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Review article

Bone graft material derived from extracted tooth: A review literature

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ABSTRACT

Dental extraction is common procedure as a treatment for severely damaged, non-restorable, malaligned, crowded or disease affected tooth such as periodontitis, adjacent to pathologic lesion requiring excision, pulp necrosis and periapical lesions for which endodontic treatment is applicable but somehow patient's as well as other factors might necessitate the its removal. Many previous studies observed that following tooth extraction alveolar process undergoes structural and dimensional change even often atrophy, repairing the deficiency remains a major challenge.

Several bone grafts are present, used to preserve or augment the defects of alveolar process supporting the tooth, autogenous bone graft is considered gold standard, since they have the property to induce osteogenesis, osteoinduction, osteoconduction and also have rapid healing and least immune rejection.

However, limited availability, rapid resorption of autogenous bone, defects of donor site and morbidity or discomfort from distant extraoral grafts to the patients, in case large bone needed, hinder the use of this kind of bone. Many short comings of several types of available bones lead to demand of novel grafting material over the years.

Tooth and bone exhibit similar biochemical composition hence could be utilized as bone grafting material. Osteogenic capacity of tooth derived (mainly dentin) bone graft material has been shown in many studies with significant possibility of future use. Therefore, this article discusses the similarity between bone and tooth, the use of tooth derived bone graft.

1. Introduction

Tooth extraction is one of the most common procedures in dentistry, with almost all the extracted teeth is regarded as clinical wastes and hence discarded. It is well known that alveolar process is a structure dependent on tooth, its volume and shape is controlled by the form, axis and inclination of the teeth [1]. The evidence provided by many previous studies by Atwood in 1957, Hedegård in 1962 and Tallgren in 1972, following tooth extraction alveolar process undergoes structural and dimensional change thereby causing ridge atrophy [2]. Hence, restoring the normal functions and suitable esthetic of the patient, ridge augmentation with bone grafting materials is required.

In dentistry several bone grafting materials are available that helps in ridge preservation and augmentation of the defects in the alveolar process supporting teeth [3]. These materials used in dentistry [3–5] ranges from 1) autogenous, 2) allogeneic, 3) xenogeneic, and 4) synthetic or alloplastic.

However autogenous bone graft is considered gold standard, since they have the property to induce osteogenesis, osteoinduction, osteoconduction [6]. However, limited availability and rapid resorption of autogenous bone, defects of donor site and morbidity or discomfort from distant extra-oral grafts to the patients, in case of large bone needed, hinder the use of autogenous bone [7–9]. Many clinicians would rather prefer the use of allograft, xenograft, or synthetic bone graft materials, due to above mentioned drawbacks and since satisfactory results have been achieved with these types of bone graft materials

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[8,9].

2. Graft characteristics

Nevertheless, non-autogenous source of bone grafting materials also is present with some shortcomings. Allografts are deemed expensive; may pose risks of infection since the donor's information provided is restricted or sometimes inadequate [5,10]. In addition to similar drawbacks to allografts, xenografts could also be a source of zoonotic disease transmission [5]. The use of xenograft has raised some ethical and religious concerns, since the use of animal derived products should be considered before use with patients consent for various religions and individuals [11,12]. While synthetic or alloplastic materials lacks in property of osteogenesis and osteoinduction [5,10]. The limitations of non-autogenous source of bone, lead to finding a novel source of autogenous bone graft that is processed from human tooth.

The aim of this article is to review some previous published article and summarize the resemblance between bone and tooth with the discussion of the recent use of tooth derived bone graft. The keys of tooth usage as bone graft material is its similarity to the human bone and the utilization of this autogenous source have been attempted by many researchers across the world. Keywords used to search for all related articles were tooth derived bone grafts in dentistry and tooth derived bone grafts used in humans or animals, preparation technique and viable particle sizes for bone grafting.

3. Resemblance between bone and tooth

Tooth and bone exhibit similar biochemical composition, comprising mainly of organic and inorganic constituents. Alveolar bone comprised of 65% inorganic and 35% organic with the percentage comparable to dentine (inorganic 65–70% and organic 30–35%) and cementum (inorganic 45–50% and organic 50–55%) [13,14]. Another remarkable property of dentin and cementum is the presence type I, type III collagen and number of growth factors including bone morphogenic protein (BMP), insulin-like growth factor-II (IGF-II), and transforming growth factor-β (TGF-β), which play a major role in promoting bone remodeling [15,16]. Majority of proteins found in bone like osteopontin (OPN), osteocalcin (OC), bone sialoprotein (BSP), osterix, type I collagen and Cbfa1 (Runx2) have also been identified in dentin, which could make it an effective substitute for another bone grafting materials available [17–20].

The bone is made up of numerous Harversian's system, while dentin is complex structure comprising of dentinal tubules [21,22]. When dentin is demineralized, the tubules become broader exposing collagen fibers making it more permeable causing an outward flow of dentinal fluid with it several enzymes and growth factors [23]. X-ray diffraction analysis (XRD) have confirmed the presence of hydroxyl apatite (HA), and also small amounts of tricalcium phosphate (TCP), amorphous calcium phosphate (ACP), and octacalcium phosphate (OCP) in different area of the tooth [24–26]. The previous study by Kim et al. conducted to compare the traditional grafting materials and autogenous tooth, they also showed using XRD that the crystalline structures autogenous tooth had similar pattern to autogenous bones [25,26].

The use of scanning electron microscope (SEM) to examine the surface structure of autogenous tooth had also been performed in the previous studies [24,26]. SEM reveals that after preparation of autogenous tooth; it is mostly homogenous with dentinal tubules and dense collagen matrix clearly visible [24]. Energy Dispersive Spectroscopy (EDS)used to study the phase of calcium phosphate apatites in tooth or Ca/P ratio, showing extensive calcium dissolution during the early phase, which is similar to autogenous bones [26]. Owning to this property the study of Priya et al. reported that extensive dissolution of calcium phosphate releasing its ions induces the reprecipitation of the apatite onto the surfaces [27]. Priya et al also observed that the calcium phosphate composite dissolution had rough surface and macroporous regions formation, which allowed the proliferation of both biological cells and bone growth [27]. This desired property of biocompatible materials is the ability tocompletely absorbed in living organisms via biodegradation, since poor biodegradation prohibits natural bone growth for prolonged periods [26,27].

4. Evidence of osteoinductivity from autogenous tooth

The prospect of inducing new bone formation of dentin has been described in many previous studies. The presence of 90% of organic matrix in the form of Collagen type I and other non-collagenous proteins as growth factors like endogenous BMP, phosphoproteins, osteocalcin, proteoglycans, osteonectin and sialoprotein in dentin is well documented [20,28–30]. The first documented evidence of regenerative potential of autogenous demineralized dentin matrix (DDM) was provided by the study of Yeomans and Urist and according to the study of Urist, BMP in DDM and bone possesses the osteoinductive property [31]. The study of Bessho et al, purified BMP was homogenous and could induce bone formation when implanted in muscle pouch of wistar rats within 3 weeks. Even though the BMP derived from dentin was different to BMP from bone, the mode of action of both is identical [28]. In other words, two types of BMP exhibit the same action in the body [28,32,33]. Since BMP belongs to the family of TGF-β and are the only signaling molecules that can solely induce de novo bone formation at orthotopic and heterotopic sites, making them clinically valuable as substitutes to bone graft [28,34].

LIM mineralization protein 1 (LMP-1) was first defined by the study of Boden et al, which regulates differentiation and maturation of osteoblasts and hence bone formation [35]. Later the previous study of Wang et al. identified the expression of LMP-1 mainly in predentin, odontoblasts and the endothelial cells of blood vessels of teeth with suggestion that LMP-1 plays an important role in differentiation of odontoblast and also mineralization of dentin matrix of human teeth [36]. The osteoinductive property of autogenous demineralized dentin matrix (ADDM) on experimental surgical bone defects in the parietal bone of rabbits using the guided bone regeneration (GBR) technique incorporating human amniotic membrane (HAM) was evaluated in the study of Gomes et al. The experimental bone defect repaired faster, and new bone formation was stimulated in groups that used ADDM slices. The ADDM slices were entirely integrated into the newly formed bone tissue, having been resorbed during the bone remodeling process [37].

DDM granules derived from human impacted tooth by the study of Murata et al., independently induced bone and cartilage formation in subcutaneous tissues of nude mice, showing property of bone induction [38]. The previous study by Kim Kyung-Wook in 2014 showed when DDM was grafted into the muscle of nude mouse (subcutaneously) and evaluated for hard tissue induction histo-morphologically, that induced cartilage and bone independently in soft tissues Hence human DDM could be good alternative to autogenous bone graft materials [39].

5. Previous study reporting osteoconductivity of autogenous tooth

Besides the property of osteoinduction, BMP present in the ADDM also could act as matrix or framework for new and native bone to perpetuate and regenerate, thereby showing osteoconductivity property [40]. Previous studies published by Carvalho et al, Catanzaro Guimarães, Gomes et al., have investigated the osteopromotive property of ADDM. The protein substrate that exists in ADDM was found to be free from degradation and helped in socket repair [37,41,42]. Furthermore, Gomes et al. also observed an increase in the osteogenic cells after implantation of ADDM in wounds [37]. Similarly, the study of Carvalho et al 5 mm defect at buccal bone of mandibular molar area in 36 rabbits and dividing them into four groups as control group (untreated defect), polytetrafluoroethylene (PTFE) barrier group, PTFE + ADDM group and experimental group (ADDM). The experimental group had normal bone formation with less inflammation postoperatively and ADDM was

completely incorporated in the newly formed bone tissue and was resorbed during bone remodeling [42]. The previous study of Nampo et al suggested that material prepared from extracted teeth may have the potential as bone grafting material for jawbone formation since it is more predictable and show less resorption [17].

Several proteins are common to bone, dentin and cementum such as OPN and DSP, BSP, osteocalcin, DMP-1, osterix and Runx2, and these are reportedly involved in bone formation and resorption [20,28,33]. It is commonly acknowledged that these NCPs play key biological roles in the formation of bone and dentin [43]. Apart from these, the previous article of de Oliveira et al. immunostaining of BMP-2 and BMP-4 in osteoblasts during the upper second molar sockets wound healing of Holtzmann rats when filled with human DDM showed DDM acting as a scaffold for osteoblast differentiation and actively producing new bone. The effects of human DDM in the healing process of tooth sockets were, in some part, owed to matrix degradation, resulting from controlled delivery of BMP-2 and BMP-4 since the immuno-reactivity of both proteins were increased in extraction sockets at 10 days when almost entire DDM was degraded [44].

The animal model from cranium of mini pig and sinus of porcine showed excellent osteo-conductive healing capacity of human DDM when placed in bony defects, which could be attributed to minerals present in DDM, such as low-crystallinity HA and TCP [45,46]. A study conducted in New Zealand rabbit calvarium with 3 circular defects, the CT- scans after one and six weeks of defects filled the dentin had a higher mineral (density) content showing a higher density than the autologous bone andit incorporated in the bone without inflammation and gradually resorbed and replaced by new bone [47]. Similar result was seen in bony defect (5 mm) in femur of New Zealand White rabbits, when autogenous dentin treated with liquid nitrogen at −196 °C for 20 min was used [48].

6. Suitable particle size of autogenous tooth preparation as grafting

Previously mentioned article showed for extracted tooth to be turned into efficent bone grafting materials was a tedious process and required special center or time consuming demineralization technique [18,49,50]. However, since more and more dentists and researchers around the world have seen the tooth, once considered as clinical wastes, as inexpensive autogenous alternative to several comercially available grafting materials the cumbersome preparation technique is been replaced by much quicker, more chairside and less inexpensive ways. A remarkable study of Koga et al. showed that partially demineralized dentin matrix (PDDM) induced prominent bone regeneration [51]. Since previous studied showed that demineralization of tooth exposed the tubule and as they become wider it serves as a channel for releasing essential proteins, which may promote growth and differentiation of osteoblasts. However process of demineralization is time consuming and could destroy some of the growth factors [15]. Thereby, PDDM prepared by the previou study of Koga et al. took just 40 min to prepare and also superior bone inductivity compared to completely demineralized dentin matrix or non-demineralized dentin [51].

Both animal model and clinical studies of Koga et al. and Minamizato et al., showed that PDDM grafting could successfully induced alveolar bone regeneration in implant dentistry without any complications. Histological examination also showed APDDM was surrounded by newly formed bone and osteoclastic activity (Howship's lacunae) was prominent suggesting remodeling and biocompatibilty of grafting material [51,52]. The additional previous study of Binderman et al. suggested that autogenous mineralized dentin particulate, which takes 20 min to prepared, was firmly integrated with newly formed bone, creating a solid site for anchorage of dental implants [49,53]. The APDDM or mineralized dentin particulates prepared instantly after tooth extraction for bone augmentation, taking benefit of the relatively little preparation time with partial or no demineralization, has possibilty of becoming one of the options for bone substitute in implant dentistry [51,52].

The particles sizes of most commercially available bone grafting ranges from 300 μm to 1500 μm. Several previous studies have focused on the influence of particle size of graft materials on bone regeneration [49,53]. However, there is no consensus on optimal particle size of graft materials for bone regeneration. Some graft material such as xenografts and FDBA resulted in superior bone formation, and more absorbability with smaller particles in certain sites in oral cavity. On the other hand larger sized particles could be sucessfully used at other areas in the oral cavity [54–56]. Nevertheless, this article is more concern about the suitable particle size for tooth derived bone grafts and hence a notable previous study of Minamizato et al. has shown that particle size ranging between 400 μm to 800 μm showed superior new bone formation in 16 patients that underwent bone augmentation prior to implant placement [52]. The previous article of Koga et al. showed particle size of 200 μm to 1000 μm of the PDDM in rat calvarial bone defect all had defected spaces filled with newly formed bone especially at 8 weeks after surgery using images of μCT [51]. From this time, the authors suggested mixture of particles with variable sizes may have better results [51,52]. The study of Bindermann et al. using Smart Dentin Grinder by KometaBio, USA found that mineralized dentin particulates ranging betweeen 300–1200 μm successfully used for socket preservation, bone augmentation in sinuses or filling bone defects. Similarly many authors also suggested fine particulate < 300 μm is considered as a non-efficient particulate size for bone grafting [49,53].

7. Autogenous tooth in clinical applications

Several published previous clinical studies have shown the potential applications of autogenous tooth as a bone grafting material. The process of preparation of this autogenous tooth varies from center to center, depending on its clinical use which could be either in block or particulate forms [50]. Since it is autogenous the risk of immune rejection and nonpathogenic. As discuss earlier the use of tooth derived bone graft in animal model have been shown to be effective with excellent biocompatibility, hence the clinical applications of tooth derived bone graft are illustrated in Table 1.

8. Discussion

The use of extracted tooth, which is considered as biomedical waste and hence disposed, unlocks the simple and readily available bone substitution material. The different and various preparation methods of extracted tooth provide their potential use as bone substitutes. Various previous published studies had shown the possibility of tooth derived bone graft materials. The demineralized dentin matrix is exceedingly biocompatible with the property of both osteoinductive and osteoconductive which have been highlighted in previous studies conducted in vitro as well as in animal models [31,37,38,41,71].

The resemblances between tooth and bone makes it safe and effective grafting materials. Another remarkable property of dentin and cementum is the presence type I, type III collagen and of number of growth factors including BMP, IGF-II, and TGF-β, which play a major role in promoting bone remodeling [13–16]. Majority of proteins found in bone like OPN, osteocalcin, BSP, osterix, type I collagen and Cbfa1 (Runx2) have also been identified in dentin, which could make it an effective substitute for another bone grafting materials available, since these reportedly involved in bone formation and resorption [17–20].

The first documented evidence of regenerative potential of autogenous demineralized dentin matrix (DDM) was provided the previous study of Yeomans and Urist in animal model and according to Urist, BMP in DDM and bone possesses the osteoinductive property which led to more and more advancement and development that would define its use in human [31]. The first clinical case in human was sinus lifting procedure using autogenous DDM in the 2003 reported at IADR

Table 1
Clinical application of Tooth Derived Bone Graft.

author & year of publication	Murata M., 2003 [57]	Gomes MF. et al., 2006 [58]	Kim YK. et al., 2010 [23]	Kim YK. et al., 2011 [59]
Graft	Crushed autogenous DDM	Autogenous demineralized dentin matrix (ADDM)	Autogenous tooth (AutoBT) particle size (0.5-1 or 1-2 mm) in diameterb	Autogenous tooth bone graft in powder or block forms
Number of patients	1	14 patients (27 dental sockets)	6	2
Anatomical site	Sinus lifting (24-26 area)	Mandibular third molar dental sockets	Maxilla: 5 Mandible: 1	Socket preservation in mandible& maxilla with simultaneous sinus lifting
Result	• 5 months after sinus lifting 3 implants could be placed at the DDM grafted site • Biopsy tissue showed mature bone intertwined with remaining DDM granules	• The radiographic analysis of ADDM + PTFE group showed greater homogenous bone radiopacity than the Control group and PTFE group, during all the observation times. • ADDM gradually disappearedfrom dental socket during the repair process, suggesting its resorption during the bone remodeling process • ADDM was biocompatible with the bone tissue of the surgical wounds of human dental sockets	• Histologic exam of AutoBT grafted area revealed gradual resorption & replacement with new bone • New bone formed by direct union with residual AutoBT • New bone formation was detected in 46 ~ 87%	• Good healing • Able to place implant after 3-3.5 months of bone grafting
Reported follow up period	> 5 months	90 days	3-6 months	3-3.5 months
Complication	Not Reported	Not Reported	Not Reported	Not Reported
Level of evidence	First clinical case report	Clinical study	Case Series	Case Report

Author & year of publication	Kim YK. & Choi YH., 2011 [60]	Kim YK.& Yi YJ., 2011 [61]	Lee JY. and Kim YK., 2012 [62]	Park SM et al. 2012 [14]
Graft	Autogenous tooth-bone powder	Autogenous tooth-bone powder	AutoBT	Block type, Powder type, and Block + Powder type AutoBT
Number of patients	1	1	37 patients (54 implants)	250 patients (133 implants)
Anatomical site	Mandible (In combination with auto-tooth transplantation (ATT) and space between the root and the alveolar socket filled with Autogenous tooth-bone powder)	Anterior atrophic maxilla	• Maxilla and mandible	Maxilla and mandible
Result	• During ATT, a large bony defect usually occurs due to the difference between the size of the recipient site and that of the donor tooth or owing to periodontal disease • Increased initial stability with the use of this autogenous tooth-bone graft material • Excellent periodontal regenerative healing	• Bone grafting in combination with ridge expansion showed favorable healing of autogenous tooth bone graft was observed.	• The mean peri-implant marginal bone loss after 1-year implant placement was 0.33 ± 0.63 mm • Autogenous tooth bone graft was confirmed to be a safe procedure, showing excellent bone healing through a 2-year	• The average initial stabilization of placed implants was 74 ISQ with secondary stability increase to 84 ISQ • **Radiological assessment**: The average loss of crestal bone in the mandible as measured 6 months on the average after the application of prosthesis load was 0.29 mm, ranging from 0 mm to 3.0 mm.
Reported follow up period	10 months	6 months	31 months	4-12 months
Complication	Not Reported	Not Reported	• Wound dehiscence and hematoma occur in 7 patients (8 implants) • Osseointegration failure in 2 patients (4 implants)	• und dehiscence: 10
Level of evidence	Case Report	Case Report	Retrospective cohort study	Clinical study

Author & year of publication	Kabir MA et al. 2014 [63]	Gideon H. & Binderman I. 2014 [53]	Pohl V. et al. 2016 [64]	Kim YK. et al. 2016 [65]
Graft	Demineralized dentin matrix (DDM)	Autogenous dentin particulate	Particulate tooth material	Demineralized dentin matrix
Number of patients	2	> 100 procedures	6	5
Anatomical site	Anterior maxilla and Mandibular third molar	Maxilla and Mandible	Maxilla (sinus elevation surgery with implant placement)	Maxilla: 4 Mandible: 1

(*continued on next page*)

Table 1 (*continued*)

Author & year of publication	Kabir MA et al. 2014 [63]	Gideon H. & Binderman I. 2014 [53]	Pohl V. et al. 2016 [64]	Kim YK. et al. 2016 [65]
Result	• **Anterior maxilla**: Bone grafting at defect of pyogenic granuloma with DDM, post-operative radiography indicated excellent bone healing by remodeling with dentin matrix after 1 year • **Mandibular third molar**: Post-operative radiographs showed the extracted socket healed fully with new bone	• 48 extraction sites filled with particulate dentin after 4 months the particulate and newly formed bone restored distal root of tooth 47 • No sign of bone loss around dental implants placed after bone grafting with autogenous dentin particulate • Sinus opening filled with particulate dentin healed in 2 months with 3 implants inserted after 3 months and immediate solid anchorage was achieved	• Normal postop healing with prosthetic restoration • The average peri-implant probing pocket depth after 5 years ranged between 1.86 mm (ML) and 2.07 mm (DB) • The average peri-implant bone resorption during the 1st year was 0.63 mm, with lowest = 0 mm and maximum = 2.9 mm • histological evaluation showed osteoconductive and osteogenesis with encapsulation of tooth enamel and dentin and partial resorption of the tooth graft • Immuno-histochemical showed new vessel formation in the augmented area.	• All cases showed increased and complete cortico-cancellous bone formation at the final follow-up compared with follow-up after the second surgery. • Decrease in buccal height and alveolar ridge width ranged from • −0.4 to -3.3 mm and from -0.4 to -4.2 mm, respectively • The change in bone area ranged from -8.1 to -36.2%.
Reported follow up period	12 months	24 months	5 years	5 years 5.8 months
Complication	Not Reported	Not Reported	Not Reported	• 1mm of buccal marginal bone loss in 1 case after 6 years 7 months
Level of evidence	Case Report	Case Series	Case Report	Prospective longitudinal case series

Author & year of publication	Joshi CP et al. 2016 [66]	Kim YK et al. 2017 [67]	Joshi CP et al. 2017 [68]	Kim YK et al. 2017 [69]	Pang KM et al. 2017 [70]	Minamizato T et al. 2018 [52]
Graft	Autogenous tooth graft (ATG)	Demineralized dentin matrix block (ABTB: Autogenous Tooth Bone Graft Block)	Allogenous Tooth Graft	Allogenic demineralized dentin matrix (DDM)	Autogenous tooth graft material (AutoBT)	Autogenous partially demineralized dentin matrix (APDDM)
Number of patients	15 patients per 3 extraction sites Out of 3 sites, 1: ATG 2: β-TCP 3(control): left ungrafted	22	15 patients per 4 extraction sites Out Of 4 sites, 1: whole tooth allograft (WTA) 2: dentin allograft (DA) 3: freeze-dried bone allograft (FDBA) 4 (control): left ungrafted	18	24 patients with 33 graft sites AutoBT: 21 sites of 15 patients Bio-Oss®: 12 sites of 9 patients	16 patients underwent dental implant placement after APDDM transplantation
Anatomical site	Total 45 sites (15 of each grafting material) **Maxilla:**18 (10-ATG 8-β-TCP) **Mandible:** 12 (5-ATG 7-β-TCP). maxilla ungrafted: 8 ungrafted mandible: 7	Maxilla:12 Mandible: 10	Total 60 sites (15 of each grafting material) **Maxilla:** 26 (WTA: 9, DA: 7, and FDBA:10) **Mandible:** 19 (WTA: 6, DA: 8, and FDBA: 5) ungrafted maxilla: 7 ungrafted mandibles: 8	Maxilla: 10 Mandible: 8	Maxilla: 21 Mandible: 12	Maxilla: 9 Mandible: 7
Result	• Statistic difference in width and height of alveolar crest compared within all the 3 groups • Among 3 sites, ATG-grafted sites showed superior results (minimal reduction in alveolar crest height and width) • Histological analysis also showed the same trend with more new bone formation at ATG-grafted sites	• ABTB is well incorporated and remodeled into cortico-cancellous bone with dental implant • The shape and volume were maintained with little marginal bone loss	• Compared to other sites, WTA and DA consistently showed superior results showing least reduction in alveolar crest height and width which was statistically significant ($P < 0.05$) • Histological analysis also confirmed more new bone formation at WTA and DA sites	• Like autogenous DDM, no remarkable early and late complications were observed with the use of allogenic DDM • Encapsulation of DDM particles with highly cellular fibrous tissue in soft tissues; this could be a parameter for evaluating biocompatibility • Completely remodeled with new formed bone, while DDM particles were seldom found in the newly formed bone	• Both groups showed favorable wound healing, similar implant stability and histologically confirmed new bone formation • The VD of alveolar bone increased by 5.38 ± 2.65 mm in AutoBT group and 6.56 ± 3.54 mm in Bio-Oss® group at 6 months • Histomorphometrically, new bone formation of AutoBT-grafted site was 31.24 ± 13.87% while that of Bio-Oss® was 35.00 ± 19.33%	• 7 patients underwent Socket preservation with implant placement after 4-6 months wit no implant lost with follow-up of 24 months • 3 patients with sinus lift and CT images indicating bone remodeling augmented bone • 6 patients with ridge augmentation and simultaneous dental implant placement showed APDDM been replaced by bone-like tissue at second

(*continued on next page*)

Table 1 (*continued*)

Author & year of publication	Joshi CP et al. 2016 [66]	Kim YK et al. 2017 [67]	Joshi CP et al. 2017 [68]	Kim YK et al. 2017 [69]	Pang KM et al. 2017 [70]	Minamizato T et al. 2018 [52]
	compared to β-TCP-grafted sites				• The implant stability quotient (ISQ) of implants placed in AutoBT-grafted sites measured 72.80 ± 10.81 while those placed in Bio-Oss® grafted sites measured 70.0 ± 12.86.	surgery 3 months after dental implant placement with implant lost at 24 months follow up. • Bone biopsy samples in 4 patients showed new bone surrounding APDDM.
Reported follow up period	4 months	44 months & at least 1 year after functional loading	4 months	12 months	6 months	24 months
Complication	Not Reported	Not Reported	Not Reported	Dehiscence: 3 cases	Not Reported	Not Reported
Level of evidence	Prospective, randomized controlled pilot clinical trial	Case Series	Prospective, randomized controlled pilot clinical trial	Retrospective clinical study from 2013-16	Prospective, randomized clinical trial	Clinical Pilot study

Congress by Dr. Murata [57]. The pioneering work of Dr. Murata led to the more acceptance and further clinical use of tooth derived bone graft material. Consequently, the recycling of once considered biomedical waste into bone grafting material not only would be practical but also an innovative biomaterial, which is both safe and effective. Furthermore, if certain standardized dentin preparation protocol is achieved [50] since it has both osteoconductive and osteoinductive properties, which would render dentin particles as an efficient and affordable bone graft substitute, hence more accepted and applicable.

Many previous studies suggested the need for a faster way of transforming extracted in to ready to use bone grafting materials. Hence the recent publications are more focused on chairside tooth preparation that could be employed in a clinical setting. The particle size efficient as the use for tooth derived bone grafting is also currently been discussed and pioneering research work of many previous researchers have shown that size ranging from 300 to 1200 μm is ideal for new bone formation [49,52]. However, the presence of variety of different sizes in dentistry is because diversity of human oral cavity, where some sizes could be suitable for some maxillary defects might not be appropriate for mandible and vice versa [54–56]. Another drawbacks when using tooth derived bone grafts is its availability, limited indications and as mentioned earlier issues associated to preparation [52].

In conclusion with consequently, several previous studies are initiated to find and alternative source such as allogeneic teeth however the risks of transmission disease could not be fully disregarded. Currently off-the-shelf, like other commercially available bone grafting materials are still far-fetched. On the other hand, with future technology and advancement the use of extracted tooth as an effective bone grafting material could become more readily accessible and successful.

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