


Tooth shell technique: A proof of concept with the use of autogenous dentin block grafts

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ABSTRACT

Background: Autogenous bone block graft is considered the gold standard for lateral bony defects. Dentin has been identified to be a suitable autogenous bone graft material due to its structural and chemical similarities to the alveolar bone.

Methods: This proof of concept study describes the clinical application of the tooth shell technique in 24 sites with 27 implants of 22 patients. A tooth shell was fixed laterally to the defect with microscrews. Distance between the shell and the residual bone was filled with particulate remnants of the tooth root. Implant was inserted simultaneously. Cone beam computed tomography was done after implant insertion (T1) and 3 months later at time of implant exposure (T2). Target parameters were biological complications and the resorption of hard tissue graft.

Results: Even though a graft exposure occurred in one case (4.5% on patient-level), all implants showed enough implant stability and were able to be loaded. At T2, the evaluation of the X-rays showed no case with hard tissue loss at the mesial or distal implant shoulder. All implants were completely osseointegrated.

Conclusions: The tooth shell technique showed promising results for the reconstruction of lateral alveolar crest defects. It may be considered to serve as an alternative material to avoid bone harvesting procedures.

Keywords: Autogenous, bone graft, dentin, implant, tooth shell technique.

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INTRODUCTION

Although a large number of alloplastic, allogenic or xenogenic bone substitute materials are available for reconstruction of the alveolar crest, the use of autogenous bone is still considered the gold standard. Autogenous bone has excellent osteoinductive, osteoconductive and osteogenetic characteristics; immunological reactions or the transmission of diseases can be safely avoided, and predictable augmentation results can be obtained.¹

For several years, the use of dentin as an alternative autogenous material for alveolar crest reconstruction and the grafting of bone deficits has been described and investigated in animal experiments and clinical studies.^{2–11} Dentin is a suitable grafting material because it is very similar to bone in its organic and inorganic composition. Similar to the alveolar bone, about 90% of the organic substance of dentin consists of type I collagen. Also, osteogenetically relevant structural proteins, such as osteocalcin, osteonectin, phosphoprotein and sialoprotein, can be found in

dentin. Moreover, it contains osteogenetically active factors, including bone morphogenetic protein 2 (BMP-2), tissue growth factor- β (TGF- β) and insulin-like growth factor-2 (IGF-2). As in alveolar bone, the inorganic components of dentin consist of various calcium phosphates such as hydroxylapatite, β -tricalcium phosphate, octacalcium phosphate and amorphous calcium phosphate.^{12,13} Compared with autogenous bone, the use of autogenous dentin offers the advantage of avoiding the harvesting procedure and the possible resulting donor site morbidity. In comparison to autogenous bone block graft, dentin grafts also show significantly less resorption. In a clinical study, Schwarz et al. compared autogenous tooth root grafts and monocortical bone block graft from the retromolar region of the mandible with regard to their volume stability. After 26 weeks, the mean resorption of the root grafts was 0.13 mm, whereas it was 1.03 mm for the bone block grafts.⁹

In this study, a technique was used consisting of fixing a thin tooth shell to the bony defect. The hollow space thus created was filled with the particulate

dentin of the remaining tooth. The technique described is a modification of the split-bone block technique described by Khoury (14). Using this technique, the defect to be filled is revascularized because interposition particulate bone regenerates much faster than when cortical or corticocancellous grafts are used. Therefore, better regeneration results are achievable with this technique.¹⁴ As a result of the structural and chemical similarities of dentin and alveolar bone, equally good results are expected for the procedure using a dentin shell and particulate dentin.

The aim of this retrospective observational study is the assessment of the operative success of the tooth shell technique.

MATERIALS AND METHODS

For the present retrospective observational study, cases were re-examined after the tooth shell technique with simultaneous implantation was carried out between 01.06.2019 and 31.03.2020. The patient's electronic medical records were used to assess the development of the case.

The tooth shell technique is used here for the purpose of reconstructing lateral alveolar ridge defects to enable simultaneous placement of a dentula implant. The augmentation material used was autogenous dentin. The patients were given detailed information about the surgical procedure and the possibilities of augmentation with autologous dentin. As an alternative, they were offered an augmentation with autologous bone. All patients who were included in the study gave a declaration of consent for the procedure and the use of dentine as augmentation material.

All patients underwent surgery by the same oral surgeon. The Institutional Review Board of the Baden-Württemberg Medical Council reviewed the study and approved it (ID: F-2020-068-z). The content of the present study corresponds to the EQUATOR guidelines. The intended therapy required certain inclusion criteria:

Inclusion criteria

- Patient above the age of 18 years
- Presence of a hopeless tooth
- Lateral alveolar crest defect of at least 4 mm in the region of the prospective implantation
- Patient was informed about the necessity of an alveolar crest augmentation using autogenous bone and refused the procedure
- Patient was informed about the possibility of the graft using autogenous dentin and agreed to the therapy.
- Only patients were included in whom the following implant systems were used:

(a) ASTRA TECH Implant System™ EV (Astra Tech Implant System

(b) Dentsply Sirona, York, USA), Nobel Biocare (Nobel Biocare, Kloten, Switzerland)

(c) Conelog (CONELOG®, ALTATEC GmbH, Wimsheim, Germany)

- Tooth gaps from one to a maximum of two teeth.
- Mesial limitation of the gap by a neighbouring tooth.

Exclusion criteria:

- Patient under the age of 18 years
- Patients who do not need lateral bone augmentation.
- Patients who needed lateral bone augmentation but did not have a hopeless tooth.
- Lateral alveolar crest defect less than 4 mm in the region of the prospective implantation
- Patients who refused to have a lateral augmentation with dentin.
- Patients were excluded in whom implant systems were used other than the three previously mentioned.
- Patients who have been operated on by another surgeon.

In all patients, either a hopeless tooth or a tooth not worth preserving (such as a t) that would have been suitable for grafting was present in the prospective region of implantation (Table 1). In all of the cases, the width of the bucco-palatal bone was measured with a preoperative cone beam computed tomography (CBCT) before augmentation. At least 1.5 mm of bone/autogenous dentin should cover the implants on the buccal and palatal surfaces. The achieved ridge width was a result of the desired implant diameter, a 1.5 mm buccal and 1.5 mm oral bone/autologous dentine. The desired ridge width of at least 7.3 mm was the aim, when the implant diameter was 4.3 mm. A hard tissue gain of at least 4 mm was an augmentation procedure requirement in all cases.

The following data were extracted from the electronic medical records for the study documentation:

- Base data: age, gender
- Anamnestic data: previous illnesses of the patient, systemic illnesses
- Findings data: Dental findings (findings of all existing teeth)
- Historical data: data on the implantological restoration to be examined, the subsequent prosthetic therapy and data on maintenance therapy
- Complications: infections, loss of augmentation and implant
- Implant data: implant type, implant length and implantation region
- Height and width of hard tissue graft: after augmentation with simultaneous implantation and at the time of the follow-up 3 months after

Table 1. The details of each patient, the implants used, and the ISQ measuring

Patient no.	Implant site	Implant no.	Sex	Age	Site	Reason for treatment	Implant system	Implant diameter (\varnothing) and length (L)	ISQ	C.
Patient 1	1	1	M	49	22	Endodontic c.	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	70	No
Patient 2	2	2	W	28	11	Trauma/avulsion	Astra Tech EV	$\varnothing = 4,2$ mm, L = 13 mm	65	Dehiscence
Patient 3	3	3	M	64	15	VRF	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	70	No
Patient 4	4	4	W	67	25	Endodontic c.	Astra Tech EV	$\varnothing = 3,6$ mm, L = 9 mm	70	No
		5	W	67	26	Endodontic c.	Astra Tech EV	$\varnothing = 3,6$ mm, L = 9 mm	79	No
Patient 5	5	6	M	64	46	Periodontal c.	Astra Tech EV	$\varnothing = 4,8$ mm, L = 11 mm	81	No
Patient 6	6	7	W	51	14	LF	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	76	No
Patient 7	7	8	W	59	14	Periodontal c.	Conelog	$\varnothing = 3,8$ mm, L = 11 mm	77	No
Patient 8	8	9	W	71	15	Reason unclear*	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	69	No
	9	10	W	71	25	Reason unclear*	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	68	No
Patient 9	10	11	M	70	22	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	74	No
Patient 10	11	12	W	63	36	Reason unclear*	Astra Tech EV	$\varnothing = 4,8$ mm, L = 13 mm	80	No
Patient 11	12	13	M	49	23	Periodontal c.	Nobel Active	$\varnothing = 3,5$ mm, L = 13 mm	72	No
Patient 12	13	14	W	58	15	Endodontic c.	Astra Tech EV	$\varnothing = 3,6$ mm, L = 11 mm	74	No
		15	W	58	16	Endodontic c.	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	69	No
Patient 13	14	16	M	67	12	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 11 mm	72	No
Patient 14	15	17	W	55	37	Endodontic c.	Nobel Replace	$\varnothing = 4,3$ mm, L = 11,5 mm	75	No
Patient 15	16	18	W	58	36	Endodontic c.	Nobel Replace	$\varnothing = 4,3$ mm, L = 11,5 mm	86	No
Patient 16	17	19	M	62	46	Endodontic c.	Conelog	$\varnothing = 5$ mm, L = 11 mm	82	No
Patient 17	18	20	M	57	12	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	73	No
Patient 18	19	21	M	71	12	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	66	No
	20	22	M	71	22	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	68	No
Patient 19	21	23	M	78	34	Endodontic c.	Conelog	$\varnothing = 3,8$ mm, L = 11 mm	78	No
Patient 20	22	24	M	64	21	LF	Astra Tech EV	$\varnothing = 4,2$ mm, L = 15 mm	73	No
Patient 21	23	25	W	49	24	Endodontic c.	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	67	No
		26	W	49	25	Endodontic c.	Astra Tech EV	$\varnothing = 4,2$ mm, L = 11 mm	69	No
Patient 22	24	27	W	75	22	Periodontal c.	Nobel Active	$\varnothing = 4,3$ mm, L = 13 mm	75	No

no. = number; C./c. = complication; VRF = vertical root fracture; LF = longitudinal fracture; ISQ = implant stability quotient.

*Reason unclear = tooth missing for many years.

augmentation. These data are obtained by analysing the available X-ray images.

The target parameters were biological complications. These include the following: biological complications, concerning the hard and soft tissue:

- Bleeding
- Dehiscences of the wound
- Infection with or without suppuration
- Severe loss of hard tissue graft
- Implant loss
- Transient nerve injuries
- Others

Clinical complications

The loss of the graft either through infection or unexpected massive resorption and the loss of an implant during the follow-up was defined as a severe complication.

A dehiscences of the wound, transient nerve injuries and inflammation of the grafted site were categorized as non-severe complications if the implant was fully osseointegrated.

Clinical procedure

After extraction of the respective tooth, debris, restorations and root filling material were removed as

well as the periodontal ligament from the root surface with a coarse diamond bur under water cooling (Fig. 1a). With a diamond cutting disk (Frios Micro-Saw, Dentsply Sirona Implants, Mannheim, Germany) and water cooling, a shell of root dentin about 1–1.5 mm thick was obtained (Fig. 1b). The remaining dentin was crushed with the sterile disposable grinder (Smart Dentin Grinder; Kometa Bio, Creskill, NJ, USA) to 300–1200 μ m dentin particles (Fig 1c,d). For chemical cleaning, the dentin shell and particulate dentin were put in a sterile dappen dish sealable together with a solution of sodium hydroxide (0.5N, 4 mL) and ethanol for 10 min (20 Vol.%, 1 mL) (Dentin Cleanser; Kometa Bio). After the exposure time, the supernatant was absorbed with sterile gauze, and the material was cleaned additionally for another 3 min by placing and manually shaking it in phosphate-buffered physiological saline solution (Dulbecco's Phosphate-Buffered Saline; Kometa Bio). Subsequently, it was placed for 3 min in 10% EDTA solution (EDTA solution; Kometa Bio) for partial demineralization of the dentin and exposure of the collagen fibre network, and release of osteoinductive active growth factors.¹⁵ The material obtained was then cleaned once more with a buffered saline solution. After cleaning, the dentin shell and the particulate dentin were dried at a moderate temperature (below 38°C) on a hotplate. If the grafting material

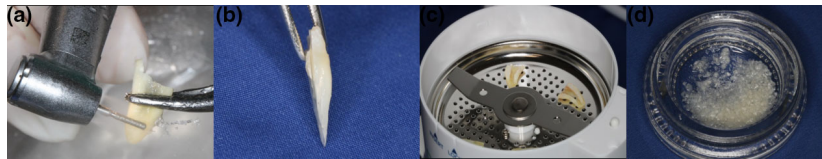


Fig. 1 (a) The illustration shows the removal of debris and foreign material, such as restorations and root filling material, as well as the periodontal ligament, from the root surface with a coarse diamond-coated bur under water cooling. (b) Dentin shell obtained from the root dentin with a diamond-coated cutting disk. (c) Sterile disposable dentin grinder (Smart Dentin Grinder) for the particulation of dentin. (d) Particulate-treated dentin.

was used immediately, it was then only slightly moistened with buffered saline solution. In cases where the grafting material was to be used at a later date, the dentin shell and the particulate dentin were stored in the same sterile vessel at -18°C until grafting. At the time of grafting, the grafting material was slightly moistened with saline after thawing. Thawing was done on the same hotplate which was used before (below 38°C).

General surgical procedure of the tooth shell technique (TST)

The grafting procedures were performed under perioperative antibiotics with Amoxicillin 750 mg t.i.d. (on one preoperative and two postoperative days). Patients with known penicillin intolerance were given Clindamycin 300 mg t.i.d.

After flap mobilization and surgical exposure of the alveolar crest, the implant site was prepared according to the protocol of the implant manufacturer. Then implants were inserted (Figs 2a-c and 4a). All implants could be inserted with sufficient primary stability. The previously obtained and prepared dentin shell was fixed laterally to the defect with osteosynthesis screws (microscrews; Stoma, Emmingen-Liptingen, Germany), and the prepared particulate dentin was placed in the hollow space between tooth shell and implant (Fig. 2d). In cases in which the accessibility made filling difficult, the exposed implant surface was first covered with particulate dentin and then the dentin shell was fixed (Fig. 4a-c). In both cases, it was the same technique, only with a different order. The stability of the dentin shell on the remaining bone was checked with dental tweezers. The dentin shell should not have any mobility. The Khoury technique

with autologous bones does not generally require a membrane. No membrane was used in the tooth shell technique either.

For passive wound closure, non-resorbable suture material was used (Supramid 5/0; Serag-Wiessner, Naila, Germany).

The implants were exposed 3 months after insertion. As part of this, the peri-implant tissue was probed at four locations (mesial, distal, oral and buccal) with a periodontal probe. Also, an implant stability measurement was carried out during the resonance frequency analysis in all cases (Ostell Idx; W&H, Buermoos, Austria). Only implants with an implant stability quotient (ISQ) of over 60 were approved for prosthetic restoration.

Radiographic evaluation

At the time of augmentation with simultaneous implantation, all implants were placed at the bone level. In all cases, the implant surfaces were completely covered by bone or hard tissue graft (autogenous dentin). To evaluate changes in the morphology of the peri-implant hard tissue, especially the buccal bone graft of the implants, a CBCT (PaX-Duo3D; Orange Dental, Biberach an der Riß, Germany) was made after implant insertion and at the follow-up 3 months later. The CBCTs were used to assess if any implant surfaces were not covered by bone or hard tissue graft. All measurements were performed with the Ez3D Plus software (Vatech Co. Ltd., Hwaseongsi, Korea). In all cases, a CBCT with a volume of $50 \times 50 \text{ mm}$ was made. For the standardization of the measurements, the implant served as a fixed point/axis. Also, all implants were placed in gaps where one or a maximum of two teeth were missing. The gaps

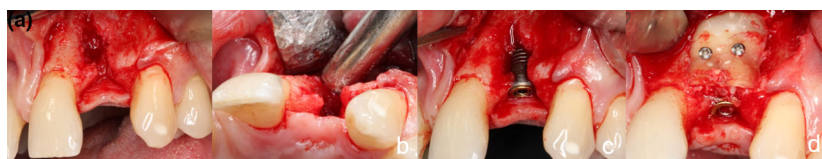


Fig. 2 (a, b) Occlusal and lateral view of the lateral defect (c) Inserted implant at site of tooth 22 with vestibular bone missing. (d) Dentin shell fixed with two osteosynthesis screws to the vestibular aspect of the implant. The hollow space created between dentin shell and implant was filled with particulate dentin.

were delimited mesially and in most cases also distally by neighbouring teeth. The pulp canals of the neighbouring teeth also served as fixed points/axes for the measurement. Since both the implant position and the pulp canal of the mesial neighbouring tooth were unchanged in the CBCT after implantation and during the follow-up check, 3 months after implantation at time of implant exposure, the CBCT could be compared with one another in a standardized manner.

To evaluate mesial and distal bone or hard tissue loss bordering the implants, measurements were made at the follow-up 3 months after implant insertion, at the mesial and distal margin of the implant shoulder similar to a 2D radiographic assessment (Fig. 3a). For mesial or distal bone or hard tissue loss, only the highest value at the mesial or distal margin was included in the analyses. The buccal hard tissue graft loss of the implants was assessed as shown in Fig. 3b. The reference point was the highest point of the implant shoulder. The examination of the CBCTs should evaluate if implant surfaces were covered by bone irrespective of hard tissue graft or not. If uncovered implant surfaces were detected, the distance between implant shoulder and the first implant/bone or implant/hard tissue contact was measured in mm (Fig. 3b).

The alveolar ridge width was measured in the bucco-palatal direction. Directly after augmentation with simultaneous implantation (T1) and at the follow-up 3 months later (T2), the width was measured 2 mm below the implant shoulder (see Fig. 3c). Moreover, the thickness of the buccal lamella was measured at three levels (L0, L2 and L4) at T0 and T1 (Fig. 3d).

Osseointegration

Complete osseointegration has been defined when:

- At none of the four measuring points within the scope of the implant exposure was a probing depth greater than 1 mm.
- The ISQ was over 60 during implant exposure.

- In the CBCT, the implant was completely surrounded by a radio-opaque structure.

Statistical analyses

Data were compiled in Excel and analysed with IBM SPSS Statistics 22 (SPSS Inc., Chicago, IL, USA) in Windows 7. All evaluations were computed at the patient level, site level and implant level. For the evaluation at the site level, the different sites were categorized as follows: block grafts were divided into sextants independently from one another (more than two tooth widths apart from each other).

Mean values and standard deviations at times T1 and T2 were calculated for Bucco-palatal alveolar ridge width and buccal lamella width (L0, L2 and L4). The difference of buccal lamella width between T1 and T2 at the different levels (L0, L2 and L4) was calculated to evaluate the resorption of the buccal lamella.

RESULTS

In the period from January 1, 2019 to March 31, 2020, the TST was carried out in 22 patients (11 females and 11 males) at 24 implant sites (Table 1). A total of 27 implants were placed simultaneously with the TST. ASTRA TECH Implant System™ EV, Nobel Biocare and Conelog were used as implant systems. The average age of the patients at the time of implantation was 60.4 years.

Severe clinical complications

After the grafting procedures with simultaneous implant insertion and during the follow-up 3 months later only a single (4.2% on-site level, 4.5% on patient-level), severe clinical complications occurred (Fig. 4d). This complication was dehiscence of a dentin shell. Three months after the graft, the exposed dentin shell was removed (Fig. 5a–c). The implant

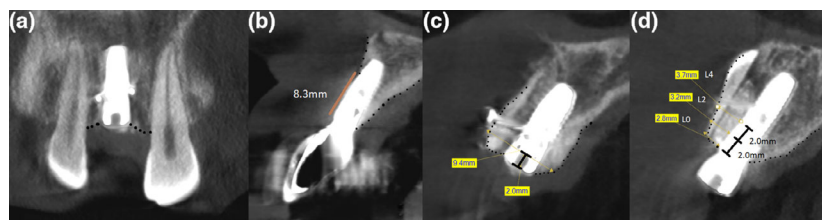


Fig. 3 Measurement of the resorption at the hard tissue grafts with cone beam computed tomography (CBCT). (a) No horizontal bone and hard tissue loss at the mesial and distal implant shoulder is detectable. (b) Measurement from the implant shoulder to the first implant/hard tissue bone contact. In this case, 8.3 mm of the buccal lamella bone was completely resorbed. (c) Measurement of bucco-palatal alveolar ridge width. (d) Measurements of the thickness of the buccal hard tissue lamella at three different levels (L0, L2 and L4). Dotted lines trace the outline of the alveolar ridge.

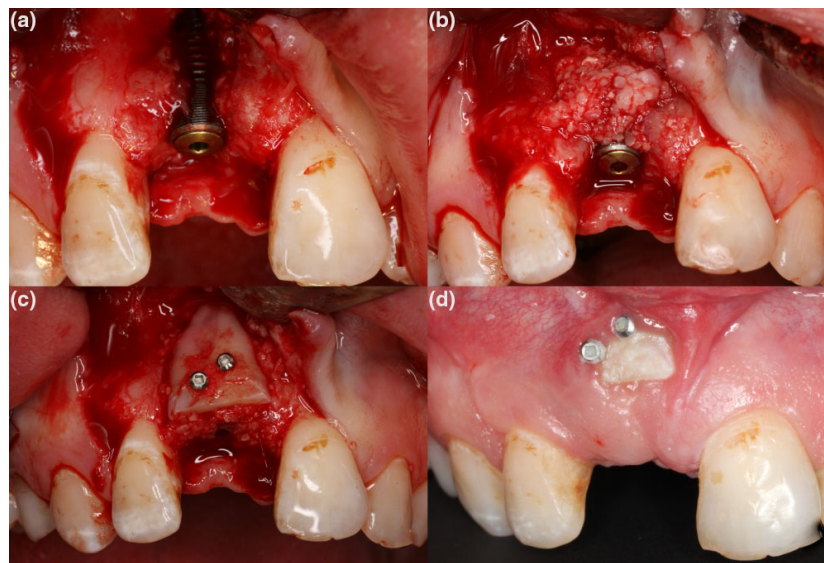


Fig. 4 (a) The inserted implant at the site of tooth 11 with a vestibular bone deficit. (b) Particulate dentin placed to the vestibular aspect of the implant. (c) A dentin shell was fixed with two osteosynthesis screws. (d) 4 weeks later, a dehiscence developed at the site of tooth 11 with partial exposure of the dentin shell and the two osteosynthesis screws.



Fig. 5 (a) The illustration shows the situation directly after the removal of the two osteosynthesis screws and the dentin shell. (b) Four weeks later, the mucosa completely covered the site. (c) At re-entry 4 weeks later, an all-ceramic crown was placed. The discolorations on the surfaces of the adjacent teeth were polished away.

was completely osseointegrated and still fully covered with hard tissue (Fig. 6c,d).

Non-severe clinical complications

During the whole follow-up period, there was no non-severe complication.

Radiographic evaluation

At the time of the follow-up, 3 months after augmentation with simultaneous implantation, the evaluation of the CBCTs showed no case with bone or hard tissue loss at the mesial or distal implant shoulder. Also, there was no loss of the buccal lamella (Fig. 6a–d). All implants were completely covered with hard tissue.

All measurements of the alveolar ridge width and resorption of the buccal lamella on the implants are summarized in Table 2 (measurement sites as shown in Fig. 3c,d). The alveolar ridge width (on patient-level) at the time of hard tissue graft was on average

9.5 mm at level L2. At the time of follow-up 3 months after augmentation, the alveolar ridge width was 9 mm at level L2. This means the resorption was 0.5 mm on average.

The thickness (on patient-level) of the buccal lamella was at the time of bone graft T1/L0 (2.8 mm), T1/L2 (3.4 mm) and T1/L4 (3.8 mm) and at time of follow-up T2/L0 (2.3 mm), T2/L2 (3.1 mm) and T2/L4 (3.4 mm). The resorption of the buccal lamella was T1-2/L0 (0.5 mm), T1-2/L2 (0.3 mm) and T1-2/L4 (0.4 mm). Since 0.3 mm resorption occurred in T1-2/L2, the oral lamella must also have resorption of 0.2 mm.

Peri-implant tissue probing

The probing depth did not exceed 0.5 mm for all implants.

ISQ values

The ISQ value was over 60 for all implants (Table 1).

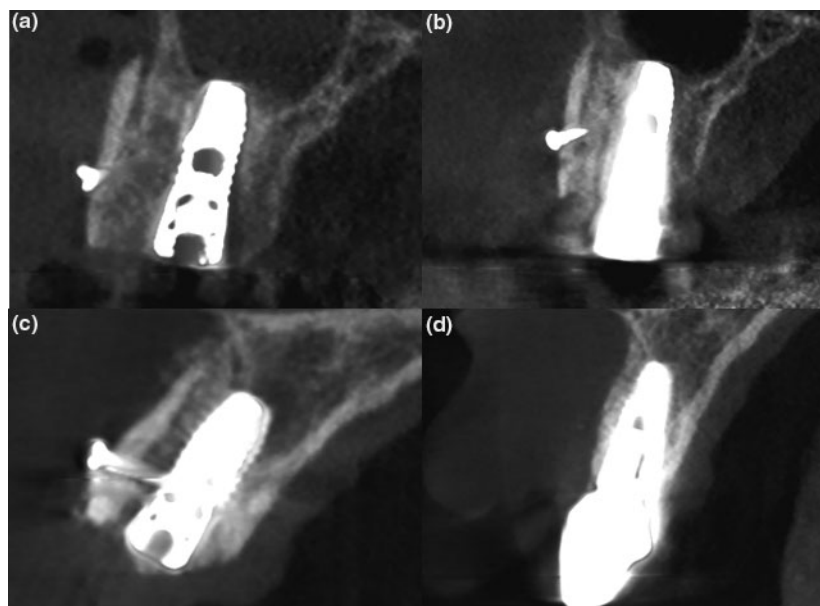


Fig. 6 (a) CBCT in the sagittal plane shows the implant at the site of tooth 15 after implantation and fixation of the dentin shell. (b) At re-entry, the augmentation material in the sagittal plane presents itself volumetrically stable and the implant has fully covered with hard tissue osseointegrated. Resorption of the palatal lamella has occurred. (c) This figure shows the only case with a severe complication. The detail of the sagittal plane shows the implant at the site of tooth 11 with the dentin shell fixed to it. (d) Despite the dehiscence and the removal of the dentin shell, a homogeneous structure with the density of cortical bone is to be seen on the buccal aspect of the implant. Resorption of the lamella has occurred on the palatal side.

Osseointegration

Since there was no increased probing depth for any of the implants, the ISQ values were over 60, and all implant surfaces were covered with hard tissue, all implants were by definition completely osseointegrated.

DISCUSSION

Research so far has been able to show that autogenous dentin is a suitable material for all kinds of alveolar crest augmentation.^{2-7,10} Autogenous dentin presents a good alternative to autogenous bone grafting as a result of the similarity of the biological characteristics and causes less strain for the patient because no second intervention is required to obtain the augmentation material so that harvesting morbidity and the risk of complications at the donor site can be eliminated.

Early implant losses in dental implantology are reported in the literature between 0.5% and 3%.^{16,17} In the present study, there was no early loss; the implant success rate was 100% during the observation period. By definition, all 24 implants were successfully osseointegrated and could be restored prosthetically. As for indicators of successful osseointegration, little or no peri-implant probing depth, an ISQ value of over 60 and complete coverage of the implant surface by hard tissue in the CBCT were assumed. It is known that increased probing depths indicate peri-

implant bone loss.¹⁸ The ISQ measurement with the Ostell device is a reproducible method¹⁹ and a widely accepted method for determining implant stability.²⁰ According to the manufacturer's information (W&H), a load from a value of 60 and over is possible. All implants in this study had a score of 65 or above. CBCTs are used as part of follow-up exams in numerous studies for assessing the alveolar ridge and the buccal lamella.^{21,22} Based on the available data, the definition adopted in this study for adequate osseointegration can be regarded as acceptable.

The study presented here combined a lateral ridge augmentation (TST) with simultaneous implantation. Ridge augmentations not only increase the surgical effort but also the intra- and postoperative risk. In the present study, a serious complication occurred in only one of 27 implants. Nevertheless, 100% of all implants were osseointegrated. Comparable studies with autologous bone and dentine block grafts also showed manageable complication rates.^{9,23}

In comparison to the autogenous bone, autogenous dentin demonstrates significantly less resorption.⁹ In the presented study, no horizontal bone loss occurred in any case of the presented study. All implants were fully covered with hard tissue. The buccal lamella was most resorbed at L0 (0.5 mm at patient level). The cause could be the flattening of the augmentation in this area. However, the only resorption of 0.3 mm (patient level) occurred in L2. The alveolar ridge width measured at L2 decreased 0.5 mm (patient level). This means that there must have been

Table 2. Mean alveolar ridge bone measurements directly after grafting (T1) and at time of follow-up (T2)

Hard tissue measurements at T1 and T2	Evaluation level		
	Patient, n = 22 (SD)	Site, n=24 (SD)	Implant, n = 27 (SD)
T1 (directly after grafting)			
Mean bucco-palatal alveolar ridge width (mm)	9.5 (1.4)	9.5 (1.4)	9.5 (1.4)
Mean buccal lamella width L0 (mm)	2.8 (0.7)	2.8 (0.6)	2.8 (0.6)
Mean buccal lamella width L2 (mm)	3.3 (0.8)	3.4 (0.8)	3.4 (0.8)
Mean buccal lamella width L4 (mm)	3.7 (1.2)	3.7 (1.3)	3.8 (1.3)
T2 (at time of follow up)			
Mean bucco-palatal alveolar ridge width (mm)	9 (1.4)	9 (1.4)	9 (1.5)
Mean buccal lamella width L0 (mm)	2.3 (1)	2.3 (1)	2.3 (1)
Mean buccal lamella width L2 (mm)	3.1 (0.9)	3.1 (0.9)	3.1 (0.9)
Mean buccal lamella width L4 (mm)	3.4 (1.3)	3.4 (1.4)	3.4 (1.4)
Mean resorption of Bucco-oral alveolar ridge bone width and buccal lamella bone plate from T1 to T2			
Bucco-oral alveolar ridge (mm)	0.5	0.5	0.5
L0 (mm)	0.5	0.5	0.5
L2 (mm)	0.2	0.3	0.3
L4 (mm)	0.3	0.3	0.4

n = number; SD = standard deviation.

resorption of 0.2 mm on the oral side, which has nothing to do with the resorption of the bone graft. The reason could be resorption of the oral bone, caused by the deperiostation after flap mobilization. A long-term resorption pattern is unknown and it may have an impact on the aesthetic outcome in the maxillary anterior region.

The present study is a proof of concept study. The aim was to determine whether the use of dentin in TST is generally successful. In this study, intrabony defects were also treated. In these cases, a guided bone regeneration is also applicable. However, compared to block transplants, it is disadvantageous that in cases of guided bone regeneration an augmentation flattening occurs during the healing process in the marginal area.²⁴ The area of application of block transplants is not limited to intrabony defects. The same range of treatments is suspected for TST as for block transplants. However, further studies must confirm this assumption.

It is unclear whether the dentin particles and shell are osseointegrated when using the TST technique. Based on the CBCTs, it cannot be said whether it is ossified buccal lamella or just dentin without osseointegration. The dentin could possibly only be remodelled by granulation tissue. In the present study, there is a lack of histological examination of the hard tissue graft. The present study did not carry out any histological examinations, since this would have led to a second operation with the tooth-shell technique with simultaneous implantation. Simultaneous implantation also prevents hard tissue histology from being obtained. Therefore, the augmentation was referred to as a hard tissue graft and not as a bone graft in the present manuscript. Regardless of this, there are histological examinations that demonstrate osseointegration of dentin augmentations.^{3,5} The fact that there

were no or only minimal (up to 0.5 mm) buccal probing depths indicates the likelihood of osseointegration of the dentine. Also, sufficiently high ISQ values were achieved in all cases.

In the TST technique, particulate dentin was placed directly on the exposed implant surfaces. It is unclear whether there is a direct connection between the titanium surface and the dentin graft. Histologically, animal experiments showed a substitutive resorption of the dentin and a contact area between implant and bone which was comparable to autogenous bone blocks.^{2,8} In the region of direct contact between dentin and titanium implant surface, the formation of root cementum and mineralized hard tissue could be identified histologically.²⁵⁻²⁷ Furthermore, the preparation of the tooth also seems to have an influence on the success rate. Studies have shown that the mechanical removal of dental plaque significantly reduced the inflammatory reaction.²⁸

If a complete tooth root is used as augmentation material, as described by Schwarz et al.,⁹ the dimension of the root will limit the augmentation width. With the tooth shell technique described here, a larger horizontal deficit can be augmented, in analogy to the bone block grafting technique by Khoury.¹⁴ The particulate dentin in the space between the bone and the dentin shell can be expected to lead to better revascularization and regeneration than a procedure using solid dentin blocks.¹⁴ Another advantage offered by this augmentation technique is that augmentation and implant insertion can be performed simultaneously if the morphology and size of the defect allow it.²⁹ And, as a result of the chemical treatment and disinfection described above which can be done in a standard dental practice environment, the tooth material can be prepared for storage and kept for later usage.

Autogenous dentin is a safe grafting material; the transmission of infectious or immunological reactions is not to be expected as it is a material of autogenous origin. A greater probability of complications, such as impaired wound healing, dehiscences or implant losses, could not be found clinically when autogenous dentin was compared to autogenous bone.³⁰ In animal experiments, however a slightly higher incidence of augmentation material exposure was observed if teeth were used that had been endodontically treated or was periodontally compromised in comparison with healthy retained teeth that were not exposed to the oral cavity environment.^{7,8} But in a clinical study published by Schwarz et al. in 2019, this observation was not confirmed. In the Schwarz study, neither impaired wound healing nor dehiscences were found for the healthy retained as well as for the endodontically treated and/or periodontally compromised teeth.¹⁰ The dehiscence described in one case with exposure of the augmentation material and the screws was very probably caused by the laceration of the full-thickness flap.³¹

The TST limits are when the tooth to be replaced is no longer present and there are no other non-preservable teeth. In cases of large alveolar crest defects, it may still be possible to resort to a donor region. A weak point of the study is the relatively short follow-up period of 3 months. The results appear promising but should be assessed with caution. Studies with a longer observation period are required. Also, comparative studies with autologous bone block transplants should be aimed for.

CONCLUSION

The tooth shell technique is a hard tissue augmentation procedure that can be performed in a dental practice environment for the reconstruction of lateral alveolar crest defects; it combines the biological benefits of autogenous material with lower morbidity, as a second intervention for harvesting autogenous bone could be avoided. Compared with the procedures described so far, the tooth shell technique using autogenous dentin could broaden the range of implantological indications. It allows larger augmentation volumes and offers the option of simultaneous implantation.

More clinical studies are needed to further investigate the augmentation results of this technique with regard to bone quantity and histology.

AUTHOR CONTRIBUTIONS

Korsch, M. invented the operating technique, took the photographs, collected and analysed the data, and kept the letter.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

REFERENCES

1. Sakkas A, Wilde F, Heufelder M, Winter K, Schramm A. Auto-genous bone grafts in oral implantology-is it still a "gold standard"? A consecutive review of 279 patients with 456 clinical procedures. *Int J Implant Dent* 2017;3:23.
2. Becker K, Jandik K, Stauber M, Mihatovic I, Drescher D, Schwarz F. Microstructural volumetric analysis of lateral ridge augmentation using differently conditioned tooth roots. *Clin Oral Investig* 2019;23:3063–3071.
3. Bormann KH, Suarez-Cunqueiro MM, Sinikovic B, *et al.* Dentin as a suitable bone substitute comparable to ss-TCP-an experimental study in mice. *Microvasc Res* 2012;84:116–122.
4. Gual-Vaques P, Polis-Yanes C, Estrugo-Devesa A, Ayuso-Montero R, Mari-Roig A, Lopez-Lopez J. Autogenous teeth used for bone grafting: A systematic review. *Med Oral Patol Oral Cir Bucal* 2018;23:e112–e119.
5. Jun SH, Ahn JS, Lee JI, Ahn KJ, Yun PY, Kim YK. A prospective study on the effectiveness of newly developed autogenous tooth bone graft material for sinus bone graft procedure. *J Adv Prosthodont* 2014;6:528–538.
6. Minamizato T, Koga T, Takashi I, *et al.* Clinical application of autogenous partially demineralized dentin matrix prepared immediately after extraction for alveolar bone regeneration in implant dentistry: a pilot study. *Int J Oral Maxillofac Surg* 2018;47:125–132.
7. Schwarz F, Golubovic V, Becker K, Mihatovic I. Extracted tooth roots used for lateral alveolar ridge augmentation: a proof-of-concept study. *J Clin Periodontol* 2016;43:345–353.
8. Schwarz F, Golubovic V, Mihatovic I, Becker J. Periodontally diseased tooth roots used for lateral alveolar ridge augmentation. A proof-of-concept study. *J Clin Periodontol* 2016;43:797–803.
9. Schwarz F, Hazar D, Becker K, Sader R, Becker J. Efficacy of autogenous tooth roots for lateral alveolar ridge augmentation and staged implant placement. A prospective controlled clinical study. *J Clin Periodontol* 2018;45:996–1004.
10. Schwarz F, Sahin D, Becker K, Sader R, Becker J. Autogenous tooth roots for lateral extraction socket augmentation and staged implant placement. A prospective observational study. *Clin Oral Implants Res* 2019;30:439–446.
11. Kim YK, Kim SG, Byeon JH, *et al.* Development of a novel bone grafting material using autogenous teeth. *Oral Surg Oral Med Oral Pathol Oral Radiol Endodontol.* 2010;109:496–503.
12. Kim YK, Lee J, Um IW, *et al.* Tooth-derived bone graft material. *J Korean Assoc Oral Maxillofac Surg.* 2013; 39:103–111.
13. Linde A. Dentin matrix proteins: composition and possible functions in calcification. *Anat Rec* 1989;224:154–166.

14. Khoury F, Hanser T. Three-dimensional vertical alveolar ridge augmentation in the posterior maxilla: a 10-year clinical study. *Int J Oral Maxillofac Implants* 2019;34:471–480.
15. Bono N, Tarsini P, Candiani G. Demineralized dentin and enamel matrices as suitable substrates for bone regeneration. *J Appl Biomater Funct Mater* 2017;15:e236–e243.
16. Zhang ZY, Meng T, Chen Q, Liu WS, Chen YH Retrospective analysis of early dental implant failure. *Beijing Da Xue Xue Bao Yi Xue Ban* 2018;50:1088–1091.
17. Fouda AAH. The impact of the alveolar bone sites on early implant failure: a systematic review with meta-analysis. *J Korean Assoc Oral Maxillofac Surg* 2020;46:162–173.
18. Schwarz F, Derks J, Monje A, Wang HL. Peri-implantitis. *J Periodontol* 2018;89(Suppl 1):S267–S290.
19. Kastel I, de Quincey G, Neugebauer J, Sader R, Gehrke P. Does the manual insertion torque of smartpegs affect the outcome of implant stability quotients (ISQ) during resonance frequency analysis (RFA)? *Int J Implant Dent* 2019;5:42.
20. Soares PB, Moura CC, Claudino M, Carvalho VF, Rocha FS, Zanetta-Barbosa D. Influence of implant surfaces on osseointegration: a histomorphometric and implant stability study in rabbits. *Braz Dent J* 2015;26:451–457.
21. Chappuis V, Rahman L, Buser R, Janner SFM, Belser UC, Buser D. Effectiveness of contour augmentation with guided bone regeneration: 10-year results. *J Dent Res* 2018;97:266–274.
22. Chopra A, Mhapuskar AA, Marathe S, Nisa SU, Thopte S, Sadiwal R. Evaluation of osseointegration in implants using digital orthopantomogram and cone beam computed tomography. *J Contemp Dent Pract* 2016;17:953–957.
23. Korsch M, Kasprzyk S, Walther W, Bartols A. Lateral alveolar ridge augmentation with autogenous block grafts fixed at a distance vs resorbable poly-D-L-lactide foil fixed at a distance: 5-year results of a single-blind, randomised controlled trial. *Int J Oral Implantol* 2019;12:299–312.
24. Troeltzsch M, Troeltzsch M, Kauffmann P, *et al.* Clinical efficacy of grafting materials in alveolar ridge augmentation: A systematic review. *J Craniomaxillofac Surg* 2016;44:1618–1629.
25. Baumer D, Zuhr O, Rebele S, Schneider D, Schupbach P, Hürzeler M. The socket-shield technique: first histological, clinical, and volumetrical observations after separation of the buccal tooth segment – a pilot study. *Clin Implant Dent Relat Res* 2015;17:71–82.
26. Hürzeler MB, Zuhr O, Schupbach P, Rebele SF, Emmanouilidis N, Fickl S. The socket-shield technique: a proof-of-principle report. *J Clin Periodontol* 2010;37:855–862.
27. Schwarz F, Mihatovic I, Golubovic V, Becker J. Dentointegration of a titanium implant: a case report. *Oral Maxillofac Surg* 2013;17:235–241.
28. Nasirzade J, Kargarpour Z, Panahipour L, Schwarz F, Gruber R. Cleaning teeth reduces the inflammatory response of macrophages to acid dentine lysate. *Int J Mol Sci* 2020;21:9207.
29. Khoury FHT, Khoury Ch, Neugebauer J, Trepelle T, Tunkel J, Zöller JE. *Augmentative Verfahren in der Implantologie. Biologie und Physiologie des Implantatlagers unter Berücksichtigung von Transplantationsverfahren.* Berlin, Germany: Quintessenz Verlag, 2009:2–30.
30. Ramanauskaitė A, Sahin D, Sader R, Becker J, Schwarz F. Efficacy of autogenous teeth for the reconstruction of alveolar ridge deficiencies: a systematic review. *Clin Oral Investig* 2019;23:4263–4287.
31. Sakkas A, Schramm A, Winter K, Wilde F. Risk factors for post-operative complications after procedures for autologous bone augmentation from different donor sites. *J Craniomaxillofac Surg* 2018;46:312–322.

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