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Übersicht

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Bone grafting to the jaws with special reference to reconstructive preprosthetic surgery

A historical review

Abstract

The first report on the transfer of fresh bone was in 1668 when van Meekeren described how a Russian surgeon had repaired a soldier's skull defect by implanting dog bone with good results. Discovery of the anesthetics, nitrous oxide and ether, in addition to the introduction of antisepsis opened up new surgical possibilities and made bone grafting a possible clinical procedure. Around the turn of the last century, papers began to appear on the restoration of continuity defects of the mandibula. In the future it will be possible to acquire a living graft in the exact size desired based on a 3D reconstruction of a CT scan of the defect.

Keywords

Mandibular defects · Bone transplants · Reconstructive surgery

The first reported transfer of fresh bone, – however, as a cross-species transplantation – was described by van Meekeren [44] in 1668. A Russian surgeon had repaired a defect in the skull of a soldier by implanting a piece of dog bone. The result was good. However, the soldier was excommunicated, and it became necessary to remove dog bone, so that the patient could be reaccepted by the church. The following review is confined nearly exclusively to the history of free autogenous bone grafts, mainly to the jaws, however, highlights from general surgery are to be mentioned, otherwise the picture would be incomplete.

Birth of bone grafting

It was first in the early 19th century, that we have documented reports on autotransplantation of bone in humans.

Von Walther [76], chief surgeon at the University of Bonn, is credited for the first successful transplantation of autogenous bone. In 1821 he published a case of replantation of the bone plate removed by trepanation in a 35 year old man. Before, he had performed the same operation in a dog and dared to do the same in a human, since the dog was doing well one year after operation. Although there was wound infection with sequestration of the tabula externa, there was a complete osseous integration. This technique was later confirmed with good results by Adamkiewicz [1] in 1889.

In 1875 von Nussbaum [46] reported the first free transplant to a 5 cm long defect in the ulna after an infected comminuted fracture. He used a sliding transplant consisting of the one half of the proximal part of the ulna and placed in the defect with little of the periosteal tissues still attached. The function was normal after half a year.

The discovery of anaesthesia and nitrous oxide in 1844 by Horace Wells, and ether by William Morton in 1846 opened up new surgical possibilities, which had never existed before. The discovery of anaesthesia and the introduction of antisepsis by Lister in 1864 made bone grafting a possible clinical procedure. Along with the colourful history of what now could be achieved, an increasing interest in what took place arose from a biological point of view.

Biological considerations

A number of different opinions appeared over the next 50 years, a few are to be mentioned. Ollier [48] performed a number of experimental studies in

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Kieferknochentransplantation und rekonstruktive präprothetische Chirurgie. Historischer Überblick

Zusammenfassung

Der erste Bericht über einen Transfer von frischem Knochen wurde 1668 von van Meekeren gegeben. Er beschrieb, dass ein russischer Chirurg den Schädeldefekt eines Soldaten durch Implantation von Hundeknochen wiederherstellte und gute Ergebnisse erzielte. Die Entdeckung von Anästhetika, Nitritoxid und Äther zusammen mit der Einführung der Antisepsis eröffneten neue chirurgische Möglichkeiten, insbesondere auch die der Knochentransplantation. Ungefähr um die Jahrhundertwende erschienen erste Veröffentlichungen über die Wiederherstellung von Kontinuitätsdefekten der Mandibula. In Zukunft wird es möglich sein, lebenden Knochen in exakt der gewünschten Größe, basierend auf einer 3D-Computerrekonstruktion des Defekts, einzusetzen.

Schlüsselwörter

Mandibuladefekte · Knochentransplantate · Rekonstruktive Chirurgie

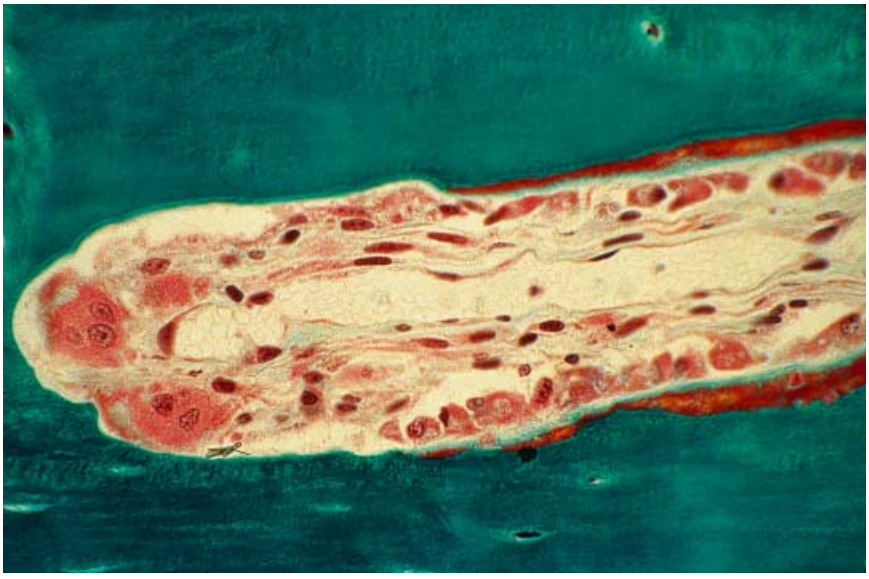

Fig. 1 ▲ **The cutting cone, the basic remodeling unit of a non-vital bone graft as well as the basic part in the secondary osteon formation. To the left osteoclasts are seen, to the right osteoblasts and osteoid seam is present ×125 (Courtesy of Robert K. Schenk, University of Bern, Switzerland)**

rabbits, cats, dogs, birds and concluded in his famous thesis "*Traité experimental et clinique de la régéneration des os et de la production artificielle du tissu osseux*" in 1867, that all parts of bone graft survived, and emphasized the importance of an intact periosteum. He only accepted autogenous bone graft for clinical use.

In 1895 Barth [7] nearly came to the opposite conclusion, that all parts of grafted bone will die, and the major importance of a bone graft is to be osteoconductive. The main factor in regeneration of a bone defect would be the osteogenic property of the host bone. He thought, that the transplanted bone is resorbed and replaced by the host, consequently bone of autogenous as well of allogenic or heterogeneous origin could be used.

He placed incinerated bone in the peritoneal cavity of a cat; 6 weeks later he found it penetrated by connective tissue and in several places by bone, being lined by osteoblasts. He introduced the term "schleichender Ersatz" to describe the process of bone replacement. This was later named *creeping substitution* by Phemister [49] in 1914 as description of the way in which any type of bone transplant is replaced by host formed autogenous bone. By the way this process is of exactly the same nature as is taking place in our skeletal system through the entire life, in this respect it is termed the BMU, the bone metabolizing unit – or the bone multicellular unit (Fig. 1).

In 1909 Georg Axhausen [2] published a very careful thesis based upon 146 animal experiments in bone grafting together with detailed histologic descriptions. One of these illustrations beautifully depicts the creeping substitution, the necrotic transplant and the surviving osteoblasts, starting production of woven bone, all the important events in the fate of an autogenous bone graft in one illustration, handmade in 1908 (Fig. 2).

He transplanted autogenous, allogenic and heterogenic bone into osseous defects as well as soft tissue with and without periosteum and came up with the following 5 conclusions:

1. A living periosteal-covered graft shows marked cellular proliferation under the periosteum, which produces and establishes a vascular connection between the graft and its bed.
2. The compact bone of a graft always exhibits empty cell spaces into the greater part of its content.
3. A graft containing marrow shows new bone formation from the marrow tissue, wherever this is in contact with living vascular tissue.
4. The viability and proliferation of allografts are more uncertain than those of autografts.

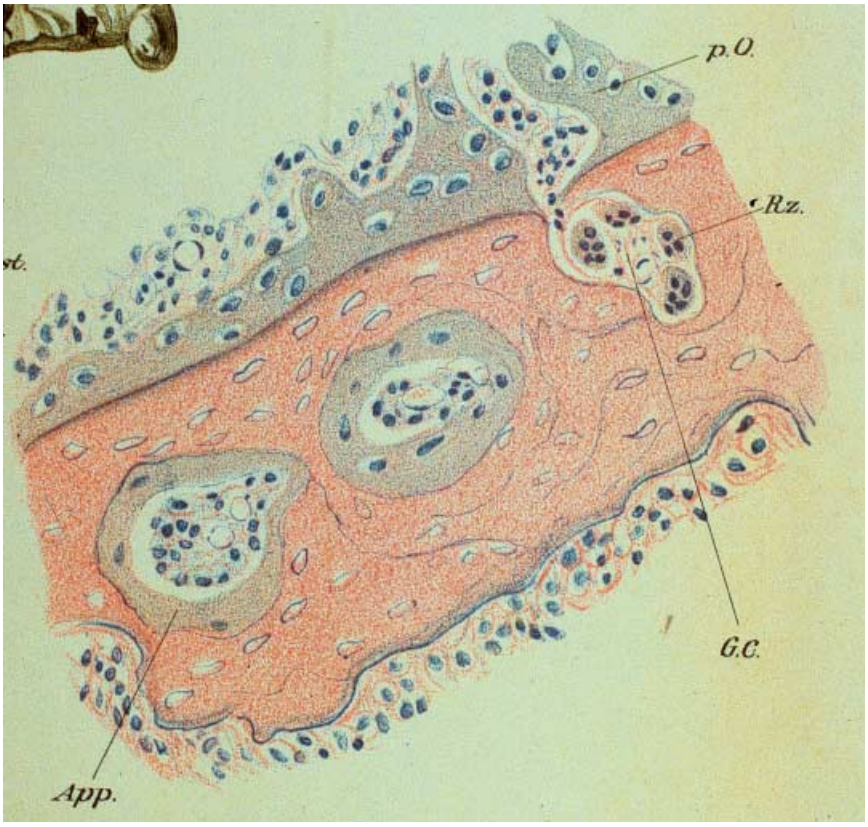

Fig. 2 ▲ **A piece of dead femur bone implanted in muscle. *p.0* new formed woven bone projecting from the surface. *RZ* osteoclasts, the front zone in a cutting cone. *G.C* enlarged capillary. *App* early lamellar bone apposition. From Axhausen, 1909 [2], Fig. 6**

5. Xenografts become incapsulated or absorbed and show neither vitality nor proliferative capacity.

Even today these conclusions are valid, although they were written nearly 100 years ago.

Start of mandibular reconstruction

Around the turn of the last century a number of papers appeared dealing with restoration of continuity defects of the mandible (Table 1). Bardenheuer [6] 1892 used a pedicled flap from the mandible itself to rebuild a mandibular defect, illustrated in von Esmarch and Kowalzig [23] (Fig. 3). W. Sykoff [66] reported on, as he called, the autoplastic transplantation of bone. In a chin defect with continuity loss he took a graft from the mandible itself and transfered it as a free graft to the anterior defect after preparing a bed in the remaining bone. He claimed that only by using the autoplastic method you can be sure that the bone graft will survive and not be resorbed. However, he apparently did not quite believe his own words for in the last sentence of his paper he stated, that the next time he will use rib graft covered with periosteal tissue for the same purpose.

Ludwig von Rydygier [56] reported in the Zentralblatt für Chirurgie from 1908, that in 1892 he already used a pedicled bone graft from the clavicle to replace a defect in the mandible. The bone graft was surrounded by the skin, left in place for 8–12 d and then transplanted with a long skin flap to the mandible.

Not before 1978 a more sophisticated way of using the clavicle was reported by Siemssen et al. [61], who made immediate reconstruction of continuity defects of the mandible by a pedicled clavicular transplant, where the pedicle was the clavicular head of the sternocleido-mastoid muscle. Although the graft survived, the method nearly always is complicated by pain problems from the donor site and difficulties in utilizing the rather thin clavicular bone for implantation. A number of methods for restoring continuity of the mandible, that have appeared over the past years, can be characterized with

A successful restoration, but a poor rehabilitation.

1917 McWilliams [43] reported on grafting of mandibular defects after trauma and especially in cases of osteomyelitis. He emphasized that during the healing period – after removal of necrotic bone – the segments of the mandible have to be kept in right anatomical position by intermaxillary fixation. Furthermore he stressed the importance of an intact oral mucous membrane before grafting. If rupture appeared during operation the grafting was postponed. The use of a pedicled clavicle graft was emphasized in case of risk of remaining infection, where the graft was pedicled to the skin. Otherwise, grafts from tibia were preferred.

Tainter [67] 1919, a pupil of Cole, illustrated the Cole pedicled bone graft method [18] on basis of experience from 17 treated patients, where the graft was obtained form the basal part of the mandible, used as sliding graft, where the platysma and the anterior belly of the digastric muscle remain attached and the graft was wired to the anterior and posterior fragments. In discussion of the paper V.P. Blair reported on the experience in treating war injuries of the face and jaws, based upon 2300 cases mainly of the period from July 14 to November 11, 1918.

In 1938 Cole [17] presented 3 follow-up cases of his own cases treated in 1919, nearly 20 years earlier. They all showed nearly complete preservation of the height of the transplanted pedicled graft. This probably was the first documentation of the importance of preservation of vascular supply to avoid resorption. New ideas on sliding osteotomies still appear, 2001 Verdagner et al. [74] reported on techniques especially suited for patients in poor general conditions.

Transoral approach

1948 Pichler u. Trauner [50] reported that their assistant Clementschitsch had succeeded in rebuilding an atrophic maxilla with a bone graft via an trans-

Tabelle 1

Condensed survey of number of papers describing the course of event of reconstruction of the mandible with remarks on main emphasis stated by the different authors

Author	Year	Diagnosis	Type of graft	Number of patients	Author emphasis
Sykoff [66]	1900	Continuity defect, mandible chin region	Mandibular body, transposition	1	Suggests to use rib graft for the same purpose
Rydygier [56]	1908	Continuity defect mandible	Pedicled clavicle	1	Claims priority on this technique, first case operated in 1892
Vorschütz [75]	1911	Continuity defects after malignancy	Tibia	2	Immediate reconstruction, mucosal dehisciencies in both cases with loss of graft
McWilliams [43]	1917	Defects after fractures and osteomyelitis	Tibia pedicled clavicle	6	Complete tight oral mucosa, 3 mm on the intermaxillary fixation
Tainter [67]	1919	War injuries	Pedicled mandibular sliding graft	17	The pedicled graft remains a living graft
Brown [12]	1920	War-injury, continuity defects, mandible	Tibia	?	Denture or graft absolute-fixation with splints, no communication to oral cavity
Gillies [27]	1920	Continuity defects mandible	Iliac crest rib, tibia pedicled lower border	?	Review on war experiences, draw back with tibia and pedicled, no alveolar process, large discrepancy
Risdon [54]	1922	Defect fractures	Iliac crest	70	90% success, failure cause; communication to oral cavity
Ivy and Epes [36]	1927	Osteomyelitis and defect fractures	Tibia, iliac crest	7	Splinting for 3–6 months, only extraoral access, experience from war
Cole [17]	1938	Continuity defects of mandible	Pedicled mandibular lower border	3	Follow-up 3 cases from 1918, illustrates alveolar process formation, been critical point with method
Mowlem [45]	1944	Continuity defect of mandible	Iliac crest chips	36	Metal for stability, fill the defect with cellular material – cancellous bone chips
Axhausen [3]	1948	Continuity defect mandible, alveolar process	Tibia, in two steps, soft tissue preparation	?	Prepared "pedicled flap" for alveolar process reconstruction, risk of infection is the reason
Clementschitsch [16]	1950	Defects (atrophy) maxilla defects and complete augmentation	Iliac crest ?	6	The augmentation can be made extraorally or *trans*oral, mainly defect reconstruction
Converse [19]	1950	Defects, facial contour, maxilla zygoma	Iliac crest?	6	All done transorally, no visible scars and excellent exposure – use this method!
Thoma and Holland [72]	1951	Mandibular atrophy spontaneous fracture	Rib and iliac crest	2	Treatment directed towards arrest of resorption
Schmid [60]	1954	Atrophy and defects	Iliac crest	?	Transoral approach, now antibiotics, but also good results without
Axhausen [5]	1954	Continuity defects	Iliac crest	?	The graft is placed in a pocket lateral to the continuity and left there for 8 weeks (Vorpflanzung)
Gerry [26]	1956	Mandibular atrophy	Iliac crest	1	Preformed acrylic model, transoral approach, plate and wire fixation for 6 weeks
Reichenbach and Schönberger [52]	1957	War injuries, defect fractures	Iliac crest	200 (40–45) 70 (48–57)	Extraoral approach, 6% failure before antibiotics, 1% after
Lane [38]	1958	Atrophy	Iliac crest	4	Transoral approach splint for 6 weeks made in 1953
Thoma [71]	1959	Atrophy	Iliac crest and ribs	4	Extraoral approach graft to present spontaneous fracture
Rehrmann [51]	1959	Defects after tumor surgery	Iliac crest	2	Alveolar plasty 1 year after grafting
Hofer and Mehnert [33]	1964	Mandibular and maxillar atrophy	Mandibular, transposition chin region	?	Description of method. No secondary donor site
Haberzettel [29]	1968	Mandibular atrophy	Iliac crest	3	Graft at lower border of mandible
Davis et al. [20]	1970	Mandibular atrophy	Ribs	6	Chips and solid graft marked resorption
Kratochvil and Boyne [37]	1972	Atrophy	Iliac crest, particulate	1	Combines a subperiosteal implant, with particulate bone and marrow increase in height
Baker and Connole [5]	1977	Mandibular atrophy and maxilla	Rib block and chips	15 mandible 7 maxilla	66% loss of graft in mandible after 30 months
Siemssen et al. [61]	1978	Spontaneous fracture, atrophic mandible and malignancy	Pedicled clavicle	18	Preserved circulation demonstrated by technetium scanning
Fazili et al. [25]	1978	Atrophy	Iliac crest	14	After 3 years 92% of the graft resorbed, abandon the method!

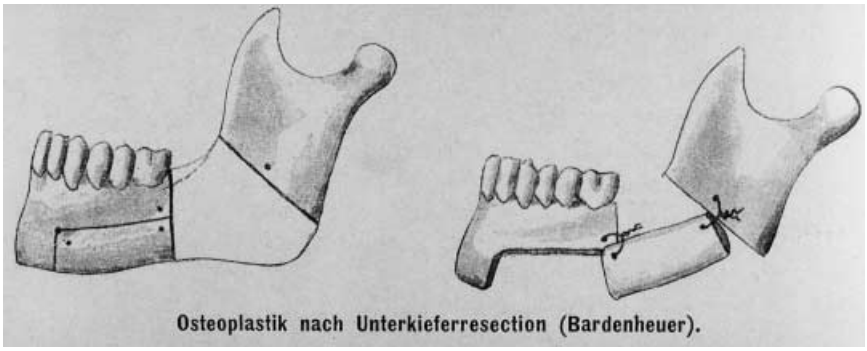

Fig. 3 ▲ **The first reported pedicled bone graft from the mandible itself, Bardenheuer 1892 [6], from Esmarch and Kowalzig 1899 [23]**

oral approach apparently an iliac crest transplant, however, this was not stated. Although this result was good, the conclusion of Pichler concerning autogenous grafts to the jaws included among other things

"Always in a complete sterile way, it means via an extraoral approach. Should a rupture of the oral mucous membrane appear, then one has to stop the operation immediately."

The same cautious attitude was expressed on the other side of the ocean by Leo Winter [77] in 1943. In his textbook he described the use of free bone grafts from the tibia, iliac crest and ribs to defect fractures of the mandible.

However, already in 1950, Converse [19] reported on 12 bone grafts and 14 bone and cartilage grafts over the last 3 years, which successfully had been placed as onlay grafts to the maxilla, zygoma and chin region via intraoral vestibular incisions. The iliac crest, medial aspect was used as graft material and the method suggested by Mowlem [45] in 1944, to use small chips of cancellous bone to pack around the onlay in the intervening crevices, was used. The onlay itself was stabilized subperiosteally and a pressure bandage was applied for a week. Nothing is mentioned about long term results and about eventual coverage with antibiotics. The inspiration to do this via a transoral approach was observations done during the war, where loose fragments exposed to the oral cavity became completely consolidated and healed without infections. The same year, 1950, Clementschitsch [16] published a number of transorally grafted cases, apparently carried out before the introduction of antibiotics, and good results although no detailed follow-ups are available.

These findings stimulated a number of surgeons in the fifties and sixties to approach the atrophic mandible with different techniques for true rebuilding, some are to be mentioned. One of the major prerequisites for the successful transoral approach was the discovery of penicillin and the rapidly appearance of other types of antibiotics, the use of which in 1951 was reviewed by Obwegeser [47] in a very comprehensive study of 33 free bone and cartilage grafts to the oral regions.

Mandibular augmentation

1954 Schmid [60] demonstrated a number of cases with reconstruction of alveolar defects and continuity defects where iliac bone grafts were used via an intraoral approach, under antibiotic coverage but claimed, that he also had been performing this before antibiotics were available. The reconstructions included both jaws. Rehrmann [51] was probably one of the first to design a surgical method for ridge augmentation with iliac crest bone followed by his design of a vestibular lingual sulcoplasty, described in his publications from the early fifties.

In 1951 and 1959 Thoma and Holland [72] and Thoma [71] published detailed analysis on the topic atrophy of the mandible. They strongly emphasized that the best treatment of atrophy of the mandible was prevention of atrophy, and that the treatment should first of all be directed to arrest the process of resorption. In emergency situations, when atrophy had resulted in a pathological fracture or when there was an extreme degree of atrophy in young patients a bone graft could be considered; they reported 2 cases with bone grafts, one with a fractured mandible and one with a regular augmentation with the purpose of reinforcing the weakened mandible.

1956 Gerry [26] reported as maybe the first from the English speaking part of the world a regular concept for a true complete rebuilding of the osseous height of the mandible with an autogenous grafts from the iliac crest with the purpose of improving the denture stability. The graft was shaped after an acrylic model of the wanted increase in height. He also reported on the use of bone chips from the maxillary alveolar process removed during alveolectomy to correct deficiencies in the mandible, inclusive correction of a receding chin, with good results. The block graft was inserted via intraoral incision, the surface of the atrophic mandible was roughened with burs and rasps to provide a bleeding surface. The graft was immobilized via an acrylic splint fixed with circum-mandibular wires. After 18 months no resorption and no need for relining of the denture were seen.

Gerry was the first to mention the importance of roughening of the surface of the recipient site when doing an onlay graft, however, nearly 40 years later the scientific proof was delivered by Gordh et al. [28] in 1997, where they demonstrated a better graft incorporation when the recipient surface was fenestrated to allow ingrowth of vessels from the marrow of the recipient site.

As a possibility Gerry mentioned the placement along the inferior border, but restrained from this due to the alterations of the face this would result in and the necessity of a supplementary operation for deepening the buccolateral sulcus.

This method was attempted by Haberzettel [29] in 1968 in 3 older women. According to the illustration a block graft from the iliac crest of 15 mm in width was nearly completely resorbed after 24 months.

The tunneling approach was introduced by Celesnik [14] in 1965, who restored atrophic mandibles via this approach. The tunnel should be made narrow, so that the mucous membrane via pressure could stabilize the transplant,

thereby avoiding any other fixation of the grafts. He emphasized that an early loading of the transplant is necessary to give the physiologic stimulus to the bone in the remodeling phase, and stated that by use of a denture resorption of the onlay graft could be avoided.

1965 Hofer and Mehnert [34] were probably the first to use a graft from the anterior part of the mandible to increase the height of an atrophic mandible.

The first real systematic approach was published by Davis et al. [20] in 1970 where they reported 6 cases, where transoral autogenous rib grafts were used to restore the atrophic mandible. In details they described how the operations were carried out, that the ribs were placed vertical and that the triangular space between the mucosa and the rib was filled with chips in order to avoid dead space.

As the first ones they put emphasis on resorption of the graft, in all the 6 patients, 1/2-2/3 were resorbed during the first 1 1/2 years, the basal part remained and became more dense.

This problem of resorption was further stressed by Davis et al. [21] in their publication from 1975 and analyzed in details by Baker and Connole [5] in 1977. Davis et al. [21] found more than 50% resorption in first 1 1/2 years postoperatively and 80% resorption of the transplanted rib grafts after 3 years.

Similarly, 1978 Fazili et al. [25] showed, that all the transplanted iliac block grafts augmenting the entire mandible were completely resorbed after 40 months in 14 patients. They took iliac crest biopsies from 6 of these in order to analyze a number of biologic parameters to see if resorption could be predicted, however, the sample did not give any conclusive results. Their conclusion was to drop this venue of augmentation in favor of the visor osteotomy.

The visor osteotomy was invented by Härle [30, 31] in 1975. He made a longitudinal osteotomy in the entire length of the mandible, like a sagittal osteotomy. Thereby the lingual mandibular plate with the soft tissues still attached could be moved in a vertical direction, and still having contact with the buccal part or placed on the top of the mandible, thereby increasing the height of the atrophic mandible by 100%. The lingual plate was fixed by wire osteosynthesis (Fig. 4).

In 1979, Härle [32] published a follow-up study on the visor osteotomy. Although the intentions of the method had been reached, a reduction in the degree of resorption to a level equivalent to the ridge resorption after vestibuloplasty, the degree of altered sensation in the mental nerve was high, 40% of 20 involved mental nerves had some degree of anaesthesia/paresthesia at a 3 year follow-up. Other techniques, using the mandibular bone itself were developed in these years. In 1976 Schettler [59] published his sandwich osteotomy and Stoelinga et al. [64] combined the visor and the sandwich osteotomy in their publication from 1978.

In 1983 Stoelinga et al. [65] published a very critical paper, where a substantial number of patients, 148 in total, had undergone interposed bone graft augmentation of the mandible, and some of them, 38, had been followed up for 4–6 years, the remaining at least 2 years after surgery. They found a high incidence of nerve disturbances and state that "nerve disturbance as found in this study is regarded as unacceptable." The height of the augmentation decreased rapidly over the first 6 months, thereafter the rate of resorption decreased over the years and was nearly parallel to what has been described by Tallgren [68] in 1972 as characteristic for the edentulous jaw.

In this paper the authors presented the 3 piece modification, which should avoid damage to the inferior alveolar nerve, a follow-up study on this method from 1986 is convincing since 60% of the patients had normal sensibility 1 year postoperatively in contrast to the findings in the paper from 1983, where one of the groups revealed disturbances in sensation in 70% of the patients 2 years postoperatively [22].

Maxillary augmentation

Ridge augmentation of the mandible has been the focus for numerous studies, however, we know, that the maxilla can be so atrophic, that neither sulcoplasties, buccal inlays or implants can create acceptable masticatory function. Further, by increasing atrophy of both jaws an inverse relationship between maxilla and mandible may be the result, which further aggravates function.

Credit is to be given to Terry et al. [70] who were among the first ones to try to rebuild the extreme atrophic maxilla in 2 patients, published in 1974. Ribs were used and a refined transpalatal vitallium strip was developed to keep the graft in place.

Farrell et al. [24] were the first one to apply the Le Fort I osteotomy for treatment of the atrophic maxilla in their report from 1976, where an iliac bone graft was interpositioned and a simultaneous submucous vestibuloplasty was made to utilize the increased height of maxilla. 14 years later Sailer [57] used the same technique, but immobilized the block graft by simultaneous installation of dental implants and drew attention to the possibility of correction of the intermaxillary relationship in all dimensions via this approach.

The impressive good results with penetrating endosseous implants fostered the idea behind the studies of Breine and Brånemark [11], published in

Fig. 4 ▶ **The visor osteotomy-technique, invented by Härle 1975 [30, 31] (Courtesy of Franz Härle, University of Kiel, Germany)**

1980, where implants extending below the maxillary process were packed with autogenous cancellous bone and bone marrow, however, only 25% remained osseointegrated. Implants preinserted in tibia and transferred after osseointegration to the atrophic maxilla resulted in a survival of 60% of the implants. Marked resorption especially of the cancellous bone with a nearly disappearance radiographically after 1 year was noted.

Local ridge augmentation, often with the use of graft material from the mandible, together with the use of membranes have been described by numerous authors. Long time studies with predictable good results have been published by Buser et al. [13] in 1996.

The introduction of implants has changed the clinical situation for the augmented edentulous patients completely. Although the implant success for implants in augmented jaws may not be quite as high as in native alveolar bone it is acceptable. The functional stimulus to the grafted area via the implants has apparently influenced the rate of graft resorption in a very positive way. A number of factors influencing the survival of both grafts and implants are still unsolved. Recent studies like the Swedish study by Blomqvist et al. [8] from 1996 raised the question if osteoporosis is an influential factor, a marked difference in implant loss between two comparable groups of patients lends support to the fact that metabolic disorders of bone are to be considered in the treatment planning, especially, when autogenous bone grafting is an integrated part of the total treatment. Simultaneous or delayed installation of implants in grafted bone is still under debate, however, it looks if the two-stage approach is preferred in most centers today.

Graft material, block or particulate

Parallel to all these clinical studies, which generally applied block grafts either from the iliac crest or ribs, experimental studies were undertaking in order to define the best autogenous material for the grafting procedure.

In 1955 Rosenberg et al. [55] described an experimental study in dogs, cavities in femur and humerus, where they compared drill shavings of autogenous cortical bone with bone blenderized in a kitchen blender. They also compared blenderized cortical bone with blenderized cancellous bone. They found no difference in rate of healing between cortical and cancellous bone. When comparing drill shavings with blenderized bone there were large fragments of dead bone after 21 d when drill shavings were used compared to hardly any visible remnants of the graft when the blenderized bone was used. The defects in the femur were 9.5 mm in diameter, in fact they were dealing with critical size defects without knowing it!

In 1967 Steinhäuser et al. [63] published important comparative studies with use of cartilage, cortical and cancellous bone in rebuilding of atrophic jaws both in animals and in 18 patients. The stability of the cancellous bone appeared earlier than with cortical bone, however, the degree of resorption was more pronounced, when cancellous bone was used. All operations were performed via the intraoral route.

In an article in Lancet in 1944, where he reported 36 cases of cancellous chip bone grafts used to restore continuity defects of the mandible Mowlem [45] stated

"On biological grounds, it was thought, that fragmentation of the graft might be expected to provide a much greater surface area, through which the transplanted bone cells would become accessible first to serum and secondly to the ingress of newly formed capillaries, and that the chance of their survival would thereby be enhanced."

To a great extent it is really the original thinking of Mowlem, which is applied today in the reconstructive maxillofacial surgery. In this context important studies of Richter et al. [53] from 1968 demonstrating the osteogenetic capacity of bone marrow and chips of cancellous bone are to be mentioned, their findings were directly applied in reconstructive preprosthetic surgery by Boyne [9,10] in his publications from 1969 and 1972 with very convincing results. These techniques were further refined by Marx and Wong [40] in 1987 and further developed by Marx and Marx et al. [39, 41] in his publications from 1994 and 1998 where the acquired present-day knowledge about the regulation of osteogenesis on a molecular level directly are applied in a clinical method within the field of reconstructive preprosthetic surgery, where the yield of new bone being formed expressed as the percentage of trabecular bone in a given area was increased from 38% in the normal mandible to 74%, when autogenous platelet-rich-plasma was added to the particulate bone graft.

Distraction osteogenesis

Although still in the phase of evolution this review would be incomplete without mentioning the distraction osteogenesis concept. The distraction principle and devices were refined by the Russian surgeon Gavriel Ilizarov [35], who designed his apparatus for distracting extremities in 1951. Already in 1973 Snyder et al. [62] performed distraction in the mandible of a dog, but it took nearly 20 years before in 1992 McCarthy et al. [42] reported the first clinical results of distraction osteogenesis of the mandible in patients with hemifacial microsomia. Since then numerous reports have appeared and the ways in which the principle can be applied in reconstructive preprosthetic surgery are nearly endless – and will for sure replace bone grafting in a number of situations [15, 58].

Tissue engineering

Tissue engineering is part of the future of bone regeneration. The bone induction principle originally discovered by Marshall Urist [73] in 1965, the knowledge of the exact nature of a number of bone morphogenetic proteins and possibilities for industrial production of these, an increasing knowledge of the sequential function in the osteogenetic phases of a number of growth factors, the increasing knowledge about biodegradable carrier materials has already opened new avenues. In 1999 Terheyden et al. [69] published one of the first papers leading directly into the future where a bone graft was produced after heterotopic implantation of deproteinized bovine bone saturated with BMP-7, recombinant human OP-1 and thereafter was used to reconstruct the mandible using microsurgical anastomosis.

Conclusions

A few conclusions may be drawn from these 101 years of experience with grafting to the jaws

1. More or less, the first 50 years mainly dealt with reconstruction, not rehabilitation. All reconstruction were carried out from an extraoral approach, the great monster was communication to the oral cavity. Allogenic and a few heterogeneous grafts were applied, but most authors preferred the autogenous graft. Ribs, tibia with the iliac crest as the preferred. The purpose was to establish continuity of the mandible.
2. Stability was a conditio sine qua non. In most instances it could be achieved via dental splints, the most grafted persons were still young, still having some teeth left. The block graft was for the same reason the preferred one, mechanics before biology!
3. Although the experimental studies from the beginning of the century clearly had illustrated the biology behind bone graft healing it was first in the middle of the last century, that it had the consequences for the choice of graft. As many cells as possible should be transferred, the surface should be as large as possible, and the possibility for ingrowth of capillaries as good as possible. The particulate graft, cancellous chips were born. Metal should be responsible for the stability.
4. The only blessing from the 2nd world war was penicillin. It opened a lot of avenues, including the intraoral approach for bone grafting. Atrophy could now be treated via an absolute augmentation, when the relative augmentation methods were not sufficient. The mandible was first approached, the denture stability was the poorest. Although resorption of the graft had been mentioned as a problem, when the grafting was confined to restore continuity, it now really became a problem, in this way a lot of ingenious surgical methods were introduced in order to overcome the resorption problem.
5. The introduction of dental implants and the documented positive influence with arrest or delay of the progression of resorption has opened new avenues for osseous restoration via bone grafting and insertion of implants, so that nearly any type of defect or atrophy now can be reconstructed, a free graft, grafts with microvascular anastomosis, grafting preceded by hyperbaric oxygen treatment, distraction osteogenesis, bone substitutes as grafting material, the possibilities are nearly countless.
6. The future is tissue engineering, the discovery of BMP, has only recently made its entry in the reconstructive surgery, still the carrier problem is unsolved – however, the knowledge of the importance of a number of growth factors in osteogenesis, the three-dimensional growth of osteoblasts and chondroblasts on suited carriers, makes it plausible, that in a not too far distance it will be possible on the basis of a three-dimensional reconstruction of the CT-scan of the defect plus a syringe with marrow cells will be able to order a living graft in the exact size it is wanted.

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