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Review Article

Effects of Orthodontic Movement on Periodontal Health in Regenerated Bone Defects: A Scoping Review

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ABSTRACT

This review maps existing evidence on how orthodontic tooth movement (OTM) influences biological responses in regions with bone deficiencies that are being regenerated using various grafting methods and materials. A systematic electronic search was carried out in four databases—PubMed, Scopus, EMBASE, and Web of Science. Extracted data included publication metadata, research design, characteristics of samples, OTM parameters, periodontal biological reactions, analytical approaches, and conclusions. In total, 30 publications met the inclusion criteria. Among them, 22 studies most frequently utilized alloplastic grafts. Orthodontic forces of 10 g or 100 g were commonly applied, with force initiation ranging from immediately after grafting to 6 months post-surgery. Twenty-four studies reported enhanced bone formation, five indicated an improvement in clinical attachment level (CAL), five found reductions in probing pocket depth (PPD), and sixteen observed varying levels of root resorption. Although the biological response of the grafted periodontium to OTM appeared generally favorable, these findings should be interpreted cautiously. Further laboratory and clinical trials are required to confirm these outcomes.

Keywords: Orthodontic movement, Periodontal regeneration, Bone graft materials, Bone defect healing

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Introduction

Restoration of missing hard tissue often depends on bone grafts and substitute materials, which serve as scaffolds to promote new bone growth [1, 2]. Autogenous bone, whether used alone or combined with synthetic substitutes, and substitute materials alone are long-established in reconstructive therapy [3]. These materials are broadly classified as natural (autografts, allografts, xenografts) or synthetic alloplasts. Although autografts remain the reference standard, synthetic options are now more widely employed due to their availability and handling properties [4].

Orthodontic therapy modifies alveolar bone architecture, producing variable effects in different oral areas. Reductions in bone thickness—particularly on the palatal and incisor sides—are often observed [5], along with soft-tissue changes such as gingival recession [6]. Persistent or excessive orthodontic forces can lead to root resorption, especially during prolonged or extensive apical movement [7].

Even so, controlled tooth movement through grafted bone can be performed safely when the grafted site is properly healed, though minor root resorption may still occur [4]. Studies have shown that allografts and β-tricalcium phosphate can alter bone metabolism, potentially slowing tooth movement in regenerated regions [8]. Consequently, this review aims to explore the biological responses of the periodontal apparatus during OTM in bone-deficient areas undergoing regenerative therapy.

Materials and Methods

Protocol and registration

The review was designed in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews) guidelines [9].

Information sources and search strategy

A detailed search protocol was implemented on 10 November 2023, covering the databases PubMed, Scopus, EMBASE, and Web of Science. Grey literature was additionally screened via OpenGrey. The full search algorithms for each database are presented in **Table 1**. No restrictions on language or publication date were applied.

Table 1. Search strategy per database.

Source	Query Structure
Web of Science	TS=((“orthodontic tooth movement” OR “dental movement” OR “orthodontic therapy”)) AND TS=((“bone imperfection*” OR “alveolar imperfection*” OR “osseous imperfection*” OR “bone grafting” OR “bone repair” OR “alveolar gap”))
Scopus	TITLE-ABS-KEY ((“orthodontic tooth movement” OR “dental movement” OR “orthodontic therapy”)) AND TITLE-ABS-KEY ((“bone imperfection*” OR “alveolar imperfection*” OR “osseous imperfection*” OR “bone grafting” OR “bone repair” OR “alveolar gap”))
Embase	(“orthodontic tooth movement” OR “dental movement” OR “orthodontic therapy”) AND (“bone imperfection*” OR “alveolar imperfection*” OR “osseous imperfection*” OR “bone grafting” OR “bone repair” OR “alveolar gap”)
PubMed	(“orthodontic tooth movement”[All Fields] OR “dental movement”[All Fields] OR “orthodontic therapy”[All Fields]) AND (“bone imperfection*”[All Fields] OR “alveolar imperfection*”[All Fields] OR “osseous imperfection*”[All Fields] OR “bone grafting”[All Fields] OR “bone repair”[All Fields] OR “alveolar gap”[All Fields])
Opengrey	(orthodontic tooth movement OR dental movement OR orthodontic therapy) AND (bone imperfection OR alveolar imperfection OR osseus imperfection OR bone grafting OR bone repair OR alveolar gap)

Study selection and eligibility criteria

Two independent reviewers (AV and CSF) screened titles and abstracts to determine eligibility, referring to full texts when data were incomplete. Any disagreements were resolved with a third reviewer (ES). No filters on date or language were used. Studies were included if they: (1) involved human or animal subjects; (2) examined orthodontic movement across bone defects repaired with natural or synthetic grafts; (3) analyzed biological or biomechanical responses in the tooth or surrounding tissues; and (4) reported the extent of movement achieved across grafted sites. Exclusion criteria included: (1) in vitro or ex vivo experiments, (2) narrative reviews, and (3) systematic reviews.

Data extraction and synthesis

Two reviewers (A.V. and C.S.F.) jointly developed a data charting framework and independently extracted all variables. The data covered: study authors and year; study design; sample details (species, age, sex, defect characteristics, graft type and location); orthodontic parameters (site, direction, magnitude, timing, method of force application, duration, and total movement achieved); biological outcomes (bone regeneration or resorption, CAL, root integrity/resorption, PPD); analytical techniques; and summarized findings. All extracted information from the included articles was synthesized descriptively for comparison.

Results and Discussion

Literature search and screening procedure

A total of 2627 records were located across the databases: PubMed (465), Scopus (763), EMBASE (632), Web of Science (767), and Opengrey (0). Once duplicates were discarded, 1113 unique references remained. Screening of titles and abstracts led to the exclusion of 1044 items. Out of the 69 papers left, 61 full texts were successfully obtained for evaluation, while 8 could not be accessed. Among the reviewed full texts, 8 were removed because orthodontic tooth movement (OTM) through grafted bone was not investigated, 9 lacked data on periodontal outcomes or orthodontic force details, 5 failed to specify the bone graft material used, and 9 did not correspond with the review’s scope or inclusion requirements. Ultimately, 30 publications fulfilled all inclusion standards and were selected for analysis. The process of identification, screening, and selection is summarized in **Figure 1**.

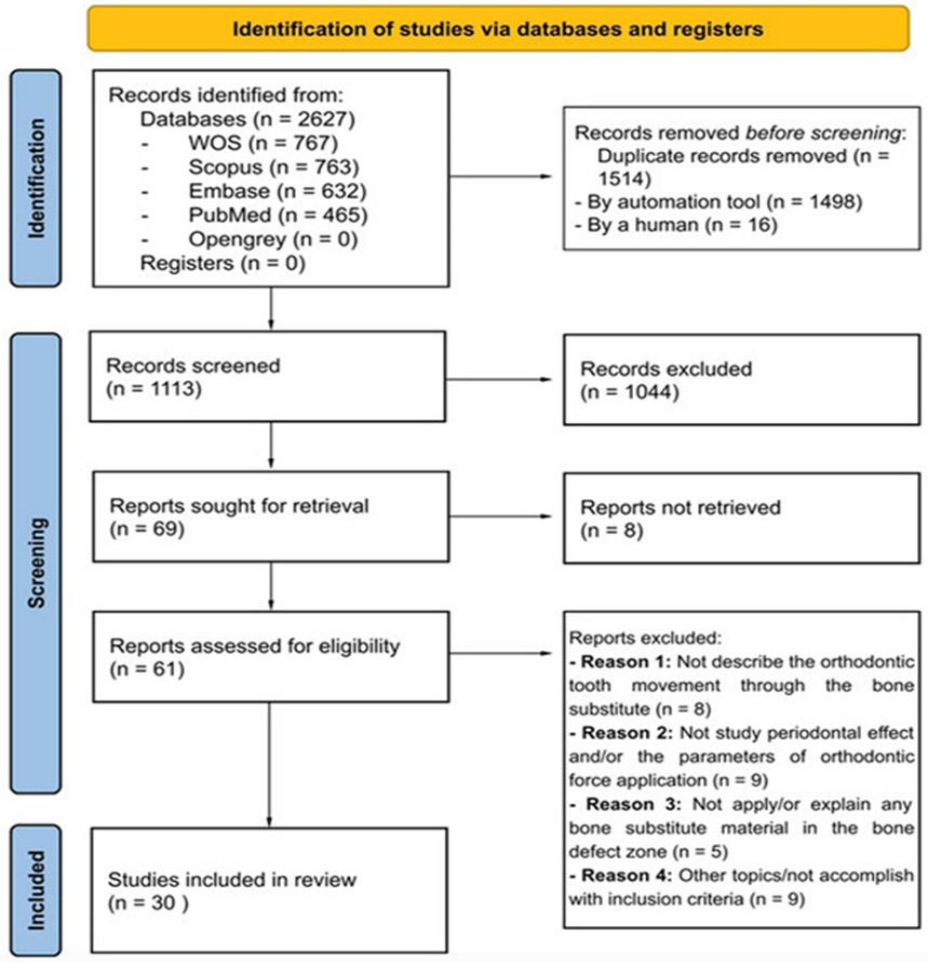

Figure 1. Diagram illustrating the article identification and selection process.

Overview of the included studies

Key descriptive data for all reviewed studies are summarized in **Table 2**. The publications ranged chronologically from 1996 [10] to 2022 [11]. Most investigations originated from China (n = 13) [12–24]. Other countries contributing included Japan (n = 3) [25–27], Germany (n = 3) [11, 28, 29], Israel (n = 2) [8, 30], Korea (n = 2) [31, 32], and single studies from Italy [33], Brazil [34], Bangladesh [10], Sweden [35], Turkey [36], Egypt [37], and the USA [38].

Table 2. Summary of study characteristics.

Study Authors/ Year	Research Design	Animal/Human	Age Range	Sex	Defect Category	Dimensions	Site of Defect	Materials for Regeneration
Ahn HW *et al.* (2014) [31]	Laboratory Study	Dog	18–24 months	12 Male	Tooth extraction site	5 mm (mesio-distal) × 5 mm (bucco-lingual) × 7 mm (vestibular)	Upper first premolar	DBB (Bio-Oss), DBM (OrthoBlast II)
Araújo M *et al.* (2001) [35]	Laboratory Study	Dog	1 year	5 Unspecified	Tooth extraction site	Not reported	Lower first/second premolar, fourth premolar	DBB (BioOssA)
Attia MS *et al.*	Laboratory Study	Human	25–48 years	10 Femal	Bone defects within	PPD > 5 mm	45 unspecifi	BG (Bio-Glass)

(2012) [37]				e, 5 Male	periodontium		ed locations	
Cardaropoli D *et al*. (2006) [33]	Clinical Case Study	Human	Not reported	3 Male	Bone defects within periodontium	PPD > 6 mm	Upper central incisor	DBB (Bio-Oss)
Fung K *et al*. (2012) [38]	Clinical Case Study	Human	68 years	1 Female	Bone defects within periodontium	15 mm height	Upper central incisor	EMD (Emdogain), BCP
Hossain M *et al*. (1996) [10]	Laboratory Study	Dog	1 year	9 Unspecified	Tooth extraction site	Not reported	Upper second/third incisor	AB, β-TCP
Jiang S *et al*. (2020) [12]	Laboratory Study	Dog	1 year	9 Male	Tooth extraction site	4.5 mm diameter × 6 mm depth	Upper first premolar	BioCaP, DBB
Kawamoto T *et al*. (2003) [25]	Laboratory Study	Dog	1.6–2.6 years	8 Female	Tooth extraction site	5 mm diameter	Upper first premolar	rhBMP-2 with PGS
Kawamoto T *et al*. (2002) [26]	Laboratory Study	Dog	1 year 5 months–2 years 3 months	8 Female	Tooth extraction site	5 mm diameter	Upper second premolar	rhBMP-2 with PGS
Klein Y *et al*. (2019) [30]	Laboratory Study	Mouse	6–7 weeks	44 Male	Tooth extraction site	Not reported	Upper first molar	BB
Klein Y *et al*. (2020) [8]	Laboratory Study	Mouse	6–7 weeks	54 Male	Tooth extraction site	Not reported	Upper first molar	AG, β-TCP
Lee KB *et al*. (2014) [32]	Laboratory Study	Dog	0.5–1 year	6 Male	Periodontal bone loss	Not reported	Upper and lower buccal bone surface	DBB (Bio-Oss), IB, SB, BCP
Li YH *et al*. (2018) [13]	Laboratory Study	Rabbit	5–6 months	30 Unspecified	Tooth extraction site	6 mm × 4 mm × 8 mm	Lower first molar	BMSCs, β-TCP
Ma Z *et al*. (2021) [14]	Laboratory Study	Dog	1.5 years	6 Male	Dehiscence-like bone defects	5 mm width, 6 mm height	Distal root of upper second premolar	DBB (Bio-Oss)
Machibya FM *et al*. (2018) [15]	Laboratory Study	Dog	18 months	6 Male	Tooth extraction site	5 mm depth, 7 mm long (mesial-distal), 5 mm wide (buccolingual)	Upper and lower first premolar	DBB (Bio-Oss), β-TCP
Mao L *et al*. (2013) [16]	Observational Study	Human	18.3 ± 4.2 years	30 Unspecified	Unilateral cleft lip and palate	Not reported	Upper canine on cleft side	AB

Moehlhenrich SC *et al*. (2021) [28]	Laboratory Study	Rat	8 weeks	21 Male	Alveolar cleft	1.7 mm diameter	Between upper first molar and anterior maxilla	AB, XHB, β-TCP, HA
Moehlhenrich SC *et al*. (2022) [11]	Laboratory Study	Rat	8 weeks	21 Male	Alveolar cleft	Not reported	Between upper first molar and anterior maxilla	AB, XHB, β-TCP, HA
Oltramari PVP *et al*. (2007) [34]	Laboratory Study	Minipig	12 months	6 Male	Tooth extraction site	Not reported	Upper and lower mesial aspect of first molar	DBB, BMP, HA
Reichert C *et al*. (2011) [29]	Clinical Case Study	Human	11.6, 13.10, 11.2 years	1 Female, 2 Male	Tooth extraction site	Not reported	Upper second premolar, upper first premolar, lower first premolar	NanoBone
Ru N *et al*. (August 2016) [19]	Laboratory Study	Rat	5 weeks	60 Male	Tooth extraction site	3 mm × 2 mm × 2 mm	Upper first molar	BCP (bone ceramic), DBB (BioOss)
Ru N *et al*. (April 2016) [18]	Laboratory Study	Rat	5 weeks	60 Male	Tooth extraction site	3 mm × 2 mm × 2 mm	Upper first molar	BCP (bone ceramic), DBB (BioOss)
Ru N *et al*. (2018) [17]	Laboratory Study	Rat	5 weeks	60 Male	Tooth extraction site	3 mm × 2 mm × 2 mm	Upper first molar	BCP (bone ceramic), DBB (BioOss)
Sun J *et al*. (2018) [20]	Laboratory Study	Rat	8 weeks	39 Male	Alveolar cleft	Not reported	Upper first molar	AB
Tanimoto K *et al*. (2015) [27]	Laboratory Study	Dog	3 months	3 Female	Alveolar cleft	5 mm width × 10 mm length	Upper third incisor	BMSCs, HA
Wang L Lei *et al*. (2017) [21]	Laboratory Study	Dog	1.5 years	2 Male	Alveolar bone imperfection	4 mm high × 3 mm wide × 3 mm deep	Upper and lower third incisor	NBCP
Yilmaz S *et al*. (2000) [36]	Clinical Case Study	Human	16 years	1 Male	Unilateral cleft and palate	Not reported	Upper anterior region	DFDBA, BG

Zhang D *et al*. (2011) [22]	Laboratory Study	Dog	24 weeks	7 Male	Alveolar cleft	10 × 5 × 15 mm	Upper third incisor	BMSCs, β-TCP, AB
Zhang FF *et al*. (2019) [23]	Laboratory Study	Rabbit	20–24 years	40 Unspecified	Tooth extraction site	6 mm × 4 mm × 8 mm	Lower first molar	BMSCs, β-TCP
Zhou J *et al*. (2018) [24]	Clinical Case Study	Human	38.4 years	7 Female, 2 Male	Vertical bone imperfection	More than one-third of root length	Upper incisor	DBB (Bio-Oss)

Abbreviations: w, weeks; m, months; y, years; M, male; F, female; Mx, maxilla; Mb, mandible; FPM, first premolar; SPM, second premolar; TPM, third premolar; FoPM, fourth premolar; FM, first molar; C, canine; TI, third incisor; I, incisor; DBB, deproteinized bovine bone; DBM, demineralized bone matrix; AB, autogenous bone; BB, bovine bone; AG, allograft; IB, irradiated bone; SB, synthetic bone; XHB, xenogenic human bone; BMP, bone morphogenetic protein; EDM, enamel matrix derivative; NBCP, nano-biphasic calcium phosphate; rhBMP-2, recombinant human bone morphogenetic protein-2; PGS, gelatin sponge complex; DFDBA, demineralized freeze-dried bone allograft; β-TCP, β-tricalcium phosphate; BG, bioactive glass; NanoBone, nanoparticulate hydroxyapatite; BCP, biphasic calcium phosphate; HA, hydroxyapatite; BioCaP, BMP2-functionalized calcium phosphate; BMSCs, bone marrow stem cells; N/R, not reported.

Study design

Of the 30 papers included, 27 were experimental in design. Additionally, there were five case reports [24, 29, 33, 36, 38] and one observational investigation [16].

Sample details

The biological models employed varied substantially. Dogs served as experimental subjects in 12 works [10, 22, 25, 26, 31, 35]. Human samples were used in seven [16, 24, 29, 33, 36–38]; rats appeared in six [11, 17–20, 28]; mice in two [8, 30]; rabbits in two [13, 22]; and minipigs in one [34].

Altogether, 581 subjects were included: 84 dogs (51 male, 15 female, 18 unspecified), 62 humans (13 male, 19 female, 30 unspecified), 261 rats (all male), 98 mice (all male), 70 rabbits (sex not provided), and 6 minipigs (all male). Details by species, sex, and age are presented in **Table 3**.

Table 3. Distribution of samples according to species, sex, and age.

Species	Canine	Human	Rat	Mouse	Rabbit	Minipig
Study Count	12	7	6	2	2	1
Sample Size (n)	84	62	261	98	70	6
Male	51	13	261	98	0	6
Female	15	19	0	0	0	0
Not Reported	18	30	0	0	70	0
Age Range	3 to 27 months	11.2 to 68 years	5 to 12 weeks	6 to 7 weeks	20 to 24 weeks	12 months

Bone defect classification

The type of bone defect varied among studies. Sixteen studies examined extraction socket grafts [8, 10, 12, 13, 15, 17–19, 23, 25, 26, 29–31, 34, 35]; seven focused on periodontal lesions [14, 21, 24, 32, 33, 37, 38]; and another seven targeted alveolar cleft conditions [11, 16, 20, 22, 27, 28, 36].

In terms of anatomical location, 21 studies assessed defects in the maxilla, 3 in the mandible [13, 23, 35], and 5 in both jaws [15, 21, 29, 32, 34]. Only a single publication did not specify the defect site [37].

Categories of grafting materials

The reviewed articles employed a broad spectrum of biomaterials for bone reconstruction, including autografts, xenografts, allografts, synthetic alloplasts, and cell-based grafts. In 17 investigations, several graft types were directly compared. Among all, 22 studies made use of alloplastic compounds [8, 10–13, 15, 17–19, 21–23, 25–29, 32, 34, 36–38]; 15 incorporated xenogenic substitutes [11, 12, 14, 15, 17–19, 24, 28, 30, 31–35]; 10 involved autogenous tissue [8, 10, 11, 13, 16, 20, 22, 24–28]; 2 relied on allografts [32, 36]; and another 2 applied stem-cell–based techniques [22, 23].

Orthodontic tooth movement (OTM) characteristics

A detailed summary of all OTM parameters is provided in **Table 4**.

Table 4. Parameters of orthodontic tooth movement.

Study Authors/Year	Site of Tooth Movement	Time Post-Surgery/Treatment	Force Characteristics	Duration of Tooth Movement	Extent of Tooth Movement
Ahn HW *et al*. (2014) [31]	Between upper canine and second premolar	Immediately, 2 w, 12 w	Mesial, 100 g, NiTi closed coil spring	6 w	1.75 to 3.44 mm
Araújo M *et al*. (2001) [35]	Between lower third premolar and first molar	3 m	Distal, 30–50 cN, Closed coil spring	2/4 w	3.85 ± 57 mm
Attia MS *et al*. (2012) [37]	Not reported	Immediately, 2 m	Not reported, 10–15 g, SS segmented arch	12 m	Not reported
Cardaropoli D *et al*. (2006) [33]	Upper central incisor	2 w	Mesial, Not reported, Segmented edgewise utility arch	4 m, 6 m, 9 m	Not reported
Fung K *et al*. (2012) [38]	Between upper central incisors	1 w post-surgery	Apical, 40 g, 014″ NiTi overlay with 017″ × 025″ SS base archwire	2 m	1 mm
Hossain M *et al*. (1996) [10]	Between upper canine and central incisor	2–4 w	Distal, Not reported, Coil spring	9–15 w	Not reported
Jiang S *et al*. (2020) [12]	Between upper second premolar and canine	Not reported	Mesial, 150 g, NiTi coil spring	8 w	DBB group: 3.59 ± 1.25 mm, BioCap group: 2.90 ± 0.84 mm
Kawamoto T *et al*. (2003) [25]	Between upper second premolar and canine	4 m	Mesial, 100 g, NiTi coil spring	2 m	2 mm
Kawamoto T *et al*. (2002) [26]	Upper second premolar ⓪	4 m	Mesial, 100 g, NiTi closed coil spring	2 m	2 mm
Klein Y *et al*. (2019) [30]	Between upper second molar and incisor	4 w	Mesial, 10 g, NiTi closed coil spring	2–3 w	550.36 ± 101.52 μm
Klein Y *et al*. (2020) [8]	Between upper second molar and incisor	4 w	Mesial, 10 g, NiTi closed coil spring	3 w	β-TCP group: 707.3 ± 30.6 μm, AG group: 648.3 ± 31.6 μm
Lee KB *et al*. (2014) [32]	Between upper/lower second premolar and third premolar	Immediately	Buccal tipping, 200 g, Closed coil spring	6 w	DBBM group: 20.81 ± 8.07°, IB group: 16.08 ± 4.14°, SB group: 27.26 ± 7.27°
Li YH *et al*. (2018) [13]	Between upper incisor and second molar	Immediately	Mesial, 80 g, NiTi tension spring	4 w	BMSCs + β-TCP group: 3.17 ± 0.26 mm, β-TCP group: 2.79 ± 0.12 mm
Ma Z *et al*. (2021) [14]	Between upper canine and first premolar	Immediately, 4 w, 8 w	Buccal, 50 g, NiTi closed coil spring	8 w	Immediate group: 2.42 mm, 9.03 ± 1.02°; 4 w group: 1.25 mm, 5.32 ± 2.19°; 8 w group: 1.62 mm, 3.24 ± 1.27°
Machibya FM *et al*. (2018) [15]	Between upper/lower canine and second premolar	1 m, 2 m	Mesial, 150 g, NiTi closed coil spring	7–8 w	Bio-Oss group: 4.22 mm, β-TCP group: 4.76 mm
Mao L *et al*. (2013) [16]	Between mandibular canine and central incisor	When canines	Mesial, Not reported, MBT bracket system, 0.022 × 0.028 inches	Not reported	Not reported

		leveled/labially			
Moehlhenrich SC *et al*. (2021) [28]	Between upper first molar and incisor	4 w	Mesial, 0.14 N, NiTi closed coil spring	8 w	Not reported
Moehlhenrich SC *et al*. (2022) [11]	Between upper first molar and incisor	4 w	Mesial, 0.14 N, NiTi closed coil spring	8 w	SB group: 0.82 ± 0.72 mm, XHB group: 0.78 ± 0.69 mm, AB group: 0.67 ± 0.27 mm
Oltramari PVP *et al*. (2007) [34]	Between upper/lower first molar and distal tooth	3 m	Mesial, 4.5 N, NiTi closed coil spring	Not reported	4 mm
Reichert C *et al*. (2011) [29]	Between upper/lower first/second premolar	6 w	Not reported, 200 g, NiTi closed coil spring	6 m, 7 m, 8 m	Not reported
Ru N *et al*. (August 2016) [19]	Between upper second molar and incisor	4 w	Mesial, 10 g, NiTi closed coil spring	28 d	BCP with less OTM than DBB
Ru N *et al*. (April 2016) [18]	Between upper second molar and incisor	4 w	Mesial, 10 g, NiTi closed coil spring	28 d	BCP with less OTM than DBB
Ru N *et al*. (2018) [17]	Between upper second molar and incisor	4 w	Mesial, 10 g, NiTi closed coil spring	28 d	BCP with less OTM than DBB
Sun J *et al*. (2018) [20]	Between upper second molar and incisor	8 w	Mesial, 100 g, Tension spring	5 d	Not reported
Tanimoto K *et al*. (2015) [27]	Between upper second incisor and canine	6 m	Distal and mesial, 100 g, Elastic chain	6 m	6 mm
Wang L Lei *et al*. (2017) [21]	Between upper/lower third incisor and canine	24 w	Labial, 100 g, Australian wire 0.016 inches	2 w	Not reported
Yilmaz S *et al*. (2000) [36]	Between upper lateral incisor and canine	6 m	Mesial tip, Not reported, Uprighting spring and Z band	32 m	Not reported
Zhang D *et al*. (2011) [22]	Between upper lateral incisor and canine	8 w	Distal, 50 g, NiTi closed coil spring	12 w	bMSCs/β-TCP: 5.345 ± 0.936 mm, β-TCP: 6.986 ± 1.412 mm, AB: 4.665 ± 0.483 mm
Zhang FF *et al*. (2019) [23]	Between lower second molar and first premolar	2 w, 4 w, 8 w, 12 w	Mesial, 80 g, NiTi tension spring	4 w	0.97 ± 0.18 mm (2 w), 1.03 ± 0.15 mm (4 w), 1.69 ± 0.16 mm (8 w), 1.11 ± 0.17 mm (12 w)
Zhou J *et al*. (2018) [24]	Upper incisor	3 m	Apical, 15 g, Segmented arch	11.3 m	Not reported

Abbreviations: Mx = maxillar; Mb = mandibular; FPM = first premolar; SPM = second premolar; TPM = third premolar; FM = first molar; SM = second molar; CI = central incisor; LI = lateral incisor; I = incisor; C = canine; w = weeks; m = months; NiTi = nickel-titanium; SS = stainless steel; N = newton; OTM = orthodontic tooth movement; β-TCP = β-tricalcium phosphate; AB = autogenic bone; AG = allograft; BCP = biphasic calcium phosphate; DBB = deproteinized bovine bone; XHB = xenogenic human bone; SB = synthetic bone; BMSCs = bone-marrow stem cells; N/R = not reported.

- *Site of tooth displacement*

Most experiments assessed movement in the maxilla (n = 30). In four of them, the mandible was studied concurrently with the upper jaw [15, 21, 32, 34]. Typically, the canine served as the anchorage element (n = 12), while the premolar acted as the moved tooth (n = 10).

- *Initiation time of orthodontic force*

The onset of mechanical activation after grafting varied substantially, ranging from immediate loading to six months post-surgery. Specifically, forces were introduced right after grafting in five studies [13, 14, 31, 32, 37]; one week later in one [38]; and two weeks later in three [10,

23, 31]. Eleven reports initiated treatment after one month [8, 10, 11, 14, 15, 17–19, 23, 28, 30]; one began at two weeks [29]; six at two months [14, 15, 20, 22, 23, 37]; five at three months [23, 24, 31, 34, 35]; two at four months [25, 26]; and three at six months [21, 27, 36]. Five investigations assessed multiple starting intervals (two to four) [14, 15, 23, 31, 37]. In two others, timing was unspecified [12, 16].

- *Direction of the applied force*

Force vectors varied with the intended tooth trajectory into the grafted segment. Mesially directed forces predominated, documented in 20 publications [8, 11–13, 15–20, 23, 25–28, 30, 31, 33, 34, 36]. Distal movement was described in 4 cases [10, 22, 27, 35]; apical movement in 2 [24, 38]; and buccal translation in 3 [14, 21, 32]. Direction was not stated in two studies [29, 37].

- *Magnitude of applied force*

The intensity of the orthodontic load spanned from 10 g to 458.87 g (≈ 4.5 N). Most authors favored a 100 g force [20, 21, 25–27, 31], while several opted for a 10 g force [8, 17, 19, 30]. Four publications did not specify the exact value [10, 16, 33, 36].

- *Technique of force delivery*

Tooth movement was achieved by different mechanical systems. The closed-coil spring was the predominant approach, employed in 23 articles [8, 10–20, 22, 23, 25, 26, 28–32, 34–36]. A continuous arch configuration appeared in three reports [16, 21, 38]; another three utilized segmented mechanics [24, 33, 37]; and one relied on an elastic chain [27].

- *Overall treatment duration*

Reported treatment periods varied greatly—from five days to thirty-two months. In animal models, active movement lasted 5 days–6 months [8, 10, 11, 13, 17–20, 22, 25, 26, 28, 30, 31, 34, 35]. In human subjects [24, 29, 33, 36, 37], durations commonly exceeded six months, with the longest follow-up reaching 32 months.

Periodontal biological responses and analytical procedures

Observations regarding the biological impact on the periodontal complex, together with the methods employed for assessment, are compiled in **Table 5**.

Table 5. Biological responses within the periodontium.

Study Authors/Year	Bone Dynamics	Attachment Level Changes	Root Condition	Pocket Depth Changes	Evaluation Techniques
Ahn HW *et al*. (2014) [31]	Promoted bone growth	Not documented	Not documented	Not documented	Tissue analysis, Micro CT
Araújo M *et al*. (2001) [35]	Enhanced bone development	Not documented	Mild root degradation	Not documented	Tissue analysis
Attia MS *et al*. (2012) [37]	Advanced bone regeneration	Improved attachment	Not documented	Not documented	Clinical evaluations, X-ray imaging
Cardaropoli D *et al*. (2006) [33]	Boosted bone formation	Strengthened CAL	Not documented	Lowered PPD	Clinical evaluations, X-ray imaging
Fung K *et al*. (2012) [38]	Increased bone regeneration	Enhanced CAL	No root degradation	Reduced PPD	Clinical evaluations, X-ray imaging
Hossain M *et al*. (1996) [10]	Strengthened bone growth	Improved PDL fiber connections	Slight root degradation	Not documented	Tissue analysis, X-ray imaging
Jiang S *et al*. (2020) [12]	Elevated bone formation	Not documented	Higher root degradation in BioCap group	Elevated PPD	CBCT, Clinical evaluations, Tissue analysis
Kawamoto T *et al*. (2003) [25]	Enhanced bone growth	Not documented	Some cementum degradation	Not documented	Tissue analysis, Tissue morphometry
Kawamoto T *et al*. (2002) [26]	Increased bone development	Not documented	Minimal cementum degradation	Not documented	Tissue analysis, Tissue morphometry
Klein Y *et al*. (2019) [30]	Promoted bone regeneration	Not documented	Not documented	Not documented	Tissue analysis, Micro CT
Klein Y *et al*. (2020) [8]	Advanced bone formation	Not documented	Not documented	Not documented	Tissue analysis, Micro CT

Lee KB *et al*. (2014) [32]	Boosted bone development	Not documented	Some cementum degradation	Increased PD	Clinical evaluations, Tissue analysis
Li YH *et al*. (2018) [13]	Enhanced bone growth (BMSCs + β-TCP outperforms β-TCP)	Not documented	No root degradation	Not documented	Tissue analysis
Ma Z *et al*. (2021) [14]	Increased bone regeneration	Not documented	Not documented	Not documented	Fluorescent imaging, Immunostaining, Tissue analysis, Tissue morphometry, Micro CT
Machibya FM *et al*. (2018) [15]	Strengthened bone formation	Not documented	Not documented	Not documented	Clinical evaluations, CT imaging
Mao L *et al*. (2013) [16]	Reduced bone growth in <25% of cases	Not documented	Minor root degradation	Not documented	Clinical evaluations, X-ray imaging
Moehlhenrich SC *et al*. (2021) [28]	Elevated bone formation (XHB highest, SB lowest)	Not documented	Not documented	Not documented	Tissue analysis, Micro CT
Moehlhenrich SC *et al*. (2022) [11]	Not documented	Not documented	Root degradation in all groups	Not documented	Tissue analysis, Micro CT
Oltramari PVP *et al*. (2007) [34]	Balanced bone loss and growth	Not documented	Minor root degradation	Not documented	Tissue analysis, Tissue morphometry
Reichert C *et al*. (2011) [29]	Not documented	Not documented	No root degradation	Not documented	Clinical evaluations, X-ray imaging
Ru N *et al*. (August 2016) [19]	BCP with greater bone growth than DBB	Not documented	Not documented	Not documented	Structural analysis, Micro CT, Nanoindentation
Ru N *et al*. (April 2016) [18]	BCP with greater bone growth than DBB	Not documented	BCP with reduced root degradation vs. DBB	Not documented	Structural analysis, Micro CT, Nanoindentation
Ru N *et al*. (2018) [17]	BCP with greater bone growth than DBB	Not documented	BCP with reduced root degradation vs. DBB	Not documented	CT imaging, Structural analysis, Tissue analysis, Micro CT, Nanoindentation
Sun J *et al*. (2018) [20]	Promoted bone formation	Not documented	Not documented	Not documented	Tissue analysis, Molecular analysis
Tanimoto K *et al*. (2015) [27]	Enhanced bone growth	Not documented	No root degradation	Not documented	Tissue analysis, X-ray imaging
Wang L Lei *et al*. (2017) [21]	No difference between new and normal periodontal tissue	No difference between new and normal periodontal tissue	No difference between new and normal periodontal tissue	No difference between new and normal periodontal tissue	Tissue analysis

Yilmaz S *et al*. (2000) [36]	Increased bone regeneration	No gingival recession	No root degradation	Not documented	Clinical evaluations, X-ray imaging
Zhang D *et al*. (2011) [22]	Elevated bone formation (BMSCs/β-TCP > β-TCP)	Not documented	Not documented	Not documented	Fluorescent imaging, Tissue analysis, X-ray imaging
Zhang FF *et al*. (2019) [23]	Not documented	Not documented	Not documented	Not documented	Tissue analysis
Zhou J *et al*. (2018) [24]	Strengthened bone formation	Strengthened CAL	Not documented	Lowered PPD	Clinical evaluations, X-ray imaging

Abbreviations: BF = bone formation; BR = bone resorption; CAL = clinical attachment level; PPD = probing pocket depth; RR = root resorption; β-TCP = β-tricalcium phosphate; BCP = biphasic calcium phosphate; DBB = deproteinized bovine bone; SB = synthetic bone; XHB = xenogenic human bone; BMSCs = bone-marrow stem cells; histo = histology; histom = histomorphometry; Rx examination = radiographic examination; microCT = micro-computed tomography; CT = computed tomography; CBCT = cone-beam computed tomography; fm = fluorescence microscopy; ic = immunohistochemistry; FE = finite element; ni = nanoindentation; PCR = polymerase chain reaction; N/R = not reported.

- *Bone response*

Across 24 studies, findings predominantly demonstrated enhanced bone formation in the grafted regions compared to control sites, following an initial phase of bone turnover. Among these, five investigations directly compared different grafting materials. In Ru's three papers [17–19], synthetic grafts showed superior regeneration relative to xenogenic substitutes. Conversely, Moehlhenrich (2021) [28] observed greater bone deposition with xenogeneic and autologous grafts than with synthetic ones. Two independent studies [13, 22] also noted that combining bone marrow stromal cells (BMSCs) with β-tricalcium phosphate (β-TCP) produced a more pronounced regenerative effect than β-TCP alone. A single article [34] stated that bone formation and resorption were balanced. In three reports [11, 23, 29], bone-level data were absent, and one study [21] did not address the post-grafting bone response.

- *Clinical attachment level (CAL)*

Most publications lacked data concerning changes in CAL during tooth movement. Only five studies [10, 24, 33, 37, 38] reported an increase in attachment level in the treated area [90.91].

- *Probing pocket depth (PPD)*

Data regarding PPD were also infrequently presented. Five studies [12, 24, 33, 37, 38] documented a reduction in pocket depth, whereas Lee's investigation [32] found an increase.

- *Root integrity / resorption*

Evidence of root resorption associated with orthodontic movement in grafted bone regions appeared in nine studies, with varying intensity. Seven papers described mild or partial resorption [10, 16, 25, 26, 32, 34, 35], while one reported more extensive damage [11]. Five studies [13, 27, 29, 36, 38] observed no resorption. Three investigations suggested that synthetic grafts caused less root resorption than xenogenic materials. No related data were included in 13 other studies.

- *Analytical techniques*

The most common evaluation approaches were histological and histomorphometric assessments. Clinical examinations were performed in nine articles [12, 15, 16, 29, 32, 33, 36, 37, 38]. Conventional radiography was used in eight [10, 16, 22, 27, 29, 36–38]. For three-dimensional imaging, micro-CT was used in nine studies [8, 11, 14, 17, 19, 28, 30, 31], while cone-beam CT (CBCT) [11] and standard CT [15] were also employed. A few works incorporated complementary techniques such as fluorescence microscopy [14, 23], immunohistochemistry [14], PCR analysis [20], and finite element modeling [17, 18, 19].

This review explores the biological responses of the periodontium to orthodontic tooth movement (OTM) within regenerated bone defects, focusing on bone remodeling, attachment level, pocket depth, and root resorption. These outcomes are affected by numerous variables — including defect type, size, and location; graft composition; force timing and magnitude; and overall treatment period.

Bone tissue possesses an inherent capacity for self-repair [39]; however, when the defect surpasses a certain threshold — a critical-size defect — spontaneous regeneration does not occur [40]. Accordingly, the ideal defect model is one that heals only upon graft placement [41]. Only three investigations [23, 25, 26] clearly defined their experimental defects as critical-sized and included empty control sites to verify the absence of spontaneous repair. While a two-walled defect may best simulate an authentic osteotomy gap, stabilizing the graft material in such models presents significant technical challenges [31].

Among the included literature, extraction sockets (predominantly in the maxilla) were the most frequently studied defect type. Variations in bone density between the maxillary and mandibular arches, and even between

anterior and posterior regions of the same bone, complicate direct interstudy comparisons [42].

Another factor strongly influencing periodontal outcomes during OTM is the graft material type [12, 31, 37, 43]. The resorption behavior of each graft largely depends on its chemical and structural composition [44]. Despite numerous alternatives, autogenous bone grafts remain the benchmark, as they uniquely combine osteoconductive, osteogenic, and osteoinductive properties essential for new bone formation [45].

This type of graft, however, presents several clinical drawbacks since it involves harvesting bone from another site, which may result in complications such as postoperative discomfort, infection risk, and scar formation [46]. The frequent preference for alloplastic grafts observed in most studies within this review stems from their advantageous properties—biological and volumetric stability, osteoconductive potential, biodegradability, absorbability, and lack of infectious transmission [47].

In a comparative investigation by Hossain [10], tricalcium phosphate displayed greater adaptive remodeling and biodegradation under orthodontic loading than particulate marrow and cancellous bone (PMCB). Within calcium phosphate-based ceramics, the rate of resorption is determined by the calcium-to-phosphate (Ca/P) ratio [21]. A reduced Ca/P ratio in β-tricalcium phosphate [48], relative to hydroxyapatite, accelerates its dissolution and absorption [49]. Although alloplastic substitutes appear promising, the inconsistency among studies prevents a definitive conclusion. Moehlhenrich [11] observed no significant difference among autogenous, xenogenic, or synthetic grafts used for alveolar cleft repair regarding orthodontic tooth movement or the extent of root resorption [50, 51].

Once the graft type was established, protocols varied concerning the initiation of orthodontic loading. Force application ranged from immediately post-surgery to six months thereafter. Some researchers propose delaying movement until 8–12 weeks post-regeneration for adequate bone consolidation [52, 53]. While most studies initiated forces after four weeks to minimize root resorption associated with incomplete material degradation [54], others suggested that earlier loading may enhance periodontal regeneration and mitigate movement inhibition [31].

The magnitude of orthodontic forces also differed considerably, likely reflecting insufficient scientific consensus on optimal force levels for clinical effectiveness [55]. It was consistently noted that heavy, sustained forces increase risks of uncontrolled tipping, hyalinization, and root resorption [56]. Nickel–titanium coil springs generate light, consistent forces without the rapid decay typical of elastic chains, and unlike stainless-steel springs, they avoid abrupt, high-intensity tensile stress [57].

Across studies, orthodontic movement within grafted bone areas facilitated bone remodeling involving sequential resorption and deposition processes [20]. This phenomenon depends on multinucleated cells responsible for graft material turnover and replacement [58]. Despite using diverse biomaterials, all reports noted an initial bone turnover phase in the grafted region. Moehlhenrich [28] found that autografts and xenografts produced greater bone formation than alloplastic substitutes, attributed to their particle porosity and geometry that enhance cellular and vascular ingrowth [59].

Nevertheless, many other studies within this review reported the opposite—favoring ceramic substitutes for their superior regenerative properties, particularly when combined with bone marrow mesenchymal stem cells (BMSCs) [13, 27]. Rokn's comparative analysis [55] revealed no statistically significant differences in osteogenesis between xenogeneic and alloplastic grafts [60, 61].

It was more challenging to assess how orthodontic movement influenced clinical attachment level (CAL) and probing pocket depth (PPD), as few studies investigated these aspects. Those that did consistently reported improved attachment levels and reduced probing depth, likely due to the release of calcium and phosphate ions enhancing osteogenic and cementogenic activity [62]. Cementogenesis was followed by reorganization of the periodontal ligament between the newly formed cementum and bone surrounding graft granules, a process stimulated by the graft material itself [10].

Root resorption remains another critical concern during orthodontic treatment involving bone grafts. The reviewed literature showed variable levels of resorption across studies. Ru's investigations [17, 18] used 3D analyses to demonstrate that resorption sites did not always correspond to regions of highest stress but rather to root surfaces experiencing stress concentration relative to their area, with smaller surfaces showing deeper craters. Moreover, ceramic grafts produced less root resorption than xenografts, helping preserve the surrounding tissues [12, 17, 18].

Some reports suggested that increased cementum erosion could be influenced by two primary factors: the presence of bone morphogenetic protein-2 (BMP2) in alloplastic calcium phosphate grafts [25, 26] and the immunogenic potential of the graft material. Xenografts, by eliciting a stronger osteoclastic response, tend to produce more extensive rhizolysis compared to ceramic-based substitutes [63].

The reviewed studies employed a range of analytical approaches to examine periodontal structural alterations induced by orthodontic forces. The most commonly used methods were histological and histomorphometric evaluations, which Kulak CA *et al*. (2010) [64] referred to as the "gold standard." Histomorphometry is applied to measure the proportions of newly generated bone and

residual graft material, while histology allows for visualizing new bone matrix formation. Although highly informative, these procedures have inherent drawbacks—they are time-intensive, destructive, and provide only two-dimensional representations of tissue [65].

For this reason, numerous studies included in this review [8, 11, 12, 14, 15, 17, 19, 28, 30, 31] adopted three-dimensional imaging tools such as CBCT, micro-CT, and CT. As indicated by Vandewergh *et al*. [66], these modalities deliver precise, non-destructive visualization of bone microarchitecture with excellent spatial resolution. However, despite these advantages, 3D imaging remains limited in differentiating between mature mineralized bone and recently formed tissue, thereby necessitating supplementary analyses such as histology and histomorphometry [67]. Other adjunctive methods—fluorescence microscopy, immunohistochemistry, PCR, and finite element modeling—were used to enhance understanding. The first three elucidated molecular and cellular mechanisms influencing tooth movement [68], whereas finite element analysis helped quantify stress and force distribution at the root level [17–19].

Although this scoping review integrates a broad selection of publications, it carries notable limitations. Several potentially relevant studies were excluded because they either failed to specify the graft material used or omitted descriptions of periodontal outcomes following orthodontic treatment. Considerable heterogeneity was also evident across the included research due to differences in methodology and the lack of standardized parameters such as animal species, bone defect type and dimensions, and timing of orthodontic force application after grafting. Human studies, in particular, were weakly designed, consisting predominantly of case reports with minimal evidentiary strength. Even the periodontal structures—defined as the tooth-supporting apparatus [69]—were incompletely analyzed, as most research concentrated on bone response while neglecting tissues such as the gingiva, periodontal ligament, and cementum. It must be noted that this scoping review aims to descriptively summarize existing findings rather than critically evaluate or synthesize them as a systematic review would [70-75].

Future investigations should seek to strengthen methodological rigor by refining specific study parameters. These include prioritizing animal species with anatomical and physiological resemblance to humans to accurately model bone defects, ensuring uniformity in defect dimensions, directly comparing distinct categories of graft materials, applying light and consistent orthodontic forces, and conducting long-term evaluations (at least six months). Furthermore, comprehensive assessments of the entire periodontium—using histological, histomorphometric, and 3D analyses, combined with clinical periodontal evaluation—should be prioritized. Human-based studies, particularly those involving patients with cleft palate or periodontal regeneration undergoing orthodontic treatment, must also be expanded and methodologically enhanced to yield more robust scientific evidence.

Conclusion

Orthodontic tooth movement within regenerated bone areas generally produced favorable biological outcomes for periodontal tissues. Nearly all studies observed enhanced bone formation and improved clinical attachment levels regardless of graft type, timing, or applied force magnitude. While root resorption appeared frequently as a side effect, it did not seem to compromise tooth viability. Nonetheless, these observations should be interpreted with caution, emphasizing the necessity for future preclinical and clinical trials with optimized designs to establish stronger evidence regarding periodontal regeneration.

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