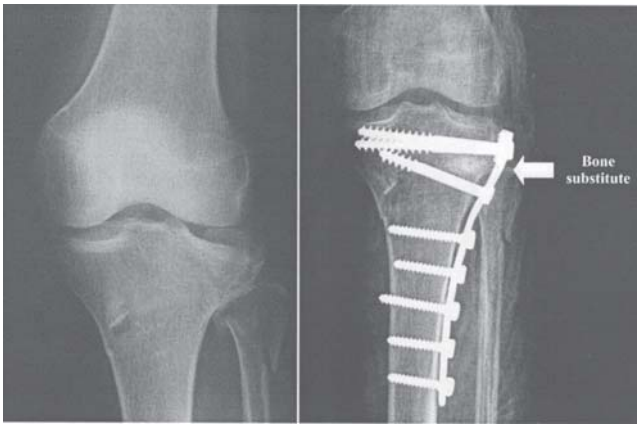

Fig. 2. Tibial plateau fracture – reduction and reconstruction with bone substitute and osteosynthesis with plate and screws

The bone substitutes included bioactive glass, ceramic, calcium phosphate and calcium sulphate. Mobilization without weight bearing was indicated for 3 months. Continuous passive motion was used in all cases. Radiological and clinical examinations were performed monthly in the first 6 months, at 12 months and once per year after that. In Group 2 (bone autograft), problems of the donor site (from where the osseous graft was

* *email: bolocan.alexa@gmail.com ; Tel.: +40722579776*

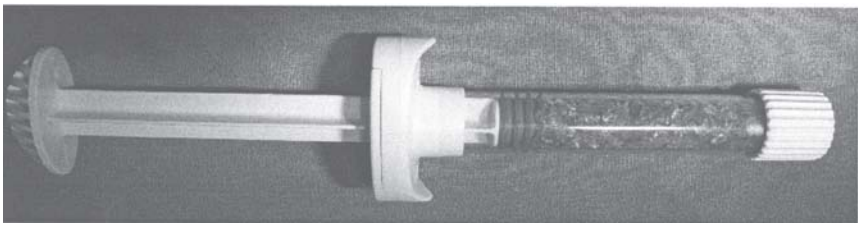

Fig. 3. Bioactive glass

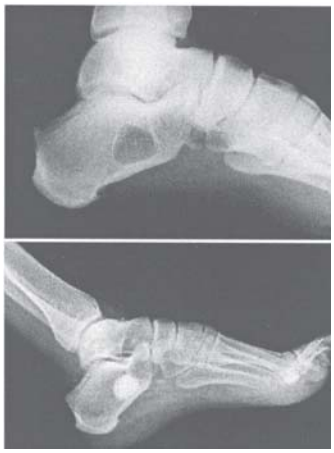

Fig. 4. Calcaneus enchondroma – preoperative and postoperative X-rays (curettage and filling with bioactive glass)

harvested) were recorded (persistent pain, skin necrosis, hematomas, dehiscences, etc.). At 6 months postsurgery, weight-bearing radiographs were used to asses the interface between bone substitute or graft and the host bone, the mechanical properties of the filling material (conservation or degradation of the structure, subsidence of the articular surface, connection to adiacent fragments, etc.). X-ray examination at 12 months provided information on osteointegration and resorbtion of the graft or bone substitute. The radiological examinations performed once per year offered information about bone remodellation at the fracture site.

Results and discussions

Union of the fracture was obtained in average at 3.5 months in the autograft group and at 4 months in the bone substitute group. At 6 months after surgery, the contact between the filling material (bone substitute or autograft) was similar in the 2 groups. Radiotransparent lines at this level were recorded in 2 cases (4.17%) in Group 1 and on 5 cases (5.21%) in Group 2. The integrity of the bone-substitute-osteosynthesis complex was conserved in 91.67% (44/48) in Group 1 and in 90.62% (87/96). The alignment of the articular surface was maintained in 89.58% (43/48) of cases in Group 1 and in 88.54% (85/96) of cases in Group 2. The connection to adjacent fragments was firm and constant in time in 89.58% (43/48) of cases in Group 1 and in 86.46% (83/96) of cases in Group 2.

At 12 months after surgery, the bone substitute was clearly visible on radiographs in 79.17% (38/48), while the graft was radiographically identifiable in only 42.71% (41/96). The difference was statistically significant ($p<0.001$). Marked condensation of the osseous graft, evocative for bone necrosis, was recorded in 6/96 (6.25%) of cases. In 5 out of these 6 cases (83.66%), the age of patients was greater than 60 years. This correlation between graft condensation and age over 60 years was statistically significant.

In the autograft group donor site morbidity consisted in 2 hematomas which subsided in time and persistent pain in 2 cases. Skin problems (dehiscence and / or necrosis) requiring excision and suture was recorded in 3 cases in the first and in 2 cases in the second group. The zone of the bone substitute was radiodense and easy identifiable even at 4 years after surgery. No septic complications related to the bone substitute were recorded.

Unlike many other tissues, the bone has the ability to heal, grow and repair itself if we provide it the right environment: good contact between fragments, solid fixation of the bone fragments, covered and aseptic zone, a source of undifferentiated stem cells which will differentiate themselves in osteoblasts – bone cells that generate bone tissue.

Autografts

The autograft is a graft that is harvested from one region of the patient skeleton (the most used areas are the iliac crest, the fibula and the ribs) and is transplanted at the fracture site. The aim is to replace missing or lost bone, to bridge bone defects resulted from explosive fractures, to provide mechanical support (when structural grafts are used) and to bring good quality bone (with multipotent cell stems) at the site of the bone trauma.

The autograft was, till recent years, the first choice for the orthopedic surgeon. That was due to a number of qualities (osteoconduction, osteoinductions, osteogenesis, mechanical support) and advantages.

Osteoconduction means that the bone graft material serves as a scaffold for new bone growth. Osteoblasts from the fracture fragments utilize the bone graft material as a framework upon which to spread, multiply and generate new osseous tissue.

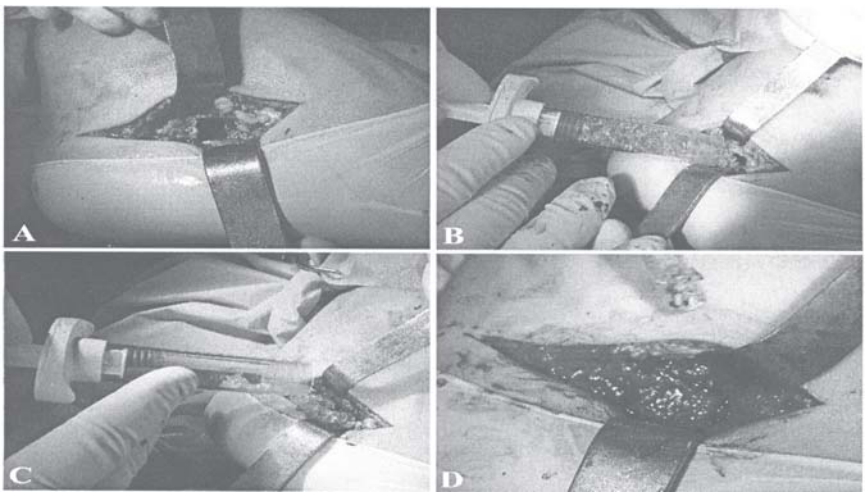

Fig. 5. Calcaneus enchondroma – intraoperative pictures: A- bone cavity after curettage, B,C – filling with bioactive glass, D – closing of cavity with bone cover

Osteoinduction is the stimulation of stem cells to differentiate into osteoblasts that then begin new bone formation. The most widely studied type of osteoinductive cell mediators are bone morphogenetic proteins (BMPs). A good quality bone graft that is osteoconductive and osteoinductive will not only serve as a frame and support for currently existing osteoblasts but will also trigger the formation of new osteoblasts, theoretically promoting faster integration of the graft.

Osteogenesis means that the stem cells and osteoblasts originating from the bone graft material contribute to new bone growth. Fresh grafts harvested from the iliac crest will provide stem cells in high numbers. The younger the patient is, the higher is the quality and concentration of stem cells per harvested volume.

The autografts can be used in 2 major ways: as structural grafts, when the graft is applied as it was harvested, maintaining its full structure (since the name) and providing mechanical resistence and support or as morsellised grafts (the grafts are grinded in a sterile bone mill, resulting in bone "gravel"), which are employed as filling material.

The advantages of autografts are: elimination of immunogenicity issues, no risk of transmitting infectious diseases, source of bone and stem cells, etc.

The disadvantages are: additional surgical costs (time and financial) for the harvesting procedure, additional morbidity (risk of infection, skin necrosis, dehiscences, hematomas, fractures, hernias, persistent pain) at the harvesting site and quantity limitation of bone graft that can be harvested.

Bone substitutes

Bone subtitutes are artificial or natural materials that can replace bones or bone tissue. They include a variety of classes: calcium sulphate and phosphate, collagen, synthetic polymers, natural coral, hydroxyapatite, demineralized bone matrix, ceramics, bone morphogenic protein and various other biomaterials. They can be gradually replaced by original tissue or incorporated into surrounding tissue. These biomaterials are osteoconductive (calcium sulphate and phosphate, collagen, ceramics, etc.) and/or osteoinductive (bone morphogenic proteins, growth factors, etc.), but only autografts and bone marrow aspirate are osteogenic.

According to their composition, the bone graft substitutes can be classified as follows:

Factor-based Bone Graft Substitutes

The cellular activity is regulated by the factors and proteins that exist in the bone tissue

Growth factors bind to receptors on cell surfaces, stimulating the intracellular environment to react. Generally, the result is the activation of a certain protein kinase that induces a series of events resulting in the transcription of messenger ribonucleic acid (mRNA) and, ultimately, into the formation of proteins.

The combined and simultaneous action of several factors result in the controlled production and resorption of bone. These factors, residing in the extracellular matrix of bone, include TGF-beta, insulinlike growth factors I and II, PDGF, FGF, and BMPs.

Cell-based Bone Graft Substitutes

Stem cells are grown in cultures in the presence of various other active substances such as dexamethasone, ascorbic acid, and β-glycerophosphate to direct cell differentiation toward the osteoblast lineage. TGF-beta and BMPs can also determine the stem cells to evolve toward the osteogenic lineage. Marrow cells containing mesenchymal stem cells have been combined with porous ceramics and implanted into canine and rat, with bony growth occurring as quickly as 2 months.

Ceramic-based Bone Graft Substitutes

More than 60% of the currently available bone graft substitutes involve ceramics, either alone or in combination with another material. These include calcium sulfate, bioactive glass, and calcium phosphate. The use of ceramics, especially calcium phosphates is due to the fact that the primary inorganic component of bone is calcium hydroxyapatite, a complex phosphate of calcium $Ca_5(PO_4)_3OH$ that occurs as a mineral and is the main structural element of vertebrate bone. In addition, calcium phosphates are osteoconductive, osteointegrative, and, in some cases, osteoinductive. Because of their brittle properties and the requirement of high temperature for scaffold formation, they are frequently combined with other materials to form a composite: Calcium sulfate is also known as plaster of Paris, Osteoset is surgical grade calcium sulfate used as a bone defect or bone void filler, AlloMatrix is Osteoset combined with DBM.

Polymer-based Bone Graft Substitutes

The polymers curently used are natural and synthetic (degradable or nondegradable) polymers. Polymer-based bone graft substitutes include the following: Healos (DePuy Orthopaedics), a natural polymer-based product, a polymer-ceramic composite consisting of collagen fibers coated with hydroxyapatite and indicated for spinal fusions; Cortoss, an injectable resin-based product with applications for load-bearing sites and Rhakoss (Orthovit), a resin composite available as a solid product in various forms for spinal applications.

Both natural and degradable synthetic polymers are resorbed by the body, leading to a complete integration of the implant. To this end, companies have used degradable polymers such as polylactic acid and poly(lactic-co-glycolic acid) as stand-alone devices and as extenders to autografts and allografts.

Bioactive glass is a biomaterial that triggers specific biological responses like osteostimulation. Experimental studies showed that bioactive glass induced attachment, proliferation and differentiation of osteoblasts. The bioglass will release soluble ions (Na, Ca, P and Si ions), which will activate certain genes to induce the synthesis of cytokines, growth factors, cell surface antigens and receptors, in other words an intense osteostimulation.

Angiogenic growth factors and vascular endothelial growth factor are also released and determine local revascularization.

The surface cavities on any foreign materials introduced in the human body provide perfect conditions for the growth of bacterial colonies. The germs tend to isolate themselves from the host by synthesizing a biofilm that is very hard to penetrate by the antibiotics and therefore the eradication of sepsis is improbable. Studies show that bioactive glass releases alkaline ions, which increase the local *p*H with an antibacterial effect.

Bone substitutes will undergo osteointegration and resorption depending on their structure. For example the resorption of calcium sulphate is very fast, while the resorption of other substitutes have a slower rate.

A porous material induces bone ingrowth and a better adherence of the substitute to the host bone.

Conclusions

The bone autograft remains the gold standard for the treatment of bone defects, despite a minimal donor site morbidity associated to a harvesting supplementary surgical procedure . Bone substitutes are the first choice in patients who are not willing to undergo the surgical procedure for harvesting an autograft. Osseous autograft and bone substitute have similar mechanical and adherence properties and lead to similar clinical and radiological results in the treatment of comminuted periarticular fractures. Preparation of the bone cavity is more laborious for the bone substitute and the screws (osteosynthesis hardware) must not be placed in its mass. Bone remodellation occurs faster in the bone graft treated patients than in those that underwent reconstruction with bone substitutes. The zone of the implanted bone substitute remains radiocondensed for at least a number of years. The use of a bone substitute does not imply a higher risk for sepsis.

References

1.HENCH LL, Thompson I (2010) Twenty-first century challenges for biomaterials. J R Soc Interface 4: 5379-5391.

2.LEPPÄRANTA O, VAAHTIO M, PELTOLA T, ZHANG D, HUPA L, et al. (2008) Antibacterial effect of bioactive glasses on clinically important anaerobic bacteria in vitro. J Mater Sci: Mater Med 19: 547-51.

3.DAY RM (2005) Bioactive glass stimulates the secretion of angiogenetic growth factors and angiogenesis in vitro. Tissue Eng 11: 768-777.

4.LINDFORS NC, HEIKKILÄ JT, KOSKI I, MATTILA K, Aho J (2009) Bioactive glass and autogenous bone as bone graft substitutes in benign bone tumours. J Biomed Mater Res Appl Biomater 90:131-136.

5.HIRN M, DE SILVA U, SIDHARTHAN S, GRIMER RJ, ABUDU A, et al. (2009) Bone defects following curettage do not necessarily need augmentation. A retrospective study of 146 patients. Acta Orthop 80: 4-8.

6.LINDFORS NC (2009) Treatment of a recurrent aneurysmal bone cyst with bioactive glass in a child allows for good re-modelling and growth. Bone 45: 398-400.

7.LEU A, Leach LK (2008) Proangiogenic potential of a collagen/ bioactive substrate. Phar Res 25: 1222-1229.

8.HEIKKILÄ JT, KUKKONEN J, AHO AJ, MOISANDER S, KYYRÖNEN T, et al. (2011) Bioactive glass granules: a suitable bone substi-tute material in operative treatment of depressed tibial plateau fracture: a prospective, randomized 1 year followup. J mat Sci – mat Med 22: 1073-1080.

9.SUOMINEN E, AHO AJ, VEDEL E, KANGASNIEMI I, UUSIPAIKKA E, et al. (1996) Subchondral bone and cartilage repair with bio-active glasses, hydroxyapatite, and hydroxyapatite-glass composite. J Biomed Mater Res 32: 543-551.

10. STOOR P, SÖDERLING E, Salonen JI (1998) Antibacterial effects of a bioactive glass paste on oral microorganisms. Acta Odontol Scand 56: 161-165

Manuscript received: 12.03.2012