Chapter 1

Introductory Chapter: Bone Grafting and Its Application in Cranial-Maxillofacial Surgery. The Role of Mesenchymal Stem Cells

Raja Kummoona

Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/intechopen.80299

1. Introduction

Bone grafting is not a new technique but has a longer history, and its important component in modern surgery begins nearly before three-and-a-half centuries.

The construction of first modern microscope by Galileo Galilei (1609) and the discovery of blood circulation by William Harvey in 1615, the first bone grafting operation was performed by a Dutch doctor in 1668, Jacob Van Meekeren. This doctor placed a piece of dog bone in a soldier's skull defect from war injury to heal in, but unfortunately, the soldier was often excommunicated by the church for being part dog, and he was pressing. The soldier did request his doctor to remove it because its presence upsets him, and the doctor discovered of how well bone grafting actually worked [1].

In the process of attempting to remove the bone graft, Van Meekeren discovered that the bone had healed too well, and he found it's actually irremovable. It was the first xenograft applied on humans. More than 150 years later, the first recorded allograft operation was performed by Dr. Walter in Germany. Later, Great British surgeon Sir William Macewen (1880) [2] (from Lexer) attempted the transplantation of bone by reconstruction of a diaphysis of a child's humerus arm from the leg of another patient and considered this as real success in bone allograft transplantation [1].

Bone grafting is an interesting topic practiced by cranial-maxillofacial surgeons and orthopedic surgeons for restoring continuity of bone after radical tumor surgery, road traffic accident with loss of bone segments, and in the cases of post-traumatic missile war injuries. Bone grafting has been used for reconstruction of congenital cranial and facial deformities and for reconstruction of the temporomandibular joint (TMJ) by chondro-osseous graft in TMJ disease and hemifacial microsomia facial deformities.

Bone grafting is a surgical technique used to fix problems by using transplanted bone to repair, rebuild, and replace missing bones in order to repair bone fracture or to replace missing bone after tumor surgery and loss of bone in trauma injury in road traffic accident and in post-traumatic missile war injuries and has also been used for reconstruction of damaged joints [3]. It is extremely a complex technique which poses a significant health risk to the patient and its liability to fail.

Bone graft was used as filler and scaffold to facilitate bone formation and generally has the ability to regenerate completely but requires a very small fracture space or scaffold to do so [3].

Bone graft may be autologous bone as cancellous or cortical or cortical-cancellous types harvested from iliac crest or from rib. Allograft a cadaveric type of bone usually obtained from bone bank or as synthetic bone made of hydroxyapatite or other naturally occurring and should be biocompatible substances with similar mechanical properties to bone.

Bone grafting is possible because bone tissue has the ability to regenerate completely once the space is provided into which it has to grow as natural bone. Bone grafting or transplantation of bone tissue is beneficial in fixing bones that have been damaged or destroyed by war or required for building bone around transplanted tooth in dental surgery. Bone grafting is a technique which requires great experience, skill, and knowledge, and great advances of bone grafting occurred during the last 4–5 decades.

Many techniques were advocated and described for reconstruction of discontinuity defect of craniofacial regions after tumor surgery or congenital deformities or traumatic injuries. Bone graft is widely used and considered as the second tissue transplantation after blood transfusion.

We successfully applied bone grafting in cranial-maxillofacial surgery in the following clinical cases:

1. Reconstruction of the mandible after radical tumor surgery.
2. Reconstruction of the mandible and maxilla after missile war injuries of the face.
3. Reconstruction of the orbital floor with large traumatic bony defect.
4. Reconstruction of the frontal bone and anterior cranial fossa.
5. Reconstruction of receded chin by sandwich technique.
6. Reconstruction of the temporomandibular joint (TMJ) by Kummoona chondro-osseous graft.

2. Reconstruction of the mandible after radical tumor surgery and post-traumatic missile injuries as secondary phase

We had a long experience in reconstruction of half of the lower jaw by free bone graft from iliac crest as autograft, and the type of graft which has been used was cortical-cancellous bone graft as a block from iliac crest. We can reshape the graft according to the required defect. The graft was chosen because its rigidity gave the contour of the mandible, which is highly vascular and applied with firm and rigid fixation. We used previously intermaxillary fixation (IMF) for the healing process for a period of 6 weeks, but nowadays, we change our technique by using rigid fixation without IMF, and we ask our patient to start functioning the jaw immediately with semifluid diet, based on Moss theory (the growth of bones is based on the functional demand of periosteal matrix of the facial skeleton) [4]. We noticed long fixation by IMF end with difficulty of mouth opening and spasm of muscles with damage to TMJ.

In children we do use rib graft for reconstruction of the lower jaw after tumor surgery. We face slight difficulties in manipulating the rib graft due to rigidity and mainly cortical type, and the amount of cancellous bone is very little, and also the rib is less vascular and less minable for cortical-cancellous bone graft from iliac crest with possibilities of pleural perforation.

Bone grafting been used for reconstruction of the mandible after radical excision of tumor surgery, and half of the mandible can be reconstructed by free bone graft from the iliac crest of cortical-cancellous type as one piece or two pieces with rigid fixation is required and IMF is not necessarily used, but mobilization of the jaw was required after few days for restoration of growth and function of the graft and the mandible. In some cases, the tumor involves half of the mandible, the body, and the ascending ramus, but without involving the condylar and subcondylar region, the tumor was resected at the level of subcondylar region, and the preserved condyle was fixed to the bone graft after reshaping the graft. The condyle with the graft was reimplanted in the glenoid fossa after firm rigid fixation through bone grafting. A series of cases were managed by the author by using this technique. We reported that tumor cases of cystic ameloblastoma do not involve the inner cortical plate, but the tumor involves the outer cortical plate and the cancellous bone. The outer cortical plate excised and the cancellous bone that involved by the tumor. The inferior dental nerve was preserved after complete excision of the tumor and decortication of the bed, and a piece of cortical-cancellous bone graft was used for reconstruction of the defect [5, 6].

We reported failure of the graft in two cases. In the first case, the area was subjected to deep X-ray therapy and the other to chemotherapy during the healing period.

3. Reconstruction of the mandible and maxilla as secondary phase of post-traumatic missile injuries

Bone grafting has been used for reconstruction of the mandible as secondary phase of missile war injuries. Sometimes, the situation is more complicated and requires flap surgery; our choice is the Kummoona lateral cervical flap [6] which has been used for the reconstruction of submental area previously subjected to high-velocity bullet injuries with a lot of scars in the submental area, and the lower lip was retracted down by scar with loss of mouth seal. The scar was excised, and the lateral cervical flap was used before 3 months of bone grafting followed by reconstruction of the bone defect by bone graft from iliac crest.

Bone grafting was done successfully for the reconstruction of defect and deformity of the maxilla by shell injuries. Previously, the area was explored and reconstructed by using bone graft from the iliac crest as cortical-cancellous bone after measuring and reshaping it. The margins of bony defect were decorticated, and the graft was successfully fixed with 0.25 mm of soft stainless steel wire; the aim was to restore the esthetic and function of the face.

4. Orbital floor reconstruction

Blowout injuries are quiet common with road traffic accident where the orbital floor content is displaced down to the sinus with herniation of orbital fat and incarceration of inferior oblique and inferior rectus muscles featuring enophthalmos and diplopia. The orbital floor defect measured if small can be successfully reconstructed by silicone rubber material sialastic (rubber silicone material) which is a biologically inert material, but once the defect is large, bone graft is harvested from the outer cortical plate of the iliac crest to simulate the floor, but our observation on bone graft of the floor might show some degree of resorptions in that case. An additional layer of silastic of 2 mm thickness is required to correct the case. It was noticed that membranous bone graft from skull vault is less liable for resorptions.

5. Reconstruction of anterior cranial fossa, orbital roof, and frontal bone

Severe craniofacial injuries may end with head injuries, with severe damage to the frontal bone, roof of the orbit, nose, and anterior cranial fossa. After the recovery of the patient from head injuries, the anterior cranial fossa is approached through bicoronal flap with craniotomy. The brain and dura are retracted backward, and the dura is repaired by the galea or temporalis muscle. The dura should be closed as watertight closure, the roof of the orbit and anterior cranial fossa was reconstructed by bone graft from the iliac crest with silastic, and the frontal bone was reconstructed by bone graft. The author successfully reported few cases with severe craniofacial trauma treated by this technique with collaboration with neurosurgeons.

6. Reconstruction of the chin

Hypoplasia of the chin or receded chin usually required bone grafting by sandwich technique by doing transverse osteotomy of the lower anterior border of the lower jaw. Bone graft was harvested from the iliac crest as horse shows cortical-cancellous bone graft inserted in between the two bones and fixed by rigid fixation with soft stainless steel wire of 0.25 mm or by plate, but some of these bone graft may show some degree of resorption. We prefer kidney-shaped silastic implant in three sizes, small, medium, and large, and the access for the silastic and bone graft is through submental incision [5].

7. Reconstruction of the temporomandibular joint (TMJ) in children

Reconstruction of the TMJ is of great challenge to maxillofacial surgeons because of difficulties of intubation in ankyloses and cases with hemifacial microsomia or first arch dysplasia syndrome and hypoplasia of the condyle.

http://dx.doi.org/10.5772/intechopen.80299

There are two successful techniques for reconstruction of the TMJ:

1. *Costochondral graft*
2. *Kummoona chondro-osseous graft*

Many other techniques have been used like sternoclavicular graft. This technique is only reported once or twice. This graft failed to restore growth of the condyle of TMJ but was used as gap arthroplasty, and this showed technical difficulties with a large head of sternoclavicular graft to fit small glenoid fossa [7].

The costochondral graft for reconstruction of the TMJ has been used since 1973 by Kennett [8] and experimental studies by Poswillo [9] on Macaca iris monkey to prove the viability of the graft and the cellular changes to simulate the condyle for restoration of growth and function of the TMJ. The objection about costochondral graft is that the junction between osteoid element and cartilaginous part is very fragile and easy to dislodge. Possibilities of pleural perforation and long duration of intermaxillary fixation (IMF) for 6 weeks end after the release of IMF. A spasm of muscles of mastication developed besides overgrowth of the graft was reported [10].

Kummoona chondro-osseous graft advocated in 1986 [11, 12] is the most popular graft nowadays because its junction between osseous element and cartilaginous cap is very stable but rigid fixation of the graft to ascending ramus with no IMF, and the child is advised to chew within the next few days to restore function and growth of the graft and the TMJ. This statement is based on Moss theory (1962) [4], the theory of functional demand of the periosteal matrix of facial skeleton.

Experimental research and study were done on a rabbit to demonstrate the viability of the chondro-osseous graft [12] and to demonstrate that the condyle is a growth center. At the end of the experiment, we did postmortem studies and observed an excellent union between the graft and ramus of the rabbit mandible.

Histological examination of the graft showed four zones. The first layer showed a thick articular layer of dense fibrocartilage due to the demand of hard masticatory process of rabbit food, the second layer showed several zones of active layers of round mesenchymal stem cells which represent the proliferative layer, and the third layer showed a series of hypertrophic chondrocyte passing through a series of changes. This layer represents the differentiation of mesenchymal stem cells to chondrocyte and osteocyte. These cellular changes represent the growth potential of the graft, and the fourth layer was an osteoid bone with bony trabecula and bone marrow spaces in between.

In the previous research on the bone and cartilage, they did find a G-protein-coupled receptor (CXCR4) predominately expressed in hypertrophic chondrocyte, while its ligand chemokine stromal cell-derived factor (SDF-1) is expressed in the bone marrow adjacent to hypertrophic chondrocyte. These findings explained the endogenous growth potential of the graft to continue to grow, repair, and remodel the condyle and restore growth of the mandible and midface in children for correction of facial deformity in the affected side.

8. Cytological changes that occurred through two mechanisms in the bones either distraction of bone or grafting bone defect by iliac crest bone graft and the role of mesenchymal stem cells

Our recent advances in bone research by experimental studies are by using rabbits as animal models for studding distraction technique for elongation of bones and studying the changes of bone grafting and the cellular changes associated and the role of mesenchymal stem cells.

Distraction is defined as the process of generating new bone by stretching distraction osteogenesis (DO). Traction on the living tissue can stimulate and maintain regeneration and growth by stimulating the proliferation of precursor cells.

The human body has an enormous regenerative ability to induce a regenerative ability and distraction osteogenesis (DO) which takes the advantages of this regenerative ability to induce the regeneration and remodeling of bone [13, 14].

We did experimental studies on rabbits by achieving distraction of the mandible [15] to demonstrate that the previous literature did not mention about the biological changes that occur in the gap created by osteotomy of the bone site desired during the latent period which is the key factor in distraction process and formation of new bone.

The mechanisms of surgical distraction technique are passed through three phases—phase one is the surgical phase, phase two is the latent period phase, and the third phase is the consolidation phase. Surgical phase is started by fitting distraction apparatus and gap creation by osteotomy. The second phase is the phase of the latent period where the biological and cellular changes occurred by formation of clot and granulation tissue with the release of growth factor (GF) from platelets with proliferation of mesenchymal stem cells derived from bone marrow, periosteum, and covering muscles with active fibroblast formation under the influence and action of growth factor (GF); this phase is the silent phase elapsed between 7 and 10 days.

Distraction of the lower jaw was achieved by using bilateral distractor designed for hand bone lengthening apparatus which was adjusted by transfixation by Kirschner wire of 1.5 mm which was passed through both mandibular bodies. Rhythmic distraction of both corticomized fragments was carried out at a rate of 1 mm/day at a rhythm of 0.5 mm twice daily for 10 days. The segments hold for 6 weeks till consolidation phase is completed, and bone formation and regeneration were evaluated radiologically.

Bone regeneration by distraction is a highly complicated and organized process. Through our research, we found in the histological studies revealed and demonstrated by our experiment that bone regeneration is based on membranous ossification preceded by formation of granulation tissue and mesenchymal stem cells derived from bone marrow of bone segments and periosteum lining and covering muscles with formation of active fibroblasts in the same direction of stretching forces by the influence of growth factor (GF) for formation of new bone, muscles, and even skin [13–15].

http://dx.doi.org/10.5772/intechopen.80299

Bone grafting is also another interesting topic. We did research on rabbits [16] by resecting a piece of bone of 1.5 cm from the lower border of rabbit mandible and reconstructed by a piece of bone from the iliac crest of the rabbit of about 2 cm after decortication of both segments of the mandible and fixed by rigid fixation by stainless steel soft wire of 0.25 mm. The rabbits were divided for purpose of experiment into two groups: one bone graft was fixed without a cover by oxidized regenerating cellulose (Surgicel) in group A, and in the second group, group B, the graft was covered by oxidized regenerating cellulose mesh (Surgicel), to study the cytological changes associated with bone grafting and the differences between two groups of rabbits in healing process and cytological status.

The aim was to study the role of mesenchymal stem cells in bone grafting. In the experiment, 12 young rabbits of 3 months of age were divided into two groups, group A and group B, each group of five rabbits and two rabbits used as control. These rabbits were subjected to surgical osteotomy by excising 1.5 cm from the body of the mandible, and bone graft of 2 cm length was harvested from the iliac crest of the rabbit and fixed by rigid fixation by soft stainless steel wire of 0.25 mm. Oxidized regenerated cellulose (Surgicel) was used as mesh to cover the bone graft of group B; 3 months later, the experiment was terminated. The histological sections were obtained every 2 weeks, 4 weeks, and 8 weeks.

Histological and cytological changes of bone grafting was quiet interesting and showed formation of clot and platelet aggregation with releasing growth factor (PGF), and healthy granulation tissue was formed with mesenchymal stem cells derived from the bone marrow, periosteum, and covering muscles with formation of a large amount of fibroblasts and tiny small vessels. Osteoblasts were seen with the chondrocyte; these changes were noticed more with bone graft that was covered by Surgicel in group B. The role of Surgicel was to accelerate the healing process of bone grafting.

This research proved to be of great value to humans for better understanding of the cellular changes and the mechanisms associated with bone grafting and distraction for elongation of bones in children. The cellular changes of distraction technique and bone grafting by inducing mesenchymal stem cells are the same except distraction induced by stretching growth potential of bones based on Illizarov theory, and the bone grafting based on maximum contact between bone graft and bony segments after decortication of the segments with rigid fixation can be achieved by plating or by soft stainless steel wire of 0.25 mm.

The management of bony defect urgently required bone grafting after traumatic injuries, after missile war injuries, and after radical cancer surgery as an urgent technique.

Author details

Raja Kummoona

Address all correspondence to: raja_kummoona@hotmail.com

Iraqi Board for Medical Specialization’s, Medical City, Baghdad, Iraq

References

[1] Wikipedia. Bone Grafting. Available from: https://en.wikipedia.org/wiki/Bonegrafting

[2] Kummoona R et al. Reconstruction of lower jaw by iliac bone graft, experimental studies on rabbit and role of mesenchymal stem cells. Journal of Stem Cell and Regenerative Biology. 2018;**4**(1):20-24

[3] Medtronic. History of bone grafting. Information for Health Care. Feb 25, 2018

[4] Dayashankara JK, Nahida DN, Aadya S, et al. Evaluation of sternoclavicular graft for reconstruction of the temporomandibular joint after gap arthroplasty. Annals of Maxillofacial Surgery. 2017;**7**:194-200

[5] Kummoona R. Surgical procedures carried on lower jaw. Editorial Research Journal of Ear Nose and Throat. 2017;**1**(1):8

[6] Kummoona R. Reconstruction by lateral cervical flap of peri oral and oral cavity: Clinical and experimental studies. The Journal of Craniofacial Surgery. 2010;**21**:660-665

[7] Moss ML. The primary of functional matrices in orofacial growth. Dental Practioner and Dental Records. 1968;**19**(2):65-73

[8] Kennett S. Temporomandibular joint the rational for grafting in the young patients. Journal of Oral Surgery. 1973;**31**(10):744-748

[9] Poswillo DE. Experimental reconstruction of mandibular joint. International Journal of Oral Surgery. 1974;**3**(6):400-406

[10] Safavi S, Manafi A. Over growth of costochondral graft in a case of temporomandibular ankyloses. The Journal of Craniofacial Surgery. 2007;**18**(6):1488-1491

[11] Kummoona R. Chondro-Ossous iliac crest graft for one stage reconstruction of ankylosed joint in children. Journal of Maxillofacial Surgery. 1986;**14**(4):215-220

[12] Kummoona R. Kummoona Chondro-Ossous graft good substitute to condylar growth center and fore correction of facial deformity in children. Archives of Otolaryngology and Rhinology. 2017;**3**(3):98-102

[13] Illizarof GA. The principle of Illizarov method. Bulletin of the Hospital for Joint Diseases Orthopaedic Institute. 1988;**48**:1-11

[14] McCarthy JG, David MD, Staffenbeerg A. Introduction of an intra oral bone lengthening device. Plastic and Reconstructive Surgery. 1995;**4**:978-981

[15] Kummoona R, Abdul Majeed Jassim E. Distraction technique of lower jaw on rabbit, experimental studies research. Journal of Stem Cell and Regenerative Biology. 2017;**3**(2)

[16] Lexer E. Transplantation. Annals of Surgery. 1914;**60**(2):166-194