Review Article

Timing of Orthodontic Tooth Movement After Alveolar Bone Grafting in Patients with Alveolar Cleft: A Review Article

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Abstract

Alveolar bone grafting (ABG) is a cornerstone of the multidisciplinary management of cleft lip and palate (CLP), restoring alveolar continuity and enabling dental rehabilitation. Orthodontic tooth movement (OTM) into grafted sites promotes functional loading, enhances graft stability, and facilitates the eruption of cleft-adjacent teeth. However, the optimal timing for initiating OTM post-ABG remains a subject of clinical debate. While traditional approaches recommend longer healing periods, the earlier initiation of OTM is possible with individual assessment based on radiographic evidence of bone bridge formation and clinical consideration. This review synthesizes current evidence on graft biology, healing phases, orthodontic biomechanics, and timing strategies. It aims to guide clinicians in optimizing treatment protocols for improved outcomes in cleft rehabilitation.

Keywords: alveolar bone grafting, cleft lip and palate, functional loading, graft healing, orthodontic tooth movement

Introduction

Cleft lip and palate (CLP) affects approximately 1 in 700 live births globally[1,2], with alveolar clefts present in up to 75% of cases.[3] These defects disrupt maxillary continuity, impair tooth eruption, and compromise oral function and esthetics.[3]

Alveolar bone grafting (ABG) is a standard surgical intervention to repair the alveolar clefts and any associated oronasal fistula.[4] The procedure's timing is critical and depends on the eruption of the adjacent permanent teeth, typically between 8 and 12 years of age.[4-12] The timing is based on individual needs and clinical considerations, focusing on restoring structural integrity and supporting skeletal and dental development.[8,10,13-15] This procedure also plays an important role in facilitating normal facial growth, enhancing dental rehabilitation, and promoting better oral hygiene.[5,8,11,13] ABG was first reported by Boyne and Sand, who used the principle of autogenous marrow and cancellous bone grafting for the treatment of osseous clefts of the alveolar ridge and the anterior portion of the hard palate.[5] The use of autogenous bone, commonly harvested from the anterior iliac crest, is widely acknowledged as the gold standard for its osteogenic, osteoinductive, and osteoconductive properties.[5,8,11,16,17] The cancellous bone and marrow graft from this donor site has abundant cellular content and robust osteogenic potential, which enables predictable bone formation and incorporation for reconstructing bony defects associated with alveolar clefts.[5,13,16,18]

Orthodontic treatment plays a vital role in aligning cleft-adjacent teeth, expanding the maxillary arch, and guiding eruption.[19] Tooth movement into grafted bone stimulates osteogenesis and contributes to long-term graft stability.[18,20-22] Despite its importance, the ideal timing for initiating orthodontic forces post-ABG remains controversial.[10] This review explores biological principles, healing dynamics, and clinical timing strategies to inform evidence-based practice.

Materials and Methods

A literature review was performed by searching the PubMed, Scopus, and Embase databases to identify relevant and current information on the timing of orthodontic tooth movement (OTM) following ABG. The search included studies published in English from 1972, when alveolar bone grafting was first reported, through 2025. The search strategy utilized keywords included "Cleft lip and palate", "Alveolar bone graft", "Orthodontic tooth movement and "Tooth movement timing". Additional literatures were gathered via Google Scholar and manual searches. Study selection was defined by specific criteria. Inclusion was limited to human or animal studies involving tooth movement into cleft sites or alveolar bone defects, while exclusion criteria were applied to studies involving periodontal disease or those lacking follow-up. From the gathered results, The most significant article and supporting selected studies were included in the references.

Biological principles of bone grafting

Graft selection and properties

Autogenous cancellous bone is often harvested from the iliac crest and is the gold standard for ABG due to its:

Osteogenesis: Living osteoblast precursors contained within the graft promote new bone formation. These osteogenic cells, primarily osteoblast precursors, are found in bone, bone marrow, and the periosteum. Under appropriate host conditions, they can differentiate into mature osteoblasts and contribute to the formation of new bone.[17,23]

Osteoconduction: The ability of the graft to serve as a structural scaffold for the ingrowth of new blood vessels, osteoblasts, and stem cells from the host tissue.[23] This framework is vital for the eventual integration of the graft with the host bone. Inadequate cellular and vascular ingrowth may compromise graft incorporation and mechanical stability.[17]

Osteoinduction: The process by which the graft recruits undifferentiated stem cells from the surrounding host tissue. These recruited cells are then signaled to differentiate into new osteoblasts.[23] This process is associated with specific bone growth factors, such as bone morphogenetic proteins (BMPs) and platelet-derived growth factors, which regulate cell differentiation and proliferation.[17,23]

Healing phases

Graft incorporation proceeds through three overlapping stages[23]:

Stage 1: Inflammation (0-4 weeks). In this phase, a cascade of inflammatory and reparative events occurs, including vascular invasion, osteoclast activation, and recruitment of mesenchymal stem cells (MSCs).[17]

Coagulated blood fills the graft bed, limiting blood loss, while vascular buds from the host tissue infiltrate the graft within the first day.(24) The inflammatory response is mainly composed of lymphocytes, plasma cells, mononuclear cells, and osteoclasts.(23,25) Revascularization begins as early as 48 hours and rapidly progresses, repopulating marrow spaces with MSCs.(24) Surgical trauma and hypoxic conditions within the graft induce osteocytic autolysis, with necrosis marked by empty lacunae, while necrotic graft marrow is removed by macrophages.(24,25) Despite ischemic injury, some osteogenic cells within the graft survive through diffusion of nutrients from surrounding soft tissues.(24) The associated metabolic byproducts, low oxygen tension, and reduced pH act as chemoattractants that recruit host-derived MSCs. Under the influence of osteoinductive factors, these MSCs differentiate into osteoblasts and contribute to the formation of new bone along necrotic trabeculae.(25) During the first 2 weeks, fibrous granulation tissue becomes predominant at the site, accompanied by increased osteoclastic activity while the number of inflammatory cells decreases.(24) The neovascularization may already be complete approximately 3 weeks post-grafting, with new bone deposited along trabecular surfaces, thereby increasing bone mass.(26) By the end of this phase, active bone resorption and new bone formation are established throughout the interior of the graft.(25)

Stage 2: Repair (4-12 weeks). This stage is characterized by woven bone formation, osteoid deposition, and marrow repopulation. During this period, the woven bone forms around necrotic trabeculae and resorption of devitalized tissue begins. Histologically, osteoblasts line the dead bone cores and deposit osteoid around them, while osteoclasts resorb the necrotic parts.(24) Concurrently, new capillary ingrowth and hematopoietic marrow repopulation occur.(23,25) There are two types of woven bone histologically. The dark and well-defined margin type of woven bone appears to rapidly remodel into mature bone, while another type, indistinct demarcation, may complete this process after 4 weeks; however, they serve the same function.(26) Autogenous graft remains clearly visible up to 4 weeks postoperatively but appear less distinct by 8 weeks, consistent with active remodeling and replacement by new bone.(27) By 8 weeks, cleft areas appear solid and histologically composed predominantly of viable bone, while bone remodeling activity diminishes as osteoblasts and osteoclasts become less evident.(20)

Stage 3: Remodeling (12+ weeks). The remodeling stage is characterized by replacement with mature lamellar bone and cortical consolidation. By approximately 6 months, substantial replacement of the cancellous autograft with host bone is achieved, and by 12 months, complete remodeling and cortical consolidation are complete.(28) This process restores skeletal strength and results in structural integration of the graft with the host skeleton.

The total resorption of the graft, accompanied by its replacement with living bone, is termed "creeping substitution," and this process is most pronounced at the graft–host interface.(25)

Autografts, both cancellous and cortical, undergo a similar process in the early stages of healing and incorporation.(24,25) However, histologically, there are three notable differences. Cancellous autografts are revascularized more rapidly and completely, undergo creeping substitution, and generally achieve full repair over time.(24) In contrast, cortical autografts experience slower revascularization because of their dense, low porosity structure, which delays vascular ingrowth through Volkmann's and Haversian canals until osteoclastic resorption has created pathways.(8,24,26) Incorporation in cortical grafts begins with osteoclastic activity rather than osteoblastic deposition, and widespread resorption continues for several months(26), leading to transient mechanical weakness. Thus, cancellous grafts typically demonstrate greater strengthening compared to cortical grafts.(23,24) Although new bone formation is detectable around the first several weeks, cortical grafts often remain a mixture of viable and necrotic bone for an extended period, with up to 40% of the original necrotic tissue persisting after 1 year.(17,24)

Radiographic changes mirror histological progression, with increased radiodensity early due to osteoid deposition and a gradual decrease over months as resorption and remodeling progress.(24,25,27) By 3 months, the margins between the graft and host bone gradually become indistinct as incorporation progresses.(29) At this time, the radiographic appearance shows little difference compared with findings at 6 months or 1 year.(25,30) Moreover, autogenous cancellous bone grafting does not interfere with the development of teeth adjacent to the cleft.(7,31)

Orthodontic tooth movement and graft interaction

Orthodontic treatment for patients with CLP aims to align teeth adjacent to the cleft site, reconstruct the collapsed alveolar arch by arch expansion, facilitate the eruption of permanent teeth, establish the proper space for dental replacement, and stabilize the maxillary segment.(8,22,32)

Biological effects of orthodontic tooth movement

Orthodontic forces stimulate bone remodeling via two pathways. The first is the receptor activator of nuclear factor kappa-B (RANK) and receptor activator of nuclear factor kappa-B ligand (RANKL) pathway. RANKL, a membrane adhesion protein produced by osteoblasts and bone marrow stromal cells, binds to RANK receptors on osteoclast precursor cells or mature osteoclast membranes. This ligand–receptor interaction promotes osteoclast differentiation and maturation, while also suppressing apoptosis.(33,34) Mechanical stress enhances RANKL expression via osteocytes, amplifying osteoclast-mediated resorption and strengthening the remodeling response.(20,35) The second pathway involves Runt-related transcription factor 2 (RUNX2) expression. RUNX2, a member of the Runt-related transcription factor family, serves as a critical regulator of osteoblast differentiation, chondrocyte maturation, and bone matrix production.(20,36) Increased RUNX2 expression during the late remodeling phase promotes osteogenesis and integration of the graft with the host bone.(20)

Clinical goals

With a combined surgical–orthodontic approach, including alveolar bone grafting, cleft-adjacent teeth can erupt or be orthodontically guided into the grafted area, thereby improving tooth positioning and reducing the need for prosthodontic intervention.(8,22,32)

Tooth eruption through the graft stimulates physiological osteogenesis(8), while functional loading controlled by orthodontic forces can stimulate bone turnover, prevent graft resorption, provide root support, shape the dentoalveolar arch, and enhance the long-term stability of the alveolar support.(6-8,10,18,21-23,27,37-39) Conversely, a lack of stress on the grafted bone may result in suboptimal volume maintenance and weaker support for adjacent teeth.(22,23) Indistinct graft margins and cortical continuity indicate successful integration.(29,40)

Orthodontic loading after grafting not only supports bone reconstruction and prevents postoperative bone resorption but also facilitates proper teeth alignment, normal root development, and eruption of adjacent teeth, particularly the canines near the cleft site.(6,7,19,21,38)

Timing strategies for orthodontic intervention

Traditional approach

Historically, orthodontic tooth movement (OTM) began 6 months post-ABG to allow for graft stabilization.(41,42) However, this delay may lead to unnecessary resorption and reduced graft volume.(39,43) Bone graft density was reported to markedly decrease at 1 month following grafting, followed by a gradual decline until stabilization was observed at 6 months postoperatively.(41) Some studies resumed OTM once the cleft-adjacent tooth can be bonded, following either spontaneous eruption or surgical exposure.(4,8,44)

Early intervention (3-6 months)

Some studies support initiating OTM as early as 3 months postoperatively, once the grafted bone has achieved initial osseointegration.(4,10,45) Initiating tooth movement at approximately 3 months may not only facilitate closure of the gap in the maxillary arch but also provides functional stress that stimulates bone remodeling and prevents graft resorption.(10,43,46)

Radiographically, little difference is observed in bone bridging between the 3-month follow-up and later follow-ups at 6 or 12 months, indicating that much of the remodeling occurs within the first 3 months.(30,46) The residual cortical bone at the previous cleft site typically decreases during this period, reflecting the active turnover of transplanted bone; however, satisfactory outcomes can still be expected.(40)

Long-term follow-up demonstrates that graft volume decreases significantly between 3 months and 1 year, despite maintenance of adequate bone bridging.(39) Therefore, to preserve graft stability, it is recommended that the site be placed under physiological stress through the eruption of adjacent teeth, orthodontic tooth movement, or dental implant placement once adequate bone formation is confirmed. This functional loading appears essential to minimizing progressive resorption and supporting long-term stability of the graft.(39,46) However, some studies have reported significant graft resorption by 3 months, raising the question of whether earlier orthodontic intervention could reduce this loss.(10,40)

Ultra-early loading (2-8 weeks)

Early initiation of OTM after alveolar bone grafting has been shown to promote favorable outcomes. It has been suggested that orthodontic intervention can begin as early as 2-3 weeks post-surgery, ideally with appliances already in place at the time of grafting to allow active movement soon after the surgical phase.(9,27) Other reports recommend initiating treatment at around 4-6 weeks, when woven bone formation is already established, providing adequate stability for functional loading.(14,47,48,49) Orthodontic treatment at this stage shows that satisfactory outcomes can be achieved when the marginal bone level is more than 50%-75% of the root length and the shortest vertical bone bridge length is ≥6.5 mm.(14) By 6-8 weeks, the grafted bone typically shows more mature lamellar organization and stable vascular networks, supporting effective tooth movement.(11,18,20,26)

Risks and considerations

External apical root resorption is a complication in orthodontic treatment for patients with clefts, particularly those with complete bilateral clefts, with the central incisors being the most affected.(4,44) This risk may be related to the limited trabecular bone in the premaxilla, where tooth movement can cause root apices to press against the dense cortical layer.(44)

Orthodontic tooth movement plays an important role in achieving satisfactory outcomes following alveolar bone grafting. Other factors, such as patient age, gender, type of cleft, surgical technique, the eruptive stage of the permanent canines, and oral hygiene, may also influence the success of the procedure.(30,40,41,50)

Two-dimensional (2D) radiographs are routinely taken for orthodontic procedures and are often readily available(12,39,51-53), and so they are the standard method for re-evaluating bone after ABG.(54) Although 2D radiographs involve less radiation exposure, they have several limitations, including image distortion, overlapping anatomical structures, and magnification errors.(14,29,53,55) Moreover, 2D radiographs cannot represent the bone graft from all perspectives and may lead to an overestimation of the outcomes of secondary ABG.(29,54,56-58)

To overcome these limitations, three-dimensional (3D) radiographs have been introduced for assessing alveolar bone grafting. This method provides accurate and reliable 3D information on the cleft defect and alveolar bone architecture, allowing evaluation of the cleft and bone graft dimensions and assessment of the bone support for permanent teeth adjacent to the cleft.(39,57) Studies have shown that 3D radiography is more efficient than 2D radiography for these purposes.(53-55,58)

Clinical recommendations

Based on current evidence, early functional loading of the graft, achieved through spontaneous eruption or orthodontic movement of cleft-adjacent teeth, may promote graft stability by maintaining bone volume and reducing resorption.(47) Conversely, delaying treatment may lead to retard anteroposterior growth, which tends to produce premaxilla relapse, canine impaction, and lingual collapse of the incisors.(43,59)

The optimal timing of tooth movement depends on the degree of graft remodeling and integration, as initiating too early may compromise root health.(18) Some studies suggest that the timing of cleft-adjacent tooth movement after grafting is not directly associated with increased risk of external apical root resorption.(46)

Following the healing phase, the woven bone starts to form within the first few weeks, transitions to lamellar bone from 4 weeks, and then undergoes remodeling through osteoclastic resorption and osteoblastic deposition.(26,48) Importantly, cancellous autografts are incorporated by forming new bone on a necrotic scaffold, which initially strengthens the graft. As the necrotic bone gradually resorbs and is replaced, the mechanical strength of the graft-host junction is restored.(24,25) Thus, applying orthodontic forces during the woven bone phase may be advantageous, as trabecular bone provides sufficient flexibility for controlled movement, while avoiding the higher resistance of fully mineralized bone.(48)

Studies support that active OTM can begin between 1 and 3 months post-ABG, once radiographic evidence confirms adequate bone support before initiating OTM. Early initiation of OTM has been associated with more predictable tooth movement, improved periodontal support, and reduced graft resorption.(9,11,14,18,37,39,47,48) Delays beyond 6 months should be avoided to ensure adequate graft stimulation and minimize the risk of graft resorption.(43,59) The timing of OTM should be individualized, taking into account the patient’s healing rate, cleft morphology, and specific orthodontic objectives. Throughout treatment, careful monitoring of root health and bone support is essential.(19,46)

Table 1: Summary of studies on the timing of orthodontic tooth movement after alveolar bone grafting.

Author (Year)	Type of study	Type of sample	Sample size	Timing of tooth movement after ABG	Type of graft	Assessment method	Key findings
Yang *et al.* (2019)[10]	Prospective	Human	20	3 months	Cancellous bone from anterior iliac crest	Periapical	Cleft-adjacent teeth could be bodily moved into the grafted bone with adequate alveolar bone support.
Datana *et al.* (2019)[30]	Prospective	Human	30	3 months	Particulate cancellous bone and marrow from anterior iliac crest	CBCT	Resorption of graft volume was determined after 3 months of grafting and related to the success of orthodontic treatment.
Maeda-lino *et al.* (2017)[46]	Retrospective	Human	30	3 months	Autogenous bone	Occlusal radiograph	Initiating orthodontic treatment within 3 months after alveolar bone graft minimizes resorption of the grafted bone.
de Ruiter *et al.* (2010)[45]	Retrospective	Human	75	12 weeks	Mandibular symphysis	Clinical visual assessment	The outcomes of postoperative orthodontic treatment showed excellent results.
Ahn *et al.* (2014)[48]	Prospective	Dogs	12	Immediately, 2 weeks and 12 weeks	Deproteinized bovine bone mineral and demineralized bone matrix	Micro-CT, histologic examination	Bone graft facilitates immediate orthodontic loading to promote OTM with favorable periodontal healing, concurrently lowering the risk of limited OTM in case of delayed postoperative force application.
Sun *et al.* (2018)[20]	Prospective	Rats	39	8 weeks	Cancellous bone from anterior iliac crest	Histological examination	OTM into the grafted area promoted bone remodeling, leading to bone resorption and followed by new bone deposition.
Ma *et al.* (2021)[49]	Prospective	Dogs	6	Immediately, 4 weeks and 8 weeks	Deproteinized bovine bone mineral	Histological examination, micro-CT	Orthodontic loading initiated at 4 weeks post-augmentation provided the most effective functional stimulation for alveolar bone graft.
Schultze-Mosgau *et al.* (2003)[47]	Retrospective	Human	68	4-6 weeks	Cancellous bone from anterior iliac crest	Panoramic radiograph	Gap closure provide more favorable results compared with gap opening.
Seike *et al.* (2012)[14]	Retrospective	Human	49	1 month	Cancellous bone from anterior iliac crest	CT	Successful orthodontic outcomes were associated with a marginal bone level of ≥3, the shortest vertical length of ≥6.5 mm, and the shortest anteroposterior bone width of ≥5 mm.
Hossain *et al.* (1996)[27]	Prospective	Dogs	9	2-4 weeks	Particulate cancellous bone and marrow from anterior iliac crest and beta-tricalcium phosphate	Histological and radiographic examination	By 4 weeks following graft placement, bone formation had occurred along the surface of the grafted material.
Turvey *et al.* (1984)[9]	Retrospective	Human	33	2-3 weeks	Cancellous bone from anterior iliac crest	Periapical and panoramic radiograph	Tooth movement initiated within several weeks following ABG tended to exhibit more predictable outcomes.

Abbreviation; ABG: Alveolar bone grafting, CBCT: Cone beam computed tomography, CT: Computed tomography, OTM: Orthodontic tooth movement

A 3D radiograph should be considered before the initiation of OTM as it provides accurate and reliable information for the position and bone support of the developing cleft-adjacent tooth following ABG.[39,57]

However, the strength of these clinical recommendations is limited by the current level of evidence available. The literature is characterized by a predominance of retrospective studies and animal models, which may not fully replicate human cleft biology. Furthermore, existing research often features small sample sizes and significant heterogeneity in graft materials and imaging methods. These limitations highlight the need for standardized, high-level prospective trials to definitively establish optimal OTM timing protocols.

Conclusions

Orthodontic tooth movement into grafted alveolar bone is a critical component of cleft rehabilitation. Based on graft healing and clinical evidence, active OTM can begin between 1-3 months post-ABG and should not be delayed beyond 6 months, as early functional loading enhances graft stability and dental outcomes. However, optimal timing is not universal, it may vary depending on patient-specific factors such as age, cleft morphology, graft type, and individual healing response. Therefore, 3D radiographic monitoring is essential to confirm bone support before initiating forces. While a personalized, interdisciplinary approach remains essential for optimizing care, it must be noted that high-level clinical evidence supporting these specific timelines remains limited.

Conflict of Interest

The authors declare no conflict of interest.

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