Historically, the management of alveolar clefts has lagged behind the surgical correction of cleft lip and palate in terms of appreciating its significance and in the evolution of surgical techniques. The first report of alveolar cleft repair using autologous tissue was in 1901 by von Eiselsberg [1], who used a pedicled flap of bone and soft tissue from the small finger. This procedure was followed by Lexer [2], in 1908, when he described the use of a nonvascularized bone graft to the maxilla. Drachter [3] reported on the repair of an alveolar cleft using tibial bone in 1914. These pioneering efforts did not gain widespread acceptance, and the correction of the alveolar cleft was largely neglected. It was not until 1952, when Axhausen [4] established concepts used for present-day methods of management, emphasizing the importance of osseous stabilization of the maxillary arch and preserving dentition, that interest in the surgical repair of alveolar clefts resurfaced. Schmid [5] then reported surgical closure of the nasolabial fistula and implantation of small iliac crest bone grafts into the bony gap.

Anatomy/morphology

Consistent with the variability seen in clefting of the lip and palate, alveolar clefts exhibit a great deal of variability in their extent (Fig. 1). They may exhibit only a mild notch on the labial aspect of the alveolar process or present as a wide gaping space between the alveolar segments. In unilateral alveolar clefts, the cleft side of the maxilla is referred to as the lesser segment. Because of a lack of transverse stability, medial collapse is common. This process results in a crossbite of the dentition, particularly in the region of the canine and first premolar. The position of the premaxilla also may show variation. Alignment may be normal, providing good dental arch form, or it may be rotated anteriorly and toward the noncleft side. This malposition is generally improved through remolding after lip repair or with the application of orthopedic forces. The central incisor adjacent to the cleft frequently is malrotated and angulated toward the cleft. The lateral incisor may be present but is commonly hypoplastic. It may be malformed and mistaken for a supernumerary tooth. Although not visible intraorally, the lateral incisor may be located within the alveolar cleft and may even protrude through the nasal floor. The periodontal attachments on the cleft side of the adjacent central incisor and canine are deficient, exposing these teeth to greater risk of future loss from lack of bony support. The pyriform rim on the cleft side is retrusive in its sagittal position. The lower pyriform margin or nasal floor is displaced inferiorly, and the anterior bony nasal aperture is constricted transversely. These factors contribute to the lack of support of the external nose, particularly the alar base, and to the asymmetry customarily seen in the cleft nasal deformity.

The bilateral alveolar cleft also presents with great variation. The paired clefts may differ in size and/or width or they may be symmetric. The premaxilla often protrudes anteriorly in relation to the lateral segments because of the unrestricted growth at the vomeropremaxillar suture. The abnormal position of

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the premaxilla can be manifest in three dimensions by an excessively inferior position and malrotation in the coronal and sagittal planes.

Dental patterns in alveolar clefts

Embryologically, the facial clefting process and the development of primary and permanent anterior tooth germs occur simultaneously. Therefore, it is not surprising that anomalous tooth formation is seen in the region of the alveolar cleft. This finding may be manifest by malformation, malposition, or absence of the lateral incisor or the presence of an additional tooth. In addition, the pattern seen in the primary dentition does not typically predict what will develop in the permanent dentition. Furthermore, permanent teeth are usually more severely affected than the primary teeth [6,7].

Treatment objectives

The goals of alveolar cleft repair have both functional and aesthetic purposes [8]. The functional objectives include closure of the nasolabial fistula, creation of a stable and continuous maxillary dental arch, improved support of teeth adjacent to the cleft site, allowance for eruption of teeth into the cleft site, provision of unrestricted orthodontic movements, and facilitation of oral hygiene (Figs. 2 and 3). With persistence of the nasolabial fistula, patients may...
experience chronic nasal regurgitation of liquids, resulting in chronic inflammation of the nasal mucosa, nasal discharge, and social embarrassment.

Aesthetic objectives are augmentation of the pyriform region and creation of a cosmetically pleasing dental arch form and tooth position. Augmentation of the hypoplastic pyriform region provides better support for the alar base of the nose, improving the asymmetry seen in the cleft nasal deformity. With successful repair of the alveolar cleft, comprehensive

Fig. 2. (A, B) Preoperative photographs of right unilateral alveolar cleft in frontal dental view and occlusal view. (C, D) Postoperative photographs of repaired right unilateral alveolar cleft after completion of orthodontic therapy in frontal dental view and occlusal view. Maxillary continuity, proper dental arch form, and good dental aesthetics have been established.

Fig. 3. (A) Preoperative occlusal radiograph of a left unilateral alveolar cleft. (B) Postoperative occlusal radiograph of repaired left unilateral alveolar cleft using autologous iliac crest cancellous bone graft. Good vertical height of bone adjacent to central incisor and canine is evident.
orthodontic therapy and dental prosthetic rehabilitation can provide a more normal, attractive smile.

Timing of repair

The timing of repair of alveolar clefts has been controversial. From a chronologic standpoint, alveolar cleft repair is defined as primary and secondary. Primary repair occurs between birth and the age of 2 years. It is typically performed at the same time as the lip repair or as a separate operation before palatal repair. Secondary repair is further divided into early, conventional or transitional, and late. Early secondary repair occurs after complete eruption of the primary dentition and before the initiation of eruption of permanent teeth. Patients are thus between the ages of 2 years and 5 or 6 years. Transitional or conventional secondary repair is performed during the mixed-dentition stage, usually between the ages of 6 and 12 years. Finally, late secondary repair is done after the eruption of the permanent dentition (usually meaning the second permanent molars). Some clinicians refer to this as tertiary repair.

The technique of alveolar bone grafting during infancy (primary repair) was introduced by Schrudde and Stellmach [9] in 1958 and subsequently became the standard of care. In the late 1960s, Skoog [10] described primary gingivoperiosteoplasty without placement of a bone graft. These protocols for primary intervention initially became popular but fell into disfavor after several reports of inhibition of midface growth [11,12]. A few surgeons still advocate primary alveolar cleft repair with bone grafting or gingivoperiosteoplasty, maintaining that their surgical technique is different than earlier methods and that they do not observe the high incidence of midface retrusion and anterior crossbite [13–15].

The most widely accepted treatment protocol is for repair during the mixed-dentition stage (see Fig. 2A, B) as initially reported by Boyne and Sands [16]. They preferred bone grafting of the cleft between the ages of 9 and 11 years, before eruption of the canine teeth. This age is believed to be appropriate because the sagittal and transverse growth of the anterior maxilla is essentially complete by the age of 8 years [17,18] and the remaining vertical growth of the maxilla primarily results from eruption of the permanent teeth [19]. Clinical analysis of facial growth in patients grafted at this age substantiates an absence of adverse effect on facial growth [20,21]. Furthermore, earlier repair, at the age of 5 through 7 years [22–25], seems feasible and without unfavorable growth consequences. This finding has been the current authors’ clinical experience, although there are no long-term studies to sufficiently substantiate this view.

Late secondary or tertiary alveolar bone grafting has been shown to have a lower success rate compared with that achieved with repair before eruption of the canine [23,26–31], regardless of the bone-graft donor site. In the unrepaired alveolar cleft, with advancing age, there is a gradual loss of bone along the distal surface of the central incisor root and along the mesial surface of the canine root. This process then limits bone-graft “take” because graft survival is compromised when it is placed next to exposed cementum.

Orthodontic management of alveolar clefts

The orthodontist plays an essential role in the treatment of patients with alveolar clefts. Orthodontic treatment interventions are usually necessary at several stages of development in children with clefts. In infancy, maxillary orthopedics may be necessary to expand the collapsed lesser segment, to mold the anterior maxillary arch, and to reduce the alveolar gap. Before secondary bone grafting, further orthodontic treatment is generally required. This treatment usually involves placement of fixed appliances on the maxillary arch. Objectives at this stage include expansion of the posterior and anterior maxilla to develop a favorable arch form and partially or completely eliminate the crossbites, alignment or derotation of malpositioned incisors, and improvement of dental function and aesthetics [32]. Approximately 4 to 6 months of orthodontic treatment should be anticipated in preparation for alveolar bone grafting. Bone grafting the alveolar cleft without proper orthodontic preparation will lead to poor results, with malposition of the lesser segment, a stabilized maxillary arch constriction, and posterior crossbite. The correction of these problems will usually necessitate additional surgical procedures.

Description of surgical technique

The patient is intubated using an oral Ring Adair Elwyn (RAE) endotracheal tube (Mallinckrodt, Inc., Glens Falls, New York) secured down the midline. Lidocaine with epinephrine is infiltrated around the periphery of the nasolabial fistula, in the labial and palatal aspects of the alveolar processes on each side of the cleft, and in the anterior hard palate. An incision is made around the labial component of the fistula, first within the loose mucosa. If the first incision is made after incisions on the alveolar processes, the
blade will be dulled and not cut effectively. The incision is continued along the margin of the alveolar cleft vertically toward the crest of the alveolus on each side, positioned equidistant between the labial and palatal surfaces. Once on the alveolar crest, the incisions are carried within the gingival sulci of the teeth on their labial aspect. Within the lesser segment, the incision is typically extended to the second primary molar. At this point, an oblique and posteriorly directed back cut is made toward the vestibule. For unilateral clefts, the labial sulcus incision is only extended to the mesial aspect of the central incisor (Fig. 4). Only limited soft tissue mobilization is indicated over the premaxilla because this tissue is not the primary source for soft tissue coverage over the bone graft.

In bilateral clefts, the incision is only carried to the distal aspect of the central incisor on each side to optimize the blood supply to the premaxilla (Fig. 5). Next, the mucoperiosteum is dissected from the alveolar processes on the labial aspect. This dissection extends to the nasal floor, exposing the lateral aspect of the anterior nasal spine and the lower pyriform rim. Through the labial approach, the mucoperiosteum is elevated off the bony walls of the cleft from the alveolar crest to the nasal floor. The anterior palatal dissection is initiated through the labial access at this time. A Dingman mouth gag is inserted for the remainder of the palatal dissection. Gingival sulcus incisions are made on the palatal aspect of the teeth on each side of the cleft. The posterior extension of these incisions is dictated by the size of the palatal component of the fistula. Larger palatal components often require continuation of the sulcus incisions to the permanent first molars to allow a more aggressive palatal flap mobilization. For larger palatal fistulas, the margins of the fistula may be directly incised before dissection of the palatal mucoperiosteum. In narrower fistulae, elevation of the palatal mucoperiosteum first to allow tenting of the soft tissue may facilitate making the marginal incisions. Once the palatal mucoperiosteum is mobilized and retracted, the soft tissue within the fistula on the palatal side is dissected superiorly to the nasal floor. This tissue is

Fig. 4. (a) Location of incisions for repair of unilateral alveolar cleft. (b) Nasal layer is repaired. (c) Bony alveolar cleft is filled with autologous bone graft. The graft is placed over the inferolateral pyriform rim as an onlay graft to augment the alar base. (d) Closure of the oral layer. The site of the back cut in the lesser segment mucoperiosteal flap is allowed to heal secondarily.
turned over toward and used to reconstruct the nasal floor. Any excess tissue is trimmed, but care must be taken to avoid over-resection, which will compromise tension-free closure of the nasal layer. Closure of the nasal layer proceeds from posterior to anterior using a 4-0 resorbable suture. Occasionally, a very small needle, such as a P-2 needle, is necessary to negotiate this area of limited access. The palatal flaps are then advanced medially and secured together with interrupted 4-0 resorbable sutures. At this time, before placement of the bone graft, it is advantageous to confirm adequate labial soft tissue mobility that will provide a tension-free closure over the bone graft. If greater mobility is needed, horizontal scoring of the periosteum at the base of the lesser segment flap usually produces the necessary laxity. Further mobility can be gained by extending the back cut and directing it anteriorly. These maneuvers will produce hemorrhage, and hemostasis should be obtained at this time.

The bone graft is now densely packed into the bony defect from the floor of the nose to the alveolar crest. Additional bone is placed along the inferolateral pyriform rim to augment the deficient alar base foundation. It is imperative that the bone graft is placed to the level of the cementoenamel junction of the adjacent teeth to ensure optimal bony height. The lesser segment mucoperiosteal flap is advanced medially and slightly palatally to cover the bone graft and to provide the oral labial closure of the fistula. Interrupted interdental papilla sutures are placed to stabilize the labial and palatal tissues toward one another and against the bony alveolar process. If there is any concern about the prognosis of the closure or the condition of the soft tissue, the entire maxillary dental arch and palate are covered with a periodontal dressing (CoePak, GC America, Inc., Alsip, Illinois), which is then removed 1 or 2 weeks postoperatively.

There are some differences in the repair of bilateral alveolar clefts compared with unilateral clefts. If both alveolar clefts are large, soft tissue coverage of the bone grafts may not be possible. In this situation, a staged repair will be necessary. As previously mentioned, the dissection of the labial mucoperiosteum over the premaxilla should be limited to avoid compromise of the vascular supply. On the palatal aspect, the margin of the fistula is incised along its entire length. Again, a conservative elevation of the soft tissue is performed to allow ease of closure of the nasal and oral layers.

**Bone-graft donor sites**

The gold-standard donor site in alveolar cleft repair is the iliac crest, typically harvested as a particulate cancellous bone and marrow (PCBM) graft [16].
The iliac crest provides the greatest volume of cancellous bone available among the commonly used sites and allows a two-team approach. Success rates using cancellous iliac bone are usually greater than 80% [23,26–28]. The major criticism for using iliac crest as a donor site is significant postoperative pain and prolonged hospitalization [33]. By using a more limited dissection of muscle and periosteum [34] or with the use of a percutaneous trephine technique [35], however, postoperative pain is substantially reduced, and patients can be discharged the day after surgery or even the same day. In the authors’ clinical practice, children are routinely discharged the following day and return to a normal gait within 1 or 2 weeks. The use of calvarial bone for closure of alveolar clefts was introduced by Wolfe and Berkowitz [36] in 1983. A success rate comparable to iliac cancellous bone has been reported [29]. Other centers, however, have demonstrated the superiority of PCBM grafts over cranial bone grafts [23,37]. The advantages of using cranial bone include having the donor site in the same operative field and minimal postoperative pain. Another potential donor site is the tibia. It also provides an abundance of cancellous bone, allows for a two-team approach, and results in only mild postoperative discomfort. The reported success rate also is similar to that for iliac cancellous bone [30,38]. The major disadvantage is a visible scar, and some clinicians do not recommend this donor site in patients younger than 18 years out of concern for damage to the epiphyseal growth plate [39]. Rib is almost exclusively used as a donor source in primary repair of alveolar clefts [13,14] and probably has no role in secondary repair because of the paucity of cancellous bone. The mandibular symphysis also has been used as a donor site in alveolar cleft repair [40,41]. As with cranial bone, it is within the same operative field and has the theoretic advantage of being membranous bone. The amount of bone available, however, particularly in children, is very limited, and the ratio of cancellous to cortical bone is low. In addition, because of the presence of developing teeth or tooth buds, this site should not be used in younger children.

**Closure of alveolar clefts using maxillary osteotomies**

As previously mentioned, the success rate for autologous bone grafting of alveolar clefts has been shown to be inferior in adolescents and adults (ie, after eruption of the canine teeth) [23,26–31]. Therefore, in older patients, other methods of treatment should be considered (Fig. 6). Approximately 25% of men with unilateral cleft lip and palate will have midface retrusion significant enough to require maxillary advancement [42]. Adolescent or adult patients may then be managed with segmental Le Fort I osteotomies to simultaneously correct the midface deficiency and to close the cleft-dental gap coincident with cancellous bone grafting [43–46]. The canine tooth is thus moved into the position of the lateral incisor and later modified to assume the form of the lateral incisor. This technique has the advantage over the staged approach of alveolar cleft bone grafting followed by maxillary advancement of achieving the surgical goals in a single procedure. In addition, another surgical procedure is eliminated if placement of an osseointegrated implant was considered for dental rehabilitation and the fabrication of a fixed bridge becomes unnecessary as the dental gap is closed.

**Innovations in the repair of alveolar clefts**

Platelet-rich plasma (PRP) is an autologous source of growth factors that has been shown to accelerate the rate and degree of bone formation in a bone graft [47]. It is obtained from autologous blood drawn immediately preoperatively or intraoperatively and differentially centrifuged into its basic components. The initial, or hard spin separates the erythrocytes from the plasma, which contains leukocytes, platelets, and coagulation factors. The second, or soft spin, which is done at a slower centrifuge speed, then separates the PRP from the platelet-poor plasma. The PRP contains several growth factors that are released from the α granules in platelets. Of particular importance are platelet-derived growth factor (PDGF) and transforming growth factor (TGF) β-1 and β-2, which have been shown to play important roles in bone regeneration and repair [48,49]. The stimulatory effect of PDGF on the healing of tibial osteotomies in rabbits has been demonstrated radiographically, mechanically, and histopathologically [50]. PDGF and TGF-β-1 and TGF-β-2 also enhance soft tissue repair [51,52] and therefore provide potential benefit in the healing of mucoperiosteal flaps.

PRP was first used in bone grafting to the maxillofacial region by Tayapongsak et al [53] for reconstruction of mandibular continuity defects. It has since been used in the repair of alveolar clefts and in the placement of osseointegrated implants [54]. Nonmaxillofacial applications have included cosmetic surgery [55] and total knee arthroplasty [56]. More rapid healing and a shorter recovery period
have been observed [55]. In addition, reduced postoperative pain and a decreased need for narcotic analgesia have been documented [56]. Commercial systems for procurement of PRP are available (e.g., Gravitational Platelet Separation System, Cell Factor Technologies, Biomet, Inc., Warsaw, Indiana; Smart PReP, Harvest Technologies Corp., Norwell, Massachusetts). These systems offer the advantages of availability within the operating room, rapid processing, minimal space requirement, and simplicity in use. The disadvantage is an added cost for the centrifuge system and the individual kits used in the preparation of the PRP. A minimal amount of blood is necessary to prepare the PRP. Approximately 60 to 100 cc of whole blood is recommended by the manufacturers to provide an adequate amount of PRP. The current authors have found that only 30 cc is necessary when performing alveolar bone grafting. A greater volume of whole blood may be necessary if placement of PRP into the bone-graft harvest site is desired.

Another recent advance in the management of alveolar clefts is interdental distraction osteogenesis.
Liou et al [57] used this technique to close large alveolar clefts that would otherwise have been difficult to treat using conventional methods. They applied the principle of bifocal distraction osteogenesis [58,59]. A segmental posterior maxillary osteotomy was performed, and the distraction device was mounted on supporting teeth across the interdentally osteotomy. With this device, the moving vector of the distracted segment can be adjusted three-dimensionally during the course of distraction. The alveolar cleft gap was closed and a new posterior dental gap was created where the bony regenerate and new attached mucosa are located. Rapid orthodontic tooth movement was instituted to close the dental gap. Subsequent to the apposition of the alveolar segments, alveolar bone grafting or gingivoperiosteoplasty will still be necessary. This technique was also reported by Yen et al [60] with a modification of the distraction device. Their device used a continuous spring force rather than incremental screw lengthening to provide the tension force needed for distraction osteogenesis. The primary advantages of interdental distraction osteogenesis in the closure of large alveolar clefts are as follows: overcoming a major soft tissue deficiency, providing attached mucosa along the alveolar ridge, and minimizing the volume of bone graft needed to reconstruct the bony gap.

Dental rehabilitation of the alveolar cleft

The final phase of treatment of alveolar clefts is the restoration of dental function and form. This step was traditionally addressed with either a conventional fixed bridge or an etched resin retained composite bridge (Maryland). These prostheses carry the disadvantage of violation of healthy tooth structure and the likely need for multiple replacements during the course of the patient’s lifetime. In 1991, Verdi et al [61] described the placement of an osseointegrated implant into a grafted alveolar cleft site. Later series reported success rates of 90% [62] and 96% [63], respectively. Both groups noted a need for repeat bone grafting in a minority of patients to provide adequate bone stock for implant placement. They also recommended a short interval time (4 mo, see reference [62]; and 6–8 wk, see reference [63]) between bone grafting of the alveolar cleft and placement of the implants.

Tooth autotransplantation has been espoused, primarily by centers outside the United States, for the replacement of missing lateral incisors in patients with alveolar clefts [64,65]. Typically, premolar teeth are transplanted because they frequently are extracted for orthodontic reasons and because they have a single root. Endodontic therapy is usually necessary. Favorable prognostic factors include the following: single-rooted teeth, stage of root development (open apex), age of patient younger than 15 years, and surgical technique [64]. Regeneration of the periodontal space and lamina dura is observed in postoperative radiographs, and orthodontic tooth movement is possible [64,65].

Summary

Treatment philosophies in the management of alveolar clefts have changed greatly over the years. Currently, the most widely accepted protocol is for repair using autologous cancellous bone from the iliac crest during the stage of mixed dentition. Preliminary data suggest that the appropriate age for surgical repair during the secondary phase can be decreased without evidence of limitation of facial growth. Further long-term studies are necessary to support this protocol, however. With a multidisciplinary approach between the various medical and dental specialties, it is now commonplace to achieve normal dentofacial aesthetics and function. The continued advances in medical and dental technology have further contributed to the excellent outcomes that are now achieved.

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