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Dentin-derived alveolar bone graft for alveolar augmentation: A systematic review

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ABSTRACT

Introduction: Application of alveolar bone graft (ABG) in alveolar augmentation is done to prevent excessive bone resorption due to tooth extraction, missing teeth, or other diseases/conditions affecting the alveolar bone. The use of autogenous dentin-derived ABG has been considered as the composition of dentin appears to be nearly analogous to that of bone.

Objective: This systematic review aims to assess the efficacy of dentin-derived ABG for alveolar augmentation of post-extraction sockets or other alveolar bone defects by evaluating volume gain and histomorphometric data.

Material and methods: A search of systematic literature was conducted in Pubmed, Scopus, Web of Science, and Embase from database inception to October 2023. The review included both randomized controlled trials (RCT), pilot studies, clinical trials, and retrospective studies reporting on dentin-derived ABG use for alveolar augmentation.

Results: Overall, 298 articles were obtained from the initial search. From these articles, 21 articles met the inclusion criteria and were included for descriptive analysis. All of the studies indicated low risk of bias. Studies of dentin-derived ABG, which used bone-derived grafts as the control group, have shown significantly higher percentages of new bone formation, gain in vertical and horizontal dimensions, and less reduction in dimensions.

Conclusions: Dentin-derived ABG was effective in volume maintenance, indicating promising results via histomorphometric and radiographic analysis.

1. Introduction

In the initial year after a tooth is removed, the alveolar ridge experiences a sequence of healing mechanisms, leading to a noticeable change in its size. This change may entail a reduction in both width and height.[1,2] Changes of width and height of the alveolar ridge are in accordance with an unavoidable horizontal and vertical bone resorption that may compromise the esthetic and functional value of dental prostheses, including implants.[3] Meanwhile, adequate bone mass is a crucial requisite for the surrounding soft tissue to remain stable and in its proper shape and for obtaining successful osseointegration.[4,5] Various techniques and methods have been proposed to preserve and maintain the alveolar ridge volume, including but not limited to, alveolar augmentation by the application of alveolar bone graft.

Alveolar augmentation is a surgical technique undertaken to prepare the alveolar ridge for receiving and retaining a dental prosthesis by improving its shape and size. The procedure might affect only a small area, as in socket grafting, or it may involve a large part of the ridge or the entire ridge itself. It can help refabricate the natural shape of the ridge after the removal of one or more teeth or after bone loss or resorption, thereby helping secure dental prosthesis and restore esthetics. According to reports, socket grafting has been shown to reduce

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the changes that occur in the alveolar bone after a tooth extraction.[3,6]

There is a wide range of biomaterials used in alveolar augmentation, including xenografts, allografts, autografts, bioactive materials, and alloplastic materials such as bioactive glass, which have been shown to achieve sufficient bone mass for treating post-extraction alveolar bone defect.[3,7–11] Utilizing autogenous bone for alveolar augmentation is regarded as the ideal choice and is widely recognized as the gold standard. Its effectiveness has been extensively demonstrated, particularly when in the form of a bone block, achieving success rates exceeding 95 %. This holds true even in cases where significant augmentation is required for highly resorbed jaws.[12] Regardless of the osteogenic, osteoinductive, and osteoconductive properties of autogenous bone, this material also possesses several drawbacks, including donor site restriction and morbidity, limited bone availability, increased trauma and risk of infection, slow recovery, and unpredictable bone resorption.[4,12] On the other hand, allogenic and xenogenic bone also have disadvantages, such as immune rejection, infection, and high cost.[3]

The use of autogenous dentin-derived alveolar bone graft (ABG) from extracted teeth in alveolar augmentation procedures has been reported in recent years.[13] The significance of this graft material lies in its relevance to tooth extraction, which is a highly common surgical procedure in dentistry. Traditionally, the teeth that were extracted were seen as discarded materials; therefore, ability to reuse extracted teeth would be an advantageous step towards the widely-accepted concept of Green Economy within the United Nations Sustainable Development Goals (SDGs).[1,14,15] Dentin is classified as a mineralized connective tissue that shares a similar composition to bone. Specifically, it consists of approximately 90 % hydroxyapatite and collagen type I, which are the primary constituents of its organic matrix. The remaining non-collagenous proteins in dentin consist of osteopontin, osteocalcin, dentin matrix protein 1, as well as various growth factors such as transforming growth factor-beta, insulin-like growth factor-II, and bone morphogenetic protein-2.[12,13] These dentin components are pivotal for healing of the alveolar socket's soft and hard tissues owing to their involvement in the mineralization and bone formation processes.

Fig. 1 indicates the possible bone remodeling mechanism when dentin-derived ABG is employed in a tissue engineering approach for alveolar augmentation processes. Several previous studies, both in vivo and human clinical trials, have demonstrated that dentin-derived ABG is well-tolerated when used to fill ridge defects and to preserve post-extraction sockets; thus, this material is expected to provide clinically beneficial results following an alveolar augmentation procedure.[16–19] Hence, This systematic review was carried out to assess the available clinical evidence regarding the effectiveness of dentin-derived ABG in alveolar augmentation procedures, specifically focusing on post-extraction sockets and other defects in the alveolar bone. The reporting is based on the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) 2020 checklist.[20]

2. Material and methods

2.1. Focused question

In order to conduct the literature search, a focused question was formulated: "What is the effectiveness of dentin-derived ABG as a bone substitute material used for alveolar augmentation when evaluated by radiograph examination and histomorphometric analyses?"

2.2. Search strategies

A systematic review protocol based on the PRISMA extension for protocols (PRISMA-P) was drafted.[20] The following electronic databases were used as search engines: PubMed (https://pubmed.ncbi.nlm.nih.gov accessed on September 15, 2023), Scopus (https://www.scopus.

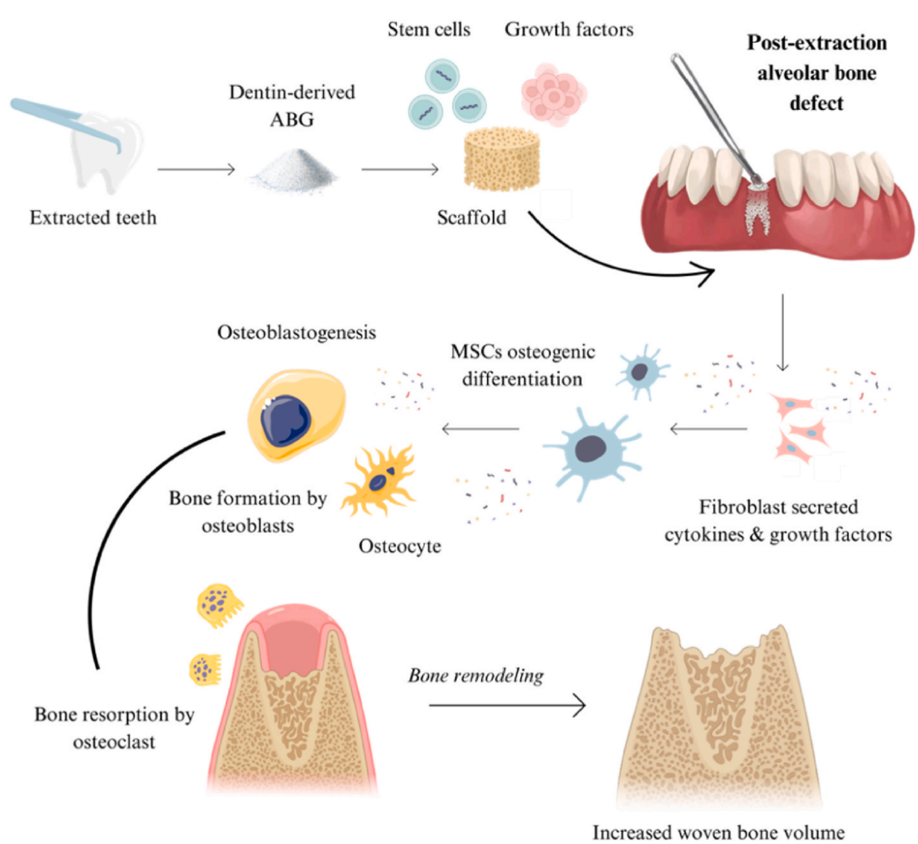

Fig. 1. Illustration of the possible bone remodeling mechanism during an alveolar augmentation procedure using dentin-derived ABG (image created with Canva (https://www.canva.com accessed on October 15, 2023)).

com accessed on September 22, 2023), Web of Science (https://www.webofscience.com accessed on September 22, 2023), and Embase (https://www.embase.com accessed on September 28, 2023). To obtain a thorough, relevant, and focussed search, the PubMed search process included keywords such as dentin, bone graft, and alveolar augmentation and its synonyms along with truncations, Boolean operators, and filters; this search strategy was replicated in the other databases (Table 1).

Furthermore, manual searches were conducted to support the electronic searches. The literature search took place between September 2023 and October 2023. The systematic review was registered on the international platform for registering systematic reviews and meta-analysis protocols (INPLASY) and assigned the registration number INPLASY2023120109.

2.3. Eligibility criteria

The inclusion criteria for the studies were as follows: full-text original articles focusing on the methodology of using dentin-derived ABG as a bone substitute material for alveolar augmentation in human socket or alveolar bone defects; all types of experimental and observational studies conducted in English on adult participants of any gender or age; the inclusion of autologous/autogenous, mineralized/demineralized/unmineralized dentin grafts, either alone or in combination, as well as additional therapies involving tissue engineering and guided bone regeneration using dentin-derived materials. The research outcomes considered included assessment of bone volume through gross examination, radiographic analysis, and histomorphometric analysis. There were no restrictions on the year of publication.

The following types of articles were excluded from the analysis: articles written in languages other than English, reviews, short communications, processes, editorial notes, expert opinions, or recommendations; animal studies, in vitro studies, and ex vivo studies were also excluded. Additionally, no duplicate studies were included in the analysis.

2.4. Study selection and data extraction

Two reviewers (D.A.M, K.B) conducted the electronic literature searches and selected the studies independently. Any disagreements were resolved by discussion with a second set of reviewers (N.H, A.P.N). The primary reviewers (D.A.M, K.B) worked to duplicate screening, extract, and recapitulate data using Mendeley Reference Manager. The data extraction process included taking information from the titles and abstracts of articles that matched the topic and its keywords, primarily using the PICO protocol (Participants: humans; Intervention: dentin-derived ABG with or without modification and combination; Controls: xenograft, autograft, allograft, left without treatment, or other regenerative materials; Outcomes: alveolar bone augmentation or socket preservation). Data relevant to methodology, sample size, duration of the studies, and the investigations carried out were further extracted from each study.

Table 1
Databases and search strategies.

Databases	Search Strategy
PubMed	((dentin*) AND ((graft*) OR (bone graft*))) AND ((((alveolar) OR (alveolar ridge)) OR (alveolar bone)) AND (((augmentation) OR (preservation)) OR (formation))) Filters applied: English, Exclude preprints.
Scopus	TITLE-ABS-KEY (((dentin*) AND (graft* OR bone AND graft*)) AND ((alveolar OR alveolar AND ridge OR alveolar AND bone) AND (augmentation OR preservation OR formation))) AND (LIMIT-TO (LANGUAGE, "English"))
Web of Science	ALL=((((dentin*) AND (graft* OR bone AND graft*)) AND ((alveolar OR alveolar AND ridge OR alveolar AND bone) AND (augmentation OR preservation OR formation)))) and English (Languages) and Review Article (Exclude – Document Types)
Embase	((dentin* AND (graft* OR (bone AND graft*))) AND ((alveolar OR alveolar AND ridge OR alveolar AND bone) AND (augmentation OR preservation OR formation)))

2.5. Quality assessment of studies

Depending on the study type, each study was assessed individually and independently by the investigators. For the quality assessment of randomized clinical trials, the Consolidated Standards of Reporting Trials (CONSORT) guidelines were utilized.[21] In the case of any disagreements, the investigators resolved them through discussion.

2.6. Risk-of-bias assessment

The risk of bias assessment was conducted using a method adapted from previous systematic reviews.[22] This assessment evaluated several quality assessment criteria, including a well-defined dentin-derived ABG process, standardized sample or subject preparation, randomization of samples or subjects, tests conducted through a blinded method, clear test method specifications, and comprehensive reporting of results. Each parameter in the articles was labeled as "Y" if reported or "N" if not reported. Based on the number of "Y" elements present, articles were categorized as having a high, medium, or low risk of bias (1–2, 3–4, or 5–6, respectively).[23]

2.7. Statistical methods

Descriptive statistics were used in this study, which had been validated prior to use. Data analyses were carries out using Microsoft Excel (2021, Microsoft, Chicago, IL, USA).

3. Results

3.1. Study selection, data extraction, and quality assessment

The electronic search generated 298 articles (PubMed, 73 articles; Scopus, 81; Web of Science, 70; and Embase, 74). Among these, 256 articles were removed following duplicate screening and title and abstract reading. Thus, full-text versions of 42 articles were assessed for eligibility. From these, 21 articles were found to match the eligibility criteria. Fig. 2 presents a flow chart of the selection process. The descriptive characteristics of the papers included in the study is presented in Table 2.

3.2. Assessment of the risk of bias and study quality

All of the 21 studies included in this systematic review had a low risk of bias. Ten studies did not report on randomization, which is considered a potential source of bias (Table 3).

3.3. Qualitative analysis

The clinical illustrative studies were selected using some criteria (Fig. 2), with the most common study designs included in this systematic review being randomized clinical trials (RCTs). However, given that there is not much data on this subject, it was challenging to focus this review solely on RCTs. In addition to that, there are a number of articles available that discuss the same topic with different combinations and techniques, which could affect the properties of grafting materials, and this could potentially answer the focused question of this review; thus in addition to 11 RCTs, we included four pilot studies,[29,31,33,36] five clinical trials or prospective studies,[1,4,7,24,30] and one retrospective study.[34] Most clinical setting studies of alveolar augmentation using dentin-derived ABG focused on post-extraction socket sites; only one study used severe periodontally compromised sockets in molars, and

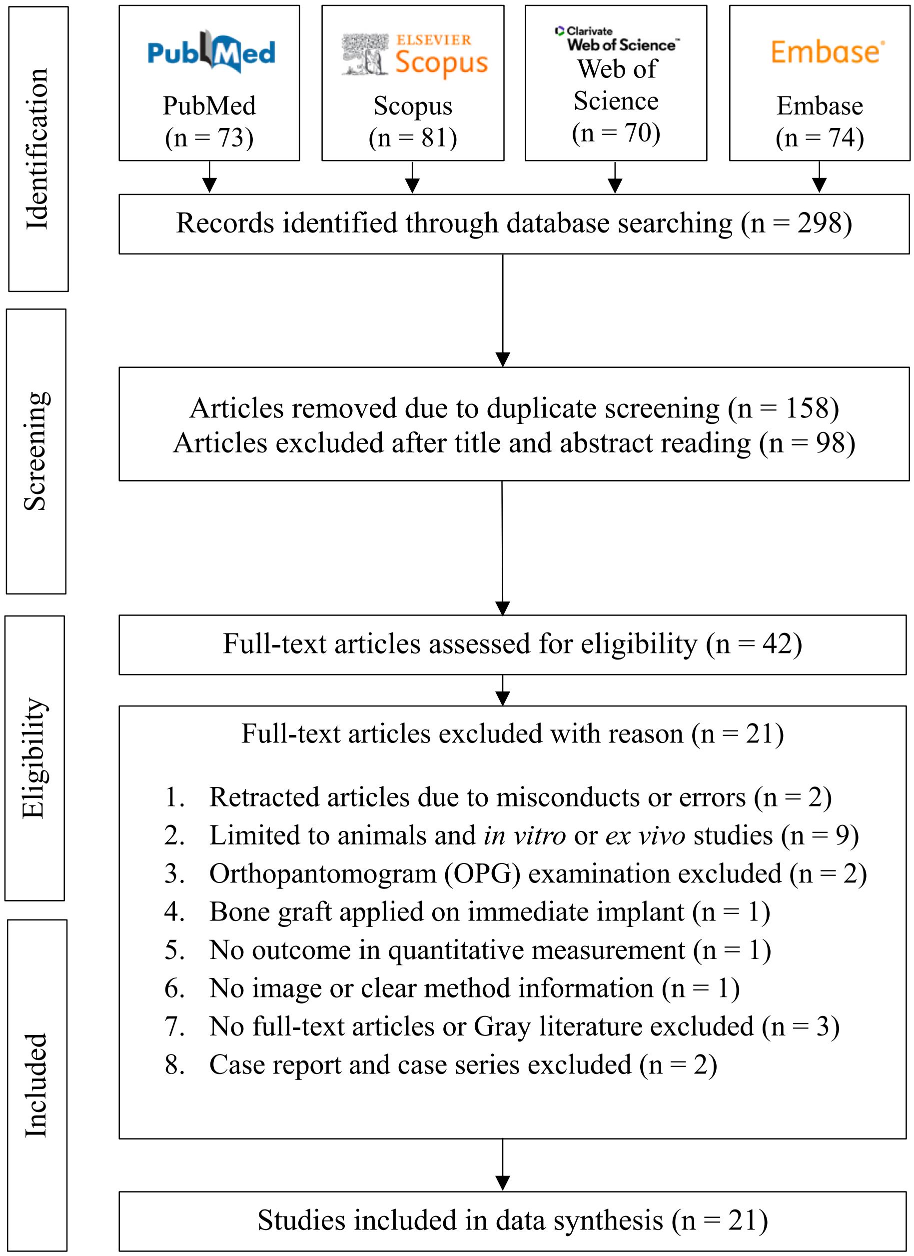

Fig. 2. A flow chart adapted from the PRISMA 2020 guideline, showing the literature search process used in this systematic review.

three studies used alveolar bone defects from edentulous sites.[1,12,26,29]

In an RCT, Santos et al. (2021) used autogenous mineralized dentin matrix (MDM) in 26 patients. This study concluded that there was a significantly higher quantity of newly formed bone and a lower amount of residual graft compared to *Bio-Oss*®, which is a widely-used biomaterial in alveolar augmentation or preservation procedure.[5] Furthermore, almost entirely other studies of dentin-derived ABG, which used a conformable bone-derived graft from various sources (e.g., inorganic bovine bone, autogenous bone, freeze-dried allograft, deproteinized bovine) as control groups, showed a considerably higher percentage of new bone formation, vertical and horizontal bone gain, and also a lower percentage of remaining residual grafts, soft tissue component, vertical and horizontal reduction or resorption.[3,12,25,29,35] Oguic et al. (2023) observed the highest percentage of newly formed bone in that category, with an overall mean (± standard deviation) for the test group being 72.55 % ± 12.14 %, evaluated four months after autogenous dentin graft and bovine xenograft mixed with autologous bone placement on post extraction socket sites of 37 patients.[35] The second highest percentage of newly formed bone was observed by Sapoznikov et al. (2023), with an overall mean of 60.75 % ± 18.22 % in the same observation period as the Oguic et al. (2023) study, but using a different source of dentin (porcine dentin-derived bone graft, Ivory Dentin Graft).[25] However, only one out of eight studies in the categories above showed a contradictory result of autogenous demineralized dentin matrix (AutoBT) compared to *Bio-Oss*® in alveolar augmentation procedure where AutoBT exhibited a smaller percentage of new bone formation with the overall mean of 31.24 % ± 13.87 %; meanwhile, the overall mean for *Bio-Oss*® was 35.00 % ± 19.33 %, while the soft tissue component was also higher in the AutoBT arm compared to *Bio-Oss*®.[27]

In terms of added combination materials or different application techniques to autogenous dentin graft, there were six corresponding articles, including one study that used the socket shield technique,[28] one study that used a combination of deproteinized bovine bone,[29] three studies that used chopped leukocyte-PRF membrane,[31,32,34] and one study that used dentin matrix in combination with human BMP-2.[3] One out of three studies that used PRF membrane as an addition to dentin

Table 2
Summary of the descriptive characteristics of the articles included in the systematic review.

Authors, Year, Country	Study Design	Subject Criteria	Type of Defect (n)	Type of Alveolar Augmentation Materials	Examination and Variables	Outcome (Mean ± SD)	Conclusion
Santos et al., 2021; Portugal[5]	Randomized clinical trial; single-blinded	52 patients (21 males and 31 females; 28–88 years)	Post extraction socket site (n = 66)	Autogenous mineralized dentin matrix (MDM); Xenograft granules (BioOss), both covered with a resorbable barrier membrane	Histomorphometry: newly formed bone (%); residual grafted bone (%); soft tissue component (%)	Newly formed bone: 47.3 ± 14.8 (MDM); 34.9 ± 13.2 (BioOss)Residual grafted bone: 12.2 ± 7.7 (MDM); 22.1 ± 10.9 (BioOss)Soft tissue: 40.5 ± 17.6 (MDM); 42.9 ± 9.6 (BioOss)	Implants placed in sites preserved with MDM had similar primary stability with the xenograft granules group due to a higher bone formation rate.
Artzi et al., 2022; Israel[24]	Clinical trial	15 patients (8 males and 7 females; mean age 50.2 ± 15.3 years)	Post extraction socket site (n = 15)	Autogenous particulated dentin graft (APDG) covered with a bioresorbable membrane	Histomorphometry: bone formation (%); residual graft bone (%); soft tissue component (%)	New bone formation: 38.4 ± 16.5Residual particulate dentin: 29.9 ± 14.4Soft tissue: 31.7 ± 14.2	Particulate dentin graft can be employed as a suitable grafting biomaterial to maintain socket site volume for further implant placement.
Sapoznikov et al., 2023; Israel[25]	Randomized clinical trial; semi double-blinded; parallel-group	36 patients (no gender specification; 23–74 years)	Post extraction of premolar or molar socket site (n = 36)	Porcine dentin-derived bone graft (Ivory Dentin Graft); Bone-derived graft (OsteoBiol-Gen-Os), both covered with a collagen membrane	Histomorphometry: new woven bone formation (%)CBCT: mean radiodensity (HU); bone height and width changes (mm)	New bone formation: 60.75 ± 18.22 (Dentin group); 42.81 ± 17.41 (Bone group) Mean radiodensity: 981.5 ± 233.9 (Dentin group); 727.6 ± 193.4 (Bone group); Bone height change: −1.02 ± 2.21 (Dentin group); −0.46 ± 1.89 (Bone group); Bone width change: −0.43 ± 1.23 (Dentin group); −0.33 ± 1.41 (Bone group)	A porcine dentin-derived bone graft material has clinical safety, tolerability, and performance for implant placement at 4 months after tooth extraction at least as good as a commercial bone-derived material.
Yang et al., 2023; China[26]	Randomized clinical trial	32 patients (17 males and 15 females; 21–79 years)	Severe periodontally compromised sockets in molars (n = 32)	Autogenous partially demineralized dentin matrix (APDDM) graft covered with a collagen sponge	Histomorphometry: newly formed bone (%); dentin graft (%); connective tissue (%) CBCT: horizontal and vertical ridge changes (mm); volumetric dimension changes (mm^3)	Newly formed bone: 39.67 ± 8.28Dentin graft: 23.66 ± 9.22Connective tissue: 36.67 ± 17.05Horizontal ridge changes 1 mm below the most coronal aspect of the alveolar bone crest: 5.03 ± 3.83, 4.50 ± 4.41, 5.20 ± 6.41 in mesial, middle, distal coronal section, respectively Vertical ridge changes at the middle part of sockets: −0.07 ± 1.56, 0.16 ± 2.23, 8.00 ± 2.35 in buccal, lingual, and central bone, respectively Volumetric dimension changes: 387.5 ± 399.8	APDDM serves as a promising new clinical alternative for the reconstruction of alveolar ridge dimension including in periodontally compromised patients.
Elfana et al., 2021; Egypt[2]	Randomized clinical trial; double-blinded; parallel arms	20 patients (4 males and 16 females; 18 years age or older)	Post single extraction socket of non-molar teeth (n = 20)	Autogenous whole tooth graft (AWTG); Autogenous demineralized dentin graft (ADDG), both covered with bioabsorbable collagen membrane	Histomorphometry: new bone formation (%); graft remnants (%); soft tissue component (%)CBCT: horizontal and vertical ridge-dimensional changes (mm)	New bone formation: 37.55 ± 8.94 (AWTG); 48.4 ± 11.56 (ADDG) Graft remnants: 17.05 ± 5.58 (AWTG); 11.45 ± 4.13 (ADDG)Soft	AWTG and ADDG are similarly effective in alveolar ridge preservation, although ADDG seems to demonstrate better

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Table 2 (*continued*)

Authors, Year, Country	Study Design	Subject Criteria	Type of Defect (n)	Type of Alveolar Augmentation Materials	Examination and Variables	Outcome (Mean ± SD)	Conclusion
						tissue: 45.4 ± 4.06 (AWTG); 40.15 ± 7.73 (ADDG) Horizontal ridge change: 0.85 ± 0.38 (AWTG); 1.02 ± 0.45 (ADDG) Vertical ridge change: 0.61 ± 0.20 (AWTG); 0.56 ± 0.24 (ADDG)	osteoinductive properties.
Pang et al., 2017; Korea[27]	Randomized clinical trial	24 patients (11 males and 13 females; age of ≥20 years)	Post extraction socket site (n = 33)	Autogenous demineralized dentin matrix (AutoBT); Anorganic bovine bone graft (BioOss), both using the covering membranes or mesh	Histomorphometry: new bone formation (%); grafted bone (%); soft tissue component (%)CBCT: vertical dimensional change (mm)	New bone formation: 31.24 ± 13.87 (AutoBT); 35.00 ± 19.33 (BioOss) Grafted bone: 8.95 ± 6.15 (AutoBT); 17.08 ± 16.57 (BioOss)Soft tissue: 59.81 ± 15.50 (AutoBT); 47.93 ± 24.46 (BioOss) Vertical dimension change: 5.38 ± 2.65 (AutoBT); 6.56 ± 3.54 (BioOss)	AutoBT shows clinical efficacy comparable to that of anorganic bovine bone material.
Elraee et al., 2022; Egypt[12]	Randomized clinical trial	42 patients (17 males and 25 females; no age criteria)	Sockets on a missing single upper central incisors and horizontal ridge defect (n = 42)	Autogenous dentin block graft; Autogenous ramus bone block graft	Histomorphometry: bone area fraction (%) CBCT: clinical ridge width gain (mm); radiographic ridge width gain (mm)	Bone fraction: 42.6 (Dentin block); 41.3 (Bone block)CRWG: 3.52 ± 0.56 (Dentin block); 2.24 ± 0.86 (Bone block)RRWG: 3.61 ± 0.61 (Dentin block); 3.41 ± 1.15 (Bone block)	Dentin block may serve as an alternative graft to support horizontal alveolar ridge augmentation.
Abo-El-Saad et al., 2023; Egypt[28]	Randomized clinical trial; split-mouth	8 patients (3 males and 5 females; mean age 36.4 years)	Bone resorption following post extraction socket in central and lateral incisors (n = 16)	Autogenous dentin graft combined with socket shield; Alloplast graft	Histomorphometry: new bone formation (%)CBCT: bone density (%); labial bone level (mm) after 3 months	Newly formed bone: 74.91 ± 9.0 (Dentin group); 51.4 ± 18.0 (Alloplast group) Bone density: 17.2 ± 12.2 (Dentin group); 26.7 ± 16.9 (Alloplast group) Labial bone level: −0.165 ± 0.07 (Dentin group); −0.21 ± 0.10 (Alloplast group)	The autogenous dentin graft combined with socket shield could be a promising technique for socket preservation.
Minetti et al., 2022; Italy[1]	Clinical trial	6 patients (2 males and 4 females; mean age 55.16 ± 14.6 years)	Alveolar bone defects from the edentulous site and post extraction socket site (n = 6)	APDG, with and without resorbable collagen membrane, Group 1 and 2, respectively	Histomorphometry: bone volume (%); residual graft (%); vital bone (%)	Bone volume: 45.69 ± 2.31 (Group 1); 37.34 ± 6.33 (Group 2)Residual graft: 7.26 ± 2.28 (Group 1); 27.54 ± 15.42 (Group 2) Vital bone: 38.42 ± 4.58 (Group 1); 9.75 ± 11.81 (Group 2)	Autogenous dentin particulate grafts seem to work best when paired with a bioresorbable membrane.
Xiao et al., 2019; China[29]	Prospective pilot clinical trial	13 patients (3 males and 10 females; 18–70 years)	Alveolar bone defects (n = 13)	Autogenous dentin shell filled with deproteinized bovine bone mineral particles mixed with CGF graft; Autogenous bone shell graft	CBCT: vertical bone gain (mm); horizontal and vertical bone resorption (mm)	VBG: 15.98 ± 1.94 (Dentin group); 14.07 ± 3.95 (Bone group)Horizontal bone resorption at 2 mm from the top of the facial bone crest: 2.41 ± 2.11 (Dentin group); 3.79 ± 2.77 (Bone group) Vertical bone resorption: 0.94 ± 1.43 (Dentin group); 1.72 ± 0.84 (Bone group)	The dentin shell technique restored bone volume successfully without major complications.

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Table 2 (*continued*)

Authors, Year, Country	Study Design	Subject Criteria	Type of Defect (n)	Type of Alveolar Augmentation Materials	Examination and Variables	Outcome (Mean ± SD)	Conclusion
Cervera-Maillo et al., 2021; Spain[30]	Prospective clinical trial	10 patients (4 males and 6 females; mean age 64 years)	Post extraction socket site and implant gap (n = 10)	APDG	Histomorphometry: new bone formation (%); residual graft (%); connective tissue (%) at 6 months	New bone formation: 41.1 ± 0.76 Residual graft: 30.0 ± 0.45 Connective tissue: 29.9 ± 0.56	A particulate dentin graft can be considered an alternative material for socket preservation, split technique, and sinus lifting.
Wang et al., 2022; China[4]	Prospective observational study	19 patients (12 females and 7 males; mean age 37.5 years)	Horizontal bone defect sites post extraction (n = 36)	Autogenous dentin graft (ADG) with guided bone regeneration	CBCT: horizontal bone gain (mm); horizontal bone resorption (mm) after 6 months	Horizontal bone gain:2.50 ± 0.72 (at 0 mm); 4.10 ± 1.42 (at 3 mm); 4.56 ± 2.09 (at 6 mm) Horizontal bone resorption: 0.48 ± 0.52 (at 0 mm); 0.52 ± 0.37 (at 3 mm); 0.48 ± 0.42 (at 6 mm)	Autogenous dentin graft with guided bone regeneration can be an effective grafting material and method for achieve horizontal ridge augmentation.
Andrade et al., 2020; Germany[31]	Clinical pilot study	4 patients (4 females; mean age 54 years)	Post extraction sockets of 4 incisors, 5 canines, and 1 premolar in the maxilla (n = 10)	Autologous dentin block with chopped leukocyte-platelet-rich-fibrin (PRF) membranes	Histomorphometry: proportional areas of the new bone (%); residual dentin graft particles (%); connective tissue (%) CBCT: vertical and horizontal ridge changes (mm)	New bone formation: 56.5 ± 22.2 Remaining dentin: 3.6 ± 6.4 Connective tissue: 39.9 ± 18.7 Vertical dimension ridge: 9.68 mm (after extraction); 11.38 mm (after 4 months) Horizontal dimension ridge: 9.69 mm (after extraction); 11.33 mm (after 4 months)	Dentin block can be a promising graft material to promote new and favorable bone formation.
Çetiner et al., 2021; Turkey[32]	Randomized clinical trial	9 patients (5 females and 4 males; 31–62 years)	Post extraction socket defect (n = 57)	Undemineralized dentin graft (Group D); Mixture of undemineralized dentin graft and PRF (Group DP), both covered with resorbable membrane; Spontaneous healing (Group C)	Histomorphometry: the average of new bone (%); connective tissue (%); blood vessel volumes (%)	Newly formed bone: 18.68 ± 1.18 (Group C); 19.32 ± 1.91 (Group D); 28.08 ± 1.44 (Group DP) Connective tissue: 27.34 ± 2.06 (Group C); 41.57 ± 3.63 (Group D); 35.39 ± 1.60 (Group DP)Blood vessels: 16.92 ± 0.66 (Group C); 14.76 ± 0.94 (Group D); 23.95 ± 1.33 (Group DP)	The use of undemineralized autogenous dentin graft with PRF increases bone formation capacity.
Shejali et al., 2020; India[33]	Pilot study	13 patients (11 females and 2 males; 18–45 years)	Post extraction socket site	A decoronated cementum-free dentin block	CBCT: clinical ridge width (mm); radiographic ridge width (mm); apico-coronal defect depth (mm) after 6 months	Clinical ridge width: 8.15 ± 1.14, the gain was 5.84 Radiographic ridge width: 7.5 ± 1.66, the gain was 5.8 Apico-coronal defect depth: 3.7 ± 1.03, the reduction was 8.2	A decoronated cementum-free dentin block demonstrated an increased width ridge for ridge augmentation.
Pohl et al., 2020; Croatia[34]	Single-arm; retrospective study	12 patients (no gender specification; mean age 51 ± 14 years)	Post extraction socket with up to 2 mm of missing buccal bone	Mineralized particulate dentin autograft and chopped PRF membrane/collagen sponge	CBCT: dimensional ridge width 1 mm below the crest; buccal and lingual height changes (mm)	Ridge width: −1.38 ± 1.24 Buccal bone height: +0.16 ± 2.34 Lingual bone height: +0.4 ± 1.68	A mineralized dentin autograft with PRF is effective in preserving post-extraction alveolar ridge dimensions.
Oguić et al., 2023; Croatia[35]	Randomized clinical trial	37 patients (29 females and 18 males; 26–28 years)	Post extraction socket in the esthetic zone of maxilla	ADG; Bovine xenograft mixed with autologous bone (BX + AB)	Histomorphometry: new bone formation (%); residual graft (%); soft tissue (%)CBCT: alveolar ridge width change (mm)	Newly formed bone: 72.55 ± 12.14 (ADG); 69.61 ± 13.53 (BX + AB) Residual graft: 10.61 ± 5.37 (ADG); 12.31 ±	Autologous dentin graft showed biocompatibility and achieved successful bone regeneration in the

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Table 2 (*continued*)

Authors, Year, Country	Study Design	Subject Criteria	Type of Defect (n)	Type of Alveolar Augmentation Materials	Examination and Variables	Outcome (Mean ± SD)	Conclusion
						7.83 (BX + AB)Soft tissue: 16.84 ± 9.18 (ADG); 18.07 ± 6.93 (BX + AB) Alveolar ridge width change: −0.88 ± 0.76 (ADG); −1.24 ± 0.99 (BX + AB)	esthetic zone of the maxilla.
Minetti et al., 2022; Italy[7]	Clinical trial	96 patients (50 females and 46 males; mean age 56.3 ± 14.7 years)	Post extraction socket site	Demineralized autologous tooth-derived material	Histomorphometry: residual graft (%); vital bone (%)	Residual graft: 7.5 ± 21.9 Vital bone: 38.0 ± 21.0	Alveolar socket preservation procedure using demineralized autologous tooth-derived biomaterial can produce new vital bone.
Isola et al., 2022; Italy[13]	Randomized clinical trial; split-mouth	14 patients (6 males and 8 females; mean age 48.2 years)	Post extraction socket site	Autogenous tooth-derived MDM graft covered with a free gingival graft (Test group); Only free gingival graft (Control group)	Histomorphometry: new vital bone (%); connective tissue (%); residual graft (%)	Vital bone: 30.22 ± 14.48 (Control group); 34.23 ± 13.56 (Test group) Connective tissue: 29.23 ± 10.16 (Control group); 27.36 ± 9.65 (Test group)Residual grafts: 19.61 ± 11.49 (Test group)	The use of an autogenous tooth-derived MDM graft covered with a free gingival graft created greater new vital bone formation, more newly formed bone, and fewer dimensional tissue changes than spontaneous healing with free gingival graft.
Del Canto-Díaz et al., 2019; Spain[36]	Clinical pilot study	6 patients (3 males and 3 females; mean age 47.6 ± 9.04 years)	Post extraction socket site	Autologous dentine material (ADM); Control group without treatment	CBCT: height of alveolar bone loss VL distance (mm); HL–BCB distance (mm); bone loss of the vestibular width VL-BCB at 1 mm crestal level (mm); densitometric (HU) on coronal, medial, apical sites at 16 weeks	VL: 9.08 ± 2.16 (ADM); 8.72 ± 2.14 (Control), the loss was 0.42 and 1.77, respectivelyHL-BCB: 0.23 ± 0.73 (ADM); 2.33 ± 2.38 (Control), the loss was 0.16 and 2.22, respectivelyVL-BCB at 1 mm: 2.68 ± 0.48 (ADM); 1.31 ± 1.63 (Control), the loss was 0.46 and 1.91, respectively Coronal density: 922.68 ± 250.82 (ADM); 564.35 ± 288.73 (Control) Medial density: 840.74 ± 392.35 (ADM); 708.33 ± 148.35 (Control) Apical density: 817.22 ± 260.79 (ADM); 876.30 ± 256.87 (Control)	Autologous dentine material may be considered a promising socket preservation material because it has lower dimensional contraction.
Jung et al., 2018; Korea[3]	Randomized clinical trial; controlled; prospective	24 patients (14 males and 10 females; 27–79 years)	Post atraumatic extraction socket site	Deproteinized bovine bone with collagen (Group A); ADDM (Group B); ADDM combined with recombinant human bone morphogenetic protein-2 (Group C)	Histomorphometry: new bone area (%); grafted area (%); soft tissue area (%) CBCT: buccal and lingual bone height (mm); alveolar ridge width at 1 mm below the marginal crest (mm)	New bone area: 22.00 ± 11.01 (Group A); 32.88 ± 14.48 (Group B); 39.09 ± 15.30 (Group C)Grafted area: 13.20 ± 9.79 (Group A); 10.72 ± 9.83 (Group B); 11.02 ± 12.72 (Group C)Soft tissue area: 64.80 ± 10.11 (Group A); 56.40 ± 8.58 (Group B); 49.88 ± 11.14	The combination of recombinant human BMP-2 with dentin matrix also demonstrated appreciable volumetric stability and higher new bone formation.

(continued on next page)

Table 2 (*continued*)

Authors, Year, Country	Study Design	Subject Criteria	Type of Defect (n)	Type of Alveolar Augmentation Materials	Examination and Variables	Outcome (Mean ± SD)	Conclusion
						(Group C)Buccal bone height: 1.14 ± 0.81 (Group A); 0.97 ± 0.39 (Group B); 0.82 ± 0.36 (Group C) Lingual bone height: 0.65 ± 0.37 (Group A); 0.76 ± 0.29 (Group B); 0.50 ± 0.22 (Group C) Alveolar ridge width at 1 mm: 1.68 ± 1.11 (Group A); 0.78 ± 0.41 (Group B); 1.54 ± 0.74 (Group C)	

Abbreviations: MDM, mineralized dentin matrix; APDG, autogenous particulated dentin graft; APDDM, autogenous partially demineralized dentin matrix; CBCT, cone beam comuted tomography; AWTG, autogenous whole tooth graft; ADDG, autogenous demineralized dentin graft; CRWG, clinical ridge width gain; RRWG, radiographic ridge width gain; ADG, autogenous dentin graft; CGF, concentrated growth factor; PRF, platelet-rich-fibrin; BX + AB, bovine xenograft mixed with autologous bone; VL distance, vertical distance; HL-BCB, horizontal line-buccal cortical bone.

block and/or graft showed a greater percentage of newly formed bone compared to undemineralized dentin graft only; however, the other two studies are non-comparable because no control groups were used.[32] On the other hand, research by Abo-El-Saad et al. (2023) and Jung et al. (2018) demonstrated the advantages of using the combination i.e., socket shield technique and shell field with deproteinized bovine bone,

Table 3
Risk of bias assessment of human clinical studies according to JBI critical appraisal.

Authors, Year, Country	Alveolar Bone Defect	Dentin Bone Graft Utilization	Sample Preparation	Randomization	Blinding of Examiner	Test Method Clearly Reported	Complete Results	Risk of Bias
Santos et al., 2021; Portugal[5]	Y	Y	Y	Y	Y	Y	Y	Low
Artzi et al., 2022; Israel[24]	Y	Y	Y	**N**	**N**	Y	Y	Low
Sapoznikov et al., 2023; Israel[25]	Y	Y	Y	Y	Y	Y	Y	Low
Yang et al., 2023; China[26]	Y	Y	Y	Y	**N**	Y	Y	Low
Elfana et al., 2021; Egypt[2]	Y	Y	Y	Y	Y	Y	Y	Low
Pang et al., 2017; Korea[27]	Y	Y	Y	Y	Y	Y	Y	Low
Elraee et al., 2022; Egypt[12]	Y	Y	Y	Y	Y	Y	Y	Low
Abo-El-Saad et al., 2023; Egypt[28]	Y	Y	Y	Y	Y	Y	Y	Low
Minetti et al., 2022; Italy[1]	Y	Y	Y	**N**	**N**	Y	Y	Low
Xiao et al., 2019; China[29]	Y	Y	Y	**N**	**N**	Y	Y	Low
Cervera-Maillo et al., 2021; Spain[30]	Y	Y	Y	**N**	**N**	Y	Y	Low
Wang et al., 2022; China[4]	Y	Y	Y	**N**	**N**	Y	Y	Low
Andrade et al., 2020; Germany[31]	Y	Y	Y	**N**	**N**	Y	Y	Low
Çetiner et al., 2021; Turkey[32]	Y	Y	Y	Y	**N**	Y	Y	Low
Shejali et al., 2020; India[33]	Y	Y	Y	**N**	**N**	Y	Y	Low
Pohl et al., 2020; Croatia[34]	Y	Y	Y	**N**	**N**	Y	Y	Low
Oguić et al., 2023; Croatia[35]	Y	Y	Y	Y	Y	Y	Y	Low
Minetti et al., 2022; Italy[7]	Y	N	Y	**N**	**N**	Y	Y	Low
Isola et al., 2022; Italy[13]	Y	Y	Y	Y	Y	Y	Y	Low
Del Canto-Díaz et al., 2019; Spain[36]	Y	**N**	Y	**N**	**N**	Y	Y	Low
Jung et al., 2018; Korea[3]	Y	Y	Y	Y	Y	Y	Y	Low

respectively.[3,28] The percentage of newly formed bone for the autogenous dentin graft combined with the socket shield technique was 74.9 % ± 9.0 %, showing a considerable difference from the alloplast graft used in the control group (51.4 % ± 18.0 %).[28] Moreover, adding deproteinized bovine bone mineral particles mixed with CGF graft can increase vertical bone gain and reduce the quantity of vertical and horizontal bone resorption, as shown in the study by Jung et al. (2018).[29] The combination of human BMP-2 to autogenous demineralized dentin matrix (ADDM) in the other study also showed a greater bone formation compared to ADDM only and deproteinized bovine bone graft. However, there are no meaningful differences in buccal and lingual bone height as well as alveolar ridge width; deproteinized bovine bone graft even showed a more favorable result for those parameters.[3]

In addition to the parameters explained above, mean radiodensity was also examined in several articles included in this systematic review. Three studies examined bone density using CBCT, one using a percentage and the other using HU as measurement units.[25,28,36] Studies by Sapoznikov et al. (2023) and Del Canto-Diaz et al. (2019) exhibited similar results, showing a higher radiodensity in dentin groups compared to the control groups.[25,36] In contrast, Abo-El-Saad et al. (2023) revealed that alloplast graft resulted in higher radiodensity compared to autogenous dentin graft combined with socket shield; the overall mean was 26.7 % ± 16.9 % and 17.2 % ± 12.2 %, respectively.[28] Despite the diverse examination results based on histomorphometric and CBCT analyses, most of the studies concluded that dentin-derived ABG is effectively used in alveolar augmentation procedures, and therefore, has the potential to be an useful bone substitute material in the future.

4. Discussion

The objective of the present investigation was to evaluate the existing clinical evidence on the effectiveness of dentin-derived ABG for alveolar augmentation of post-extraction socket sites or other alveolar bone defects. The screening and eligibility assessment of the articles identified 21 human clinical studies—twelve comparative studies and eight without a comparison group—which applied various types of grafting materials, sources of dentin, preparation methods, added combination, grafting techniques, and observation periods. In addition, the heterogenicity of the study design as well as the non-comparability of the outcomes used, represent a considerable hindrance for a comparative evaluation; therefore, a pairwise meta-analysis could not be performed. The procedure of alveolar augmentation is generally performed to avoid excessive alveolar bone resorption due to tooth extraction, deficient alveolar bone sites in case of missing teeth, or other diseases that affect alveolar bone (e.g., periodontally compromised socket).[12]

Based on several prior studies, including Jung et al. (2013), bone grafting for alveolar bone augmentation is currently considered a predictable and reliable procedure, with no radiographic change in the adjacent marginal bone level reported after augmentation.[37] While many different kinds of materials are recommended in the context of bone regeneration, many of them have drawbacks and restrictions. Autogenous bone is still considered the gold standard for bone regeneration although it has several drawbacks.[38] Consequently, research has been conducted to determine whether teeth-derived dentin grafts are a feasible substitute. The degree of osteoconductivity is indicated by histological examination, which shows the formation of new bone surrounding the grafted dentin particles in the context of preservation measures for treated socket sites.[2,24,26–31,35] On the other hand, Xiao et al. (2019), used nondemineralized dentin shells in the alveolar bone defect. Histologic outcomes showed new bone formation on the dentin shell's outer and inner surfaces, indicating the presence of osteoconductive properties.[29]

Due to its autogenous nature, dentin possesses physicochemical structures and characteristics that closely resemble those of autogenous cortical bones.[30] Similar in composition to bone, dentin is made up of 2 % noncollagenous protein, 70 % hydroxyapatite, and 18 % collagen. In addition to the type I collagen found in dentin, microporous dentinal tubules can seize BMP solution and expand their surface area in contact with proteins, thereby promoting BMP's continuous binding and release.[37] In this context, histomorphometric examinations conducted between 3 and 6 months after alveolar ridge preservation procedures showed 28.08%–74.91 % new bone formation, percentages higher than those obtained using xenogeneic bone grafts (22.00%–69.61 %),[35,37] or allogeneic graft (51.4 %).[28] Contradictorily, according to a histomorphometric analysis by Pang et al. (2017), AutoBT had lower volume fractions of newly formed bone (31.24 %) than inorganic bovine bone graft (BioOss) (35.00 %). However, it is impractical to determine which material is superior since the differences are not statistically significant and the sample size used was relatively small. Other than that, the average amounts of bone gain for AutoBT and BioOss measured at the 6-month follow-up were 5.38 and 6.56 mm, respectively. Although BioOss showed higher amount compared to the AutoBT, the findings were consistent with those of other earlier studies, suggesting that in cases with localized vertical bone defects, bone grafting can achieve approximately 5 mm of bone height without the need for barriers.[27]

Dentin was also incorporated into ridge augmentation procedures as completely extracted tooth masses. The chemical composition and abundance of dentin particles make them a highly promising material for bone regeneration purposes.[30] Particulate autogenous extracted teeth have been produced using a variety of techniques.[2,5,7,13,24,27,30–32,34–37] All the results proved that dentin particles serve as a viable substitute for bone grafts in achieving socket site preservation. Three different types of autogenous dentin graft can be identified based on the preparation method and mineralization level: mineralized dentin matrix; demineralized dentin matrix; partially demineralized dentin matrix; and undemineralized dentin.[5,35] Controversial opinions on dentin's efficacy as grafting biomaterial have been reported. Demineralized dentin induced higher bony matrix formation and bone formation in a shorter time than calcified dentin. In a recent in vitro study conducted by Koga et al. (2016), it was observed that partially demineralized dentin particles of larger size (1000 μm) exhibited superior regenerative activity compared to mineralized dentin.[39] Conversely, other researchers have demonstrated remarkable bone regeneration outcomes utilizing mineralized dentin.[5,24,30] The delayed bone-inductive characteristic of calcified dentin can be attributed to the inhibition of bone morphogenetic protein (BMP) release caused by apatite crystals. Demineralization, on the other hand, enhances the osteoinduction activity of dentin by exposing organic substances, increasing porosity and surface area, and reducing crystallinity. Nevertheless, the process of dentin decalcification is laborious and time-consuming, typically taking more than 12 h, which makes it challenging to perform after tooth extraction. Comparatively, the remodeling of mineralized dentin helps maintain the volume and contour of the grafting site. While prolonged demineralization can reduce the concentration of bone morphogenetic protein (BMP), a partially demineralized dentin matrix has shown to be more effective in promoting bone regeneration when compared to a non-demineralized or fully demineralized dentin matrix.[26]

Autogenous dentin block has advantages like osteoinduction, creeping substitution, and space-maintaining, allowing for remodeling over a specific period.[12] Three autologous biomaterials are combined to form the "dentin block": liquid fibrinogen, dentin, and L-PRF. Due to their similar composition and shared embryological ancestry, dentin can encourage the formation of bone in the alveolar ridge.[31] A study by Pohl et al. (2017) compared tooth block and dentin particles for ridge preservation in 20 patients. The study found that tooth block was a promising alternative, but dentinal blocks showed slow resorption compared to dentin particles. The tooth block showed no signs of bone remodeling and a clear margin from the bone, making it a promising alternative.[40]

From a clinical perspective, changes in buccal bone height, resorption, and ridge width 1 mm below the crest are the most significant ridge dimension changes following tooth extraction. It is crucial to preserve the height of the buccal bone, particularly in areas intended for esthetic purposes. Recession may be the result of diminished vertical buccal bone dimension. A study recently published demonstrates that there was a smaller decrease in vertical bone peak (BPR) in sites that were grafted with dentin compared to a xenograft. Specifically, the reduction in buccal bone height was found to be −1.14 mm ± 0.81 mm for sockets grafted with deproteinized bovine bone with collagen, −0.97 mm ± 0.37 mm for a demineralized dentin graft, and −0.82 mm ± 0.36 mm for sockets grafted with demineralized dentin with BMP-2.[3] The reviewed studies show that dentin-derived graft resulted in less vertical and horizontal reduction in all cases compared with control groups.[27,28,35] The results indicate that grafts derived from dentin are the best option for preserving the soft and hard tissue envelope, making treatment procedures easier. Notably, the majority of the studies included in this systematic review carried out dentin-derived grafts in anterior regions, which are the most crucial areas and where it is crucial to minimize the resorptive process.[12,28] CBCT is a precise and safer technique for assessing alterations in alveolar ridges and ridge shape following tooth extraction and grafting. It is also beneficial for pre-implant surgical planning and selecting implant diameters. The advantage of CBCT is its ability to expose patients to lower levels of radiation.[25]

Lastly, this systematic review has some limitations particularly stemming from the articles included, for example, relatively small sample sizes in the studies. In addition, some heterogenicity and inconsistency among the studies were observed, mainly in bone height measurement. Additionally, various devices and methods for tooth preparation were employed. Conducting individual studies according to a standardized protocol would yield more realiable outcomes.

5. Conclusions

Due to its osteoconductive and osteoinductive qualities, dentin-derived alveolar bone graft seems like a good choice as a graft material in alveolar augmentation procedures. The reviewed studies provided promising results about histomorphometric data and volume maintenance. In addition, the dentin graft seems to have a low rate of complications and is less expensive than alternative bone substitutes. These favorable results should be interpreted cautiously, though, as the data came from studies that were conducted in the early stages of a new clinical development, and the studies that have been conducted thus far have used diverse methodologies. Additionally, further research is required to gain a deeper understanding of the clinical behavior of this alternative biomaterial. Randomized clinical trials would be ideal, with appropriate protocols, larger sample sizes, and comparisons with a variety of bone substitutes.

Ethical clearance

Not Applicable.

Patient's/guardian's consent

Not Applicable.

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Author contributions

Conceptualization: DAM, KB, NH, APN; Methodology, Resources: DAM, KB, NH, APN; Writing–original draft preparation: DAM, KB, NH; Supervision, Validation, Writing–review and editing: NH, APN, AC, AM, KS, KH. Critical feedback: NH, AC, KS, KH. Funding acquisition: NH, AM, AC, KS, KH.

Data availability

All relevant data has been uploaded in figshare open (PRISMA checklist, PRISMA statement, PRISMA Flowchart, Tables 1–3).

Declaration of competing interest

The authors declare no conflict of interest.

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