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ORIGINAL ARTICLE

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Efficacy of autogenous tooth roots for a combined vertical and horizontal alveolar ridge augmentation and staged implant placement. A prospective controlled clinical study

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Abstract

Objectives: To assess and compare the efficacy and safety of autogenous tooth roots (TRs) and autogenous bone blocks (ABs) for combined vertical and horizontal alveolar ridge augmentation and two-stage implant placement.

Materials and Methods: A total of 28 patients in need of implant therapy and vertical ridge augmentation were allocated to parallel groups receiving either healthy autogenous tooth roots (e.g., retained wisdom teeth) ($n = 14$, $n = 15$ defects) or cortical autogenous bone blocks harvested from the retromolar area ($n = 14$, $n = 17$ defects). After 26 weeks of submerged healing, the clinical reduction in ridge height (RH) deficiency was defined as the primary outcome.

Results: Both surgical procedures were associated with a similar mean reduction in RH deficiency values, amounting to 4.48 ± 2.42 mm (median: 4.25; 95% CI: 3.08–5.88) in the TR group and 4.46 ± 3.31 mm (median: 3.00; 95% CI: 2.54–6.38) in the AB group ($p = .60$, Mann–Whitney *U*-test). In all patients investigated, the reduction in RH deficiency values allowed for an adequate implant placement at the respective sites. The frequency of complications (e.g., soft tissue dehiscences) was low (TR: $n = 4$; AB: $n = 0$).

Conclusions: Up to staged-implant placement, both TR and AB grafts appeared to be associated with comparable efficacy and safety for combined vertical and horizontal alveolar ridge augmentation.

KEYWORDS
alveolar ridge augmentation, clinical study, tooth transplantation

Clinical Relevance

Scientific rationale for study: Pre-clinical data have pointed to the biological potential of TRs serving as autografts for vertical alveolar ridge augmentation and two-stage implant placement.

Frank Schwarz and Karina Obreja contributed equally to the study and are considered joint first authors.
Robert Sader and Puria Parvini contributed equally to the study and are considered joint senior authors.

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Principal findings: At 26 weeks, TR and AB grafts resulted in a similar mean reduction in RH deficiency and ridge width, thus facilitating the placement of adequately dimensioned titanium implants in the former defect area. Secondary performance and safety endpoints were comparable in both groups.

Practical implications: TR may serve as an alternative graft to support vertical alveolar ridge augmentation and two-stage implant placement.

1 | INTRODUCTION

Vertical alveolar ridge augmentation is considered to be a highly technique-sensitive surgical approach to allow an adequate implant placement at severely compromised sites (Jepsen et al., 2019). A recent systematic review and meta-analysis has pointed to a weighted mean vertical bone gain of 4.16 mm (95% CI: 3.72–4.61 mm), with distinct differences noted between various procedures. These included distraction osteogenesis (8.04 mm), guided bone regeneration (GBR) (4.18 mm), and various types of bone blocks (3.46 mm). The reported implant survival rates amounted to 98.95%, with success rates ranging from 85% to 100% over a follow-up period of at least 5 years (Urban et al., 2019).

However, apart from the proven efficacy, it was also noted that vertical grafting is commonly associated with high post-operative complications, mainly wound infections and graft exposures/losses. These also varied among the procedures investigated and amounted to 47.3% for distraction osteogenesis, 23.9% for bone blocks, and 12.1% for GBR (Jepsen et al., 2019; Urban et al., 2019).

A recent systematic review has pointed to the high potential of autogenous tooth roots (TRs) to serve as alternative grafting material for alveolar ridge augmentation. Its efficacy has been proven in various clinical indications, with most of the evidence being available for staged lateral grafting (Ramanauskaite et al., 2019). In a controlled clinical study, TR grafts resulted in a similar gain in ridge width (RW) as with autogenous retromolar bone blocks (AB), thus allowing for an adequate staged implant placement with comparable survival and success rates (Schwarz et al., 2018; Schwarz, Hazar, et al., 2019). The biological potential of TR may be attributed to dentin serving as a rich source of transforming growth factor beta (TGF-β), which potentially triggers cellular activities following its release during the remodelling process (Nasirzade et al., 2021).

A recent pre-clinical study assessed TR grafts for vertical alveolar ridge augmentation and two-stage implant placement. It has been demonstrated that dentin block grafts were associated with a replacement resorption and a marked vertical bone gain, thus supporting the early osseointegration process (Parvini et al., 2019; Schwarz, Mihatovic, et al., 2019). A major challenge in vertical grafting is, however, related to the need to also establish an adequate RW, which is essential for staged implant placement without a secondary grafting or contour augmentation. Accordingly, vertical alveolar ridge augmentation procedures aim at establishing adequate vertical and lateral hard tissue dimensions. In the currently available literature, the resulting RW following vertical grafting is very rarely reported (Abrahamsson et al., 2012).

The aim of this prospective clinical study was to assess and compare the efficacy and safety of autogenous TR and AB blocks for combined vertical and horizontal alveolar ridge augmentation and two-stage implant placement.

2 | MATERIALS AND METHODS

2.1 | Study design and participants

In this prospective controlled clinical monocentre study, 28 patients were included who were in need for a combined vertical and horizontal alveolar ridge augmentation to allow an implant-supported fixed restoration at either tooth gaps or free-end situations. All patients were consecutively recruited and treated at the Department of Oral Surgery and Implantology, Goethe University, Frankfurt, Germany.

In the presence of one or more caries-free, partially/fully retained, or impacted wisdom teeth without clinical/radiographic signs of local pathologies (e.g., cysts), the respective patient was allocated to the TR group ($n = 14$; female: 5; male: 9; median age: 41.00 years). In the absence of any suitable wisdom teeth, the patient was allocated to the AB group ($n = 14$; female: 4; male: 10; median age: 48.00 years).

Each patient was given a detailed description of the procedure and was required to sign an informed consent before participation. The study protocol was approved by the ethics committee of the Goethe University and registered via the internet portal of the German Clinical Trials Register (DRKS00016717).

The present reporting considered the checklist items as proposed in the STROBE statement.

2.2 | Inclusion criteria

All patients had to meet the following inclusion criteria: (1) being fully able to understand the nature of the proposed surgery, (2) being a candidate for a combined vertical and horizontal alveolar ridge augmentation due to an insufficient radiographic bone height of ≤6 mm above adjacent anatomical structures (i.e., mandibular canal, nasal cavity, maxillary sinus) at the recipient site for implant placement, and (3) having healthy oral mucosa, with at least 3 mm keratinized tissue.

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2.3 | Exclusion criteria

The patients were not included in the study if they presented one of the following conditions: (1) general contraindications for dental and/or surgical treatments, (2) inflammatory and autoimmune disease of the oral cavity, (3) uncontrolled diabetes (HbA1c > 7%), (4) a history of malignancy requiring chemotherapy or radiotherapy within the past 5 years, (5) previous immunosuppressant, anti-resorptive, or high dose corticosteroid therapy, (6) smokers, (7) pregnant or lactating women, (8) women of child-bearing age who are not using a highly effective method of birth control, and (9) participation in an investigational device, drug, or biologics study within the last 24 weeks.

2.4 | Outcome assessments

The clinical reduction in ridge height (RH) deficiency being adequate for staged implant placement was defined as the primary outcome. Secondary endpoints included the clinical RW, vertical graft resorption (GR) and horizontal GR, the need for secondary grafting (i.e., due to the occurrence of dehiscence-type defects at implant placement), the need for additional grafting (i.e., contour augmentation due to a thin buccal bone plate <1 mm at implant placement), and time needed for surgery (i.e., grafting). Furthermore, safety outcomes (i.e., complications) included the occurrence of soft tissue dehiscences (yes/no), graft exposures/loss (yes/no), and wound infections (yes/no).

During surgery, the baseline deficiency in RH was measured perpendicularly from the most apical aspect of the defect bottom to the most coronal extension of the bone crest at the interproximal aspect of either the adjacent anterior tooth (i.e., refers to free end situations) or teeth (i.e., refers to tooth gaps). In case of two adjacent teeth, the lowest RH value was selected as the reference point for the measurements. RH deficiency was also assessed after augmentation, as well as during re-entry at 26 weeks, as measured from the most coronal extension of TR/AB grafts to the reference bone crest. The reduction in RH deficiency was defined as RH deficiency at 26 weeks minus RH deficiency at baseline, and vertical GR was defined as RH deficiency at 26 weeks minus RH deficiency after augmentation (Figure 1a,b).

RW was assessed immediately after augmentation, as well as during re-entry at 26 weeks. In case of a tooth gap, RW was measured at its most centric aspect, whereas in the case of a free-end situation, RW was assessed at the projected ideal implant position/s relative to the most posterior tooth. Horizontal GR was defined as RW at 26 weeks minus RW after augmentation.

All associated RH and RW measurements were performed using a millimetre-scaled periodontal probe (CP15, Carl Martin, Solingen, Germany).

Safety outcomes were recorded at day 10 as well as at weeks 4, 13, and 26 after surgery.

According to the clinical standard procedure, appropriate radiographs were taken before and after the respective surgical interventions (i.e., alveolar ridge augmentation and implant placement). All measurements were recorded by one previously calibrated investigator. Calibration included the identification of the reference points and associated linear measurements in similar surgeries performed before the initiation of the study. The study outline and the follow-up visits are summarized in Table 1.

2.5 | Sample size calculation

Calculation of the sample size was based on a non-inferiority testing of TR to AB grafts. For the power analysis, a standard normal distribution was assumed. The probability of a Type I error was set at .05. The effect size *d* was calculated based on the means and standard deviations of the gains in RW noted in both groups following lateral alveolar ridge augmentation (Schwarz et al., 2018). The margin for the reduction in RH deficiency was set at 2 mm. In order to achieve 85% power and allow a drop-out rate of 15%, a sample size of 34 patients (17 per group) was calculated. Owing to the COVID-19 pandemic, the number of included patients had to be limited to $n = 28$. For the given sample size, Type I error, and effect size *d*, the post hoc analysis revealed an achieved power of 0.80 (one-sided *t*-test, G*Power 3.1).

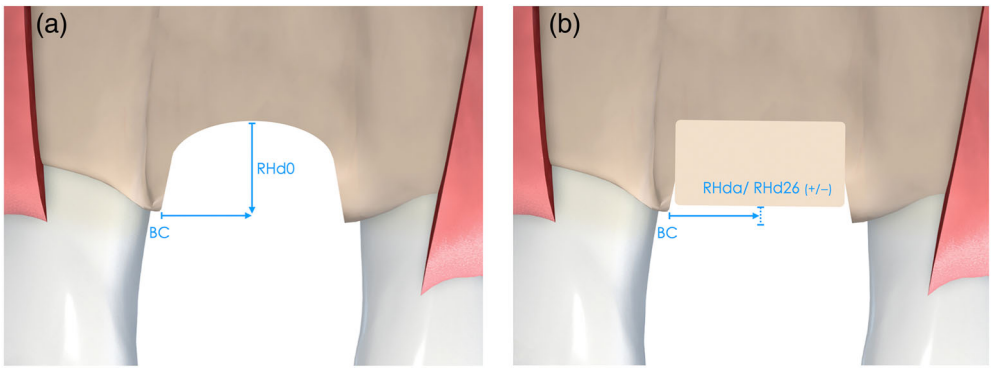

FIGURE 1 Clinical assessment of vertical bone gain and graft resorption. (a) RH deficiency at baseline was assessed from the defect bottom to the most coronal extension of the bone crest at the interproximal aspect of adjacent teeth, with the lowest value serving as reference point. (b) RH deficiency was also assessed immediately after augmentation and during re-entry at 26 weeks and measured from the most coronal extension of TR/AB grafts to the reference bone crest

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TABLE 1 Study design and follow-up visits

Visit 1 Recruitment	Visit 2 Surgery	Visit 3	Visit 4	Visit 5	Visit 6 Re-entry
	Day 0	Day 10 ± 4	Week 4 ± 1	Week 13 ± 2	Week 26 ± 4

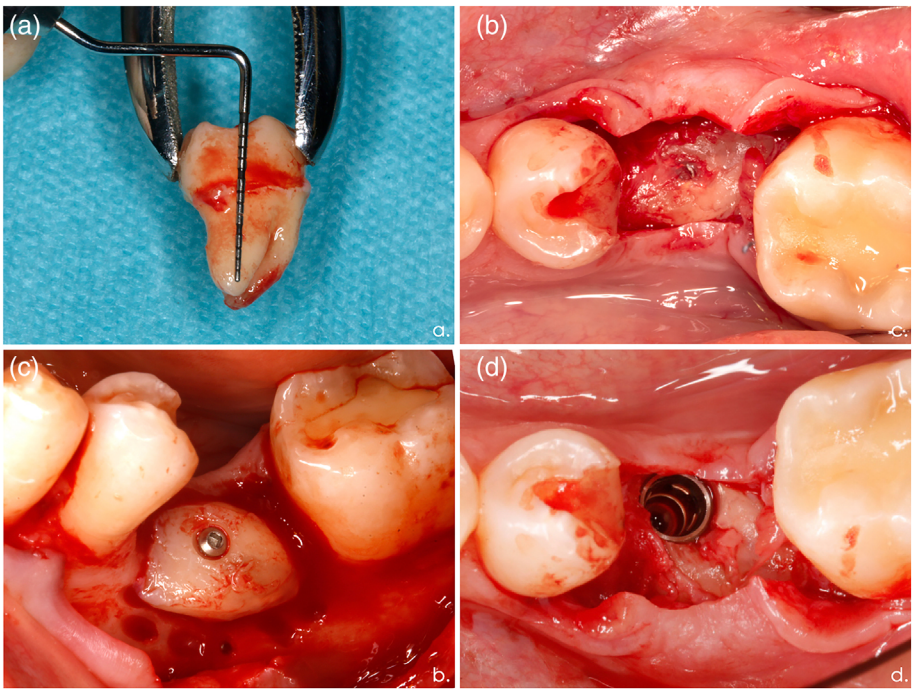

FIGURE 2 Vertical ridge augmentation—surgical procedure in the TR group. (a) TR grafts were derived from either partially/fully retained or impacted wisdom teeth. (b) Following crown decapitation, the most suitable root was separated and shaped to match the defect size. Dentin was exposed at the downward aspect of the root to facilitate ankylosis, while the cementum layer was preserved at the upward aspect. No further contour augmentation was provided. (c) Clinical re-entry at 26 weeks points to a homogeneous graft integration. (d) Clinical situation following implant placement

2.6 | Treatment procedures

The surgical procedure at all defect sites considered the preparation of a muco-periosteal flap (two vertical releasing incisions) extending to and including the respective adjacent teeth using micro-blades.

In the TR group, a second surgery was conducted for the removal of the respective wisdom tooth. All wisdom teeth could be removed without root resections. Subsequently, the roots were isolated by a horizontal separation of the crown at the cemento-enamel junction and size adapted in a way that their (1) coronal-apical extension correlated with the mesio-distal width of the respective defect sites, and (2) thickness correlated with the respective RHd0 values. To improve ankylosis between the graft and the pristine bone, the layer of cementum at the respective downward aspects of the root was carefully removed using a diamond bur until the underlying dentin was entirely exposed (Schwarz, Golubovic, Becker, et al., 2016; Schwarz, Golubovic, Mihatovic, et al., 2016) (Figure 2a,b).

In the AB group, monocortical retromolar block grafts were harvested from the external oblique line using a combination of rotating (i.e., carbide burrs) and piezoelectric (Mectron, Cologne, Germany) instruments. The precise location of the donor site was individually defined based on pre-operative radiographs considering relevant anatomical structures (e.g., course of the mandibular canal, availability of bone). AB grafts were also size-adapted to match the mesio-distal width and RH deficiency of the recipient site (Figure 3a,b).

In both groups, the receiving site was slightly flattened by a round bur to improve the contact between both TR and AB grafts and the recipient site. Moreover, cortical perforations were made to facilitate blood supply. After graft fixation using one or two titanium osteosynthesis screws (micro screw set, Stoma, Emmingen-Liptingen, Germany), the shaping of TR and AB blocks was accomplished to obtain the best possible contours. Peri-osteal releasing incisions were made to enable coronal advancement and tension-free coverage of the surgical site. All patients were provided with a peri-operative antibiotic (1 × amoxicillin 2 g) as well as a peri- and post-operative (2 days) antiphlogistic prophylaxis (prednisolon, total of 40 mg). Analgetics (ibuprofen 600 mg) were prescribed and used as necessary. Suture removal was done at day 10. After 26 weeks of healing, a muco-periosteal flap was elevated to expose the target site in the respective groups. After removing the osteosynthesis screws gently, commercially available titanium implants (Bone Level Tapered, BLX SLActive, Tissue Level, Institut Straumann AG, Basel, Switzerland and NobelActive, Nobel Biocare, Kloten, Switzerland) were inserted according to individual needs. The procedures were performed by three experienced and calibrated oral surgeons (F.S., K.O., and P.P.).

2.7 | Post-operative care

All patients were instructed to rinse twice daily with chlorhexidine mouth rinse (0.12%) for 1 week and avoid brushing or flossing at the surgical site for the first 3 weeks.

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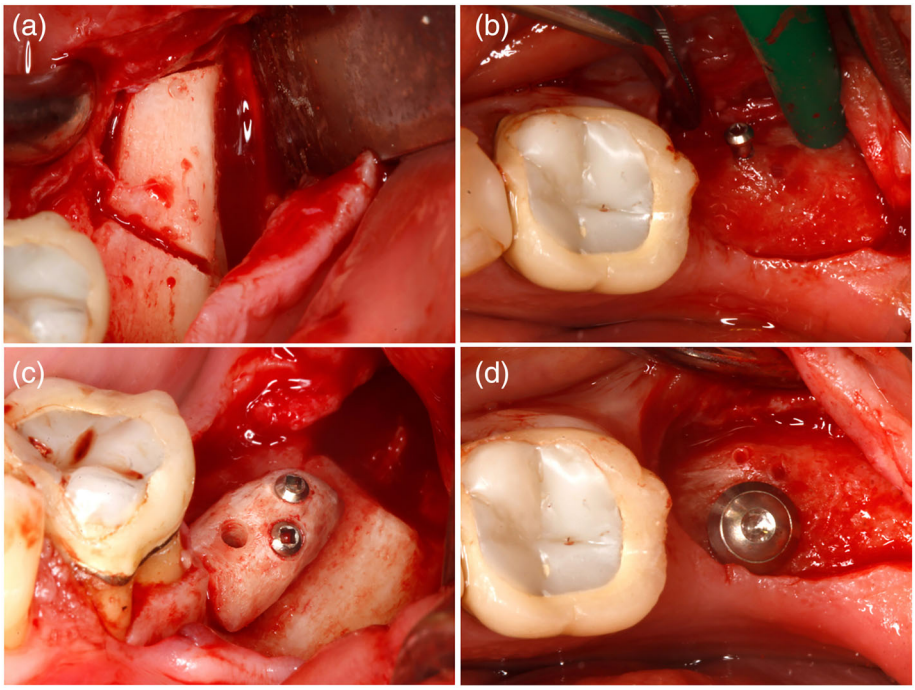

FIGURE 3 Vertical ridge augmentation—surgical procedure in the AB group. (a) The retromolar area served as donor site for the harvesting of monocortical bone blocks. (b) Shaped and predrilled AB block fixed at the defect side using osteosynthesis screws. (c) Clinical re-entry pointing to a more pronounced graft remodelling as evidenced by a protruding screw head. (d) Both augmentation procedures allowed an adequate implant placement

2.8 | Statistical analysis

Statistical analysis of the pseudonymized datasets was accomplished using a commercially available software program (IBM SPSS Statistics 27.0, IBM Corp., Armonk, NY, USA).

Mean values, standard deviations, medians, 95% confidence intervals (CI), and frequency distributions were calculated for all primary and secondary outcomes assessed at both patient level and implant level. The patient-level datasets were examined with the Shapiro–Wilk test for normal distribution.

Between-group comparisons of non-normally-distributed variables (RH deficiency at baseline, RH after augmentation, RH at 26 weeks, reduction in RH deficiency, vertical and horizontal GR) at the patient level were accomplished using the Mann–Whitney *U*-test. Between-group comparisons of normally distributed data (surgery time, RW after augmentation, RW at 26 weeks) at the patient level were accomplished using the independent *t*-test. In the presence of multiple implants, patient-level data were based on the respective mean values.

Linear regression analyses were used to depict the relationship between the reduction in RH deficiency and RH deficiency at baseline in both groups. The alpha error was set at .05.

3 | RESULTS

A total of 28 (*n*) patients exhibiting 32 (*n*) defect sites (TR = 15; AB = 17) were available for the analysis. The target sites were mainly at tooth gaps (TR = 13; AB = 12) and located in the lower jaw (TR = 10; AB = 10). Free-end situations were less frequent (TR = 2; AB = 5). Posterior regions (TR = 11; AB = 9) were more frequent than anterior regions (TR = 4; AB = 8) (Table 2).

TABLE 2 Site characteristics in AB ($n = 17$) and TR ($n = 15$) treated groups

	AB	TR
Localization		
Upper jaw	7	5
Lower jaw	10	10
Anterior sites	8	4
Posterior sites	9	11
Configuration		
Tooth gaps	12	13
Free-end situations	5	2
Surgical procedure		
Surgeon 1	0	6
Surgeon 2	2	6
Surgeon 3	15	3

Mean baseline RH deficiency was comparable ($p = .164$, Mann–Whitney *U*-test) in both groups and amounted to −4.01 ± 2.22 mm (median: −3.0; 95% CI: −5.30 to −2.73) in the TR group and − 4.32 ± 2.67 mm (median: −3.0; 95% CI: −5.86 to −2.77) in the AB group.

The mean time needed for the surgery per patient amounted to 142.85 ± 69.77 min (median: 127.50; 95% CI: 102.57−183.14) in the TR group and 150.00 ± 37.15 min (median: 150.00; 95% CI: 128.54−171.45) in the AB group ($p = .33$, Mann–Whitney *U*-test).

Both groups were associated with a comparable RH deficiency after augmentation ($p = .165$, Mann–Whitney *U*-test), amounting to

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TABLE 3 Primary and secondary performance endpoints (in mm) at the patient level

(a) TR group ($n = 14$ patients)								
	RHd0	**RHda**	**RHd26**	**RHdr**	**GRv**	**RWa**	**RW26**	**GRh**
Mean	−4.01	0.35	0.46	4.48	0.10	8.82	8.28*	−0.53
SD	2.22	0.92	1.02	2.42	1.36	1.50	1.60	1.13
Median	−3.00	0.25	0.50	4.25	0.00	9.00	8.50	0.00
95% CI	−5.30 to −2.73	−0.17 to 0.89	−0.12 to 1.05	3.08 to 5.88	−0.67 to 0.89	7.95 to 9.68	7.36 to 9.21	−1.19 to 0.11
(b) AB group ($n = 14$ patients)								
	RHd0	**RHda**	**RHd26**	**RHdr**	**GRv**	**RWa**	**RW26**	**GRh**
Mean	−4.32	−0.28	0.14	4.46	0.42	7.25	7.28	0.03
SD	2.67	0.72	1.23	3.31	1.39	1.31	1.54	0.69
Median	−3.0	0.00	0.00	3.0	0.00	7.00	7.00	0.00
95% CI	−5.86 to −2.77	−0.70 to 1.33	−0.56 to 0.85	2.54 to 6.38	−0.37 to 1.23	6.49 to 8.00	6.39 to 8.17	−0.36 to 0.43

Note: Comparisons between groups: $p > .05$ for RHd0, RHda, RHd26, RHdg, GRv, GRh (Mann–Whitney *U*-test) and RW26 (independent *t*-test).
Abbreviations: a, immediately after augmentation; GR, graft resorption (v, vertical; h, horizontal); r, reduction; RHd, ridge height deficiency; RW, ridge width; 0, immediately before augmentation; 26, during re-entry at 26 weeks.
*$p = .03$ for RWa (independent *t*-test).

0.35 ± 0.92 mm (median: 0.25; 95% CI: −0.17–0.89) in the TR and − 0.28 ± 0.72 mm (median: 0.0; 95% CI: −0.70–0.13) in the AB group.

TR grafts were associated with a significantly higher mean RW after augmentation (8.82 ± 1.50 mm [median: 9.0; 95% CI: 7.95–9.68]) when compared with AB grafts (7.25 ± 1.31 mm [median: 7.0; 95% CI: 6.49–8.00]) ($p = .03$, independent *t*-test).

3.1 | Primary and secondary performance endpoints

The primary and secondary endpoints assessed in both groups at the patient and defect level are summarized in Tables 3 and 4

3.1.1 | Primary endpoint

Mean RH deficiency at 26 weeks was 0.46 ± 1.02 mm (median: 0.50; 95% CI: −0.12–1.05) in the TR group and 0.14 ± 1.23 mm (median: 0.00; 95% CI: −0.56–0.85) in the AB group ($p = .26$, Mann–Whitney *U*-test). This resulted in a similar mean reduction in RH deficiency in both groups, amounting to 4.48 ± 2.42 mm (median: 4.25; 95% CI: 3.08–5.88) in the TR and 4.46 ± 3.31 mm (median: 3.00; 95% CI: 2.54–6.38) in the AB group ($p = .60$, Mann–Whitney *U*-test) (Table 3). At the defect level, these values corresponded to 4.40 ± 2.36 mm (median: 4.00; 95% CI: 3.09–5.70) in the TR group and 4.32 ± 3.05 mm (median: 3.00; 95% CI: 2.75–5.89) in the AB group (Table 4).

In all patients investigated, the reduction in RH deficiency allowed the successful placement of an adequately dimensioned titanium implant at respective sites. Multiple implants (i.e., two implants each) were provided in a total of four patients (TR = 1; AB = 3). The implants were located at separate tooth gaps (TR = 2; AB = 2) and free-end situations (TR = 0; AB = 4). The AB group was commonly associated with the placement of longer (≥ 10 mm) (TR = 7; AB = 12) and wider (> 3.5 mm) (TR = 8; AB = 15) implants (Table S1).

3.1.2 | Secondary endpoint

Both treatment procedures were associated with comparable mean RW values at 26 weeks, amounting to 8.28 ± 1.60 mm (median: 8.50; 95% CI: 7.36–9.21) at TR and 7.28 ± 1.54 mm (median: 7.00; 95% CI: 6.39–8.17) at AB treated sites ($p = .24$, independent *t*-test).

At 26 weeks, the resulting mean horizontal and vertical GR values were 0.10 ± 1.36 mm (median: 0.00; 95% CI: −0.67–0.89) and −0.53 ± 1.13 mm (median: 0.00; 95% CI: −1.19–0.11) in the TR group. Comparable outcomes were also noted in the AB group, with mean horizontal and vertical GR values amounting to 0.42 ± 1.39 mm (median: 0.00; 95% CI: −0.37–1.23) and 0.03 ± 0.69 mm (median: 0.00; 95% CI: −0.36–0.43), respectively ($p = .183$ and $p = .915$, Mann–Whitney *U*-test).

A secondary grafting was indicated at one defect site in the TR group, while a contour augmentation was deemed necessary at two defect sites in the AB group.

3.2 | Complications

A soft tissue dehiscence during the initial healing period was noted at four defect sites of the TR group, which was, however, not associated with a graft exposure or signs of wound infection. All patients were provided with topical chlorhexidine application until a complete granulation of the dehisced area was noted within 4–6 weeks without any further adverse events during follow-up. None of the AB treated defect sites was associated with a soft tissue dehiscence.

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TABLE 4 Primary and secondary performance endpoints (in mm) at the defect level

(a) TR group ($n = 15$ defect sites)								
	RHd0	**RHda**	**RHd26**	**RHdg**	**GRv**	**RWa**	**RW26**	**GRh**
Mean	−3.96	0.33	0.43	4.40	0.10	8.70	8.20	−0.36
SD	2.15	0.89	0.99	2.36	1.31	1.52	1.57	1.27
Median	−3.00	0.00	0.50	4.00	0.00	8.00	8.00	0.00
95% CI	−5.16 to −2.77	−0.16 to 0.83	−0.11 to 0.98	3.09 to 5.70	−0.62 to 0.82	7.85 to 9.54	7.32 to 9.07	−1.07 to 0.33
(b) AB group ($n = 17$ defect sites)								
	RHd0	**RHda**	**RHd26**	**RHdg**	**GRv**	**RWa**	**RW26**	**GRh**
Mean	−4.20	−0.23	0.11	4.32	0.35	7.55	7.52	−0.14
SD	2.48	0.66	1.11	3.05	1.27	1.41	1.58	0.42
Median	−3.0	0.00	0.00	3.0	0.00	7.50	7.00	0.00
95% CI	−5.48 to −2.93	−0.57 to 0.10	−0.45 to 0.68	2.75 to 5.89	−0.30 to 1.00	6.83 to 8.28	6.71 to 8.34	−0.36 to 0.07

3.3 | Clinical observations during re-entry

Clinical re-entry at Visit 6 revealed a homogeneous integration of both TR and AB grafts in the former defect area, thus resulting in marked vertical and horizontal hard tissue gains. This was evidenced by a firm and stable connection of the graft to the host bone subsequent to the removal of the osteosynthesis screws as well as clinical signs of a hard tissue remodelling extended to the confines of the defect area (Figures 2c and 3c). While integrated AB grafts could not be differentiated from the adjacent pristine bone, TR grafts were commonly discernible by a well-preserved outer contour of the root structure. In both groups, the grafted areas revealed comparable bleeding characteristics during implant bed preparation. All implants could be inserted with good primary stability (i.e., no clinical mobility) (Figures 2d and 3d).

3.4 | Regression analysis

The linear regression analysis revealed a significant correlation between the reduction in RH deficiency and baseline RH deficiency (Figure 4a,b) in both TR (Coef: .90; R^2: .821; $p = .001$) and AB groups (Coef: .94; R^2: .884; $p = .001$). In particular, a 1-mm increase in RH deficiency at baseline (e.g., from −2.0 to −3.0 mm) had a positive effect of 0.99 mm reduction in RH deficiency in the TR group and 1.16 mm in the AB group.

4 | DISCUSSION

The results of the present study revealed that both surgical procedures were associated with a similar mean reduction in RH deficiency, amounting to 4.48 ± 2.42 mm (95% CI: 3.08–5.88) in the TR group and 4.46 ± 3.31 mm (95% CI: 2.54–6.38) in the AB group, which allowed an adequate implant placement at all sites investigated. Nevertheless, the individual site-specific outcomes noted at TR treated sites usually necessitated the placement of narrower and shorter implants when compared with AB treated sites. The reduction in RH deficiency was significantly correlated with baseline RH deficiency, thus indicating that in both groups vertical bone gain was particularly pronounced at severely deficient alveolar ridges.

These reductions in RH deficiency are within the range of reported outcomes following vertical grafting using autogenous onlay bone blocks as evaluated in a previous systematic review and meta-analysis. Based on five RCTs, the weighted mean vertical bone gain amounted to 3.53 mm (95% CI: 2.21; –4.85 mm) (Urban et al., 2019). In the studies evaluated, however, AB grafts were commonly combined either with titanium meshes (Roccuzzo et al., 2004, 2007) or titanium-reinforced barrier membranes (Rocchietta et al., 2016), which were shown to be associated with a significant reduction of GR. On the contrary, the present analysis revealed that, in the absence of any measures for graft protection, both AB and TR groups revealed only minor vertical GR values. While GR tended to be more pronounced in the AB group, these differences did not reach statistical significance in the TR group. While a previous clinical study on lateral alveolar ridge augmentation pointed to significantly higher horizontal GR values for AB grafts (mean: 1.03 mm; 95% CI: 0.39–1.67 mm) over TR grafts (mean: 0.13 mm; 95% CI: −0.4–0.67 mm) (Schwarz et al., 2018), the present analysis did not point to a more pronounced horizontal GR at AB treated sites. In this context, it must be emphasized that vertical grafting is also directed at establishing an adequate crestal width to allow for staged implant placement (Jepsen et al., 2019). Nevertheless, the resulting horizontal crestal bone gain obtained following vertical grafting may not directly be comparable with that following lateral grafting, which is mainly due to the absence of an initial crestal bone width. In particular, median baseline RW values in the latter study were 4.50 mm in the TR group and 5.00 mm in the AB group. Following lateral grafting, median RW values amounted to 10.00 mm in both TR and AB groups (Schwarz et al., 2018). The resulting median RW values at 26 weeks were 11.00 mm in the TR group and 8.50 mm in the AB group. Considering the aforementioned horizontal GR values, TR grafts were associated with a significantly higher RW gain (median:

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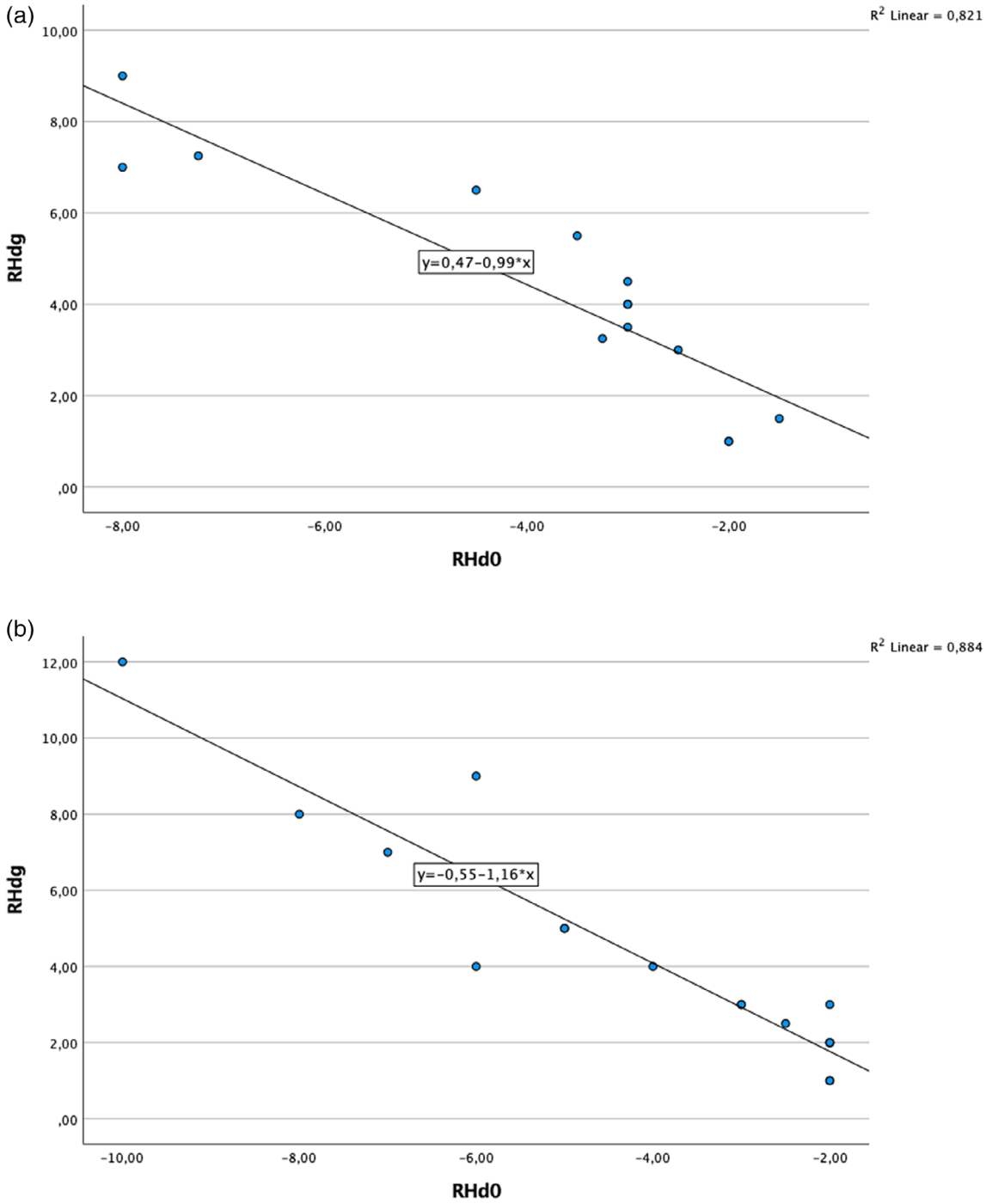

FIGURE 4 Linear regression plots to depict the relationship between the reduction in RH deficiency and baseline RH deficiency values. (a) TR group. (b) AB group

5.00 mm) as opposed to AB grafts (median: 4.00 mm) (Schwarz et al., 2018). When comparing these data following lateral grafting with those noted in the present study, it is apparent that the mean RW values after augmentation and subsequently the RW values at 26 weeks following vertical grafting were markedly lower, amounting to 8.82 and 8.28 mm in the TR group and 7.25 and 7.28 mm in the AB group, respectively. While the RW values at 26 weeks were significantly higher in the TR group, these differences over the AB group may mainly be attributed to differences in graft size, resulting in different RW values after augmentation.

Unfortunately, the resulting crestal RW following vertical grafting using AB grafts has been very rarely reported in the available literature. However, limited data pointed to low mean RW values after augmentation and at 6 months amounting to 3.8 ± 0.8 mm and 2.7 ± 0.8 mm (Abrahamsson et al., 2012), which in turn may necessitate a secondary grafting or contour augmentation. Similar outcomes were

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also reported in a previous preclinical study employing TR grafts for vertical grafting, since implant placement was associated with the occurrence of vestibular/oral dehiscence-type defects due to a narrow RW at 9 out of 13 defect sites investigated (Schwarz, 2019). In contrast, the convenient RW values at 26 weeks obtained in the present study commonly (i.e., TR: 14/15 sites; AB: 15/17 sites) allowed for a staged implant placement without the need for additional lateral grafting. Nevertheless, the use of TR may be challenging in cases when their degree of retention necessitates multiple root resections, thus limiting the resulting graft size.

When further analysing the present data, it was also observed that the complication rates (i.e., initial soft tissue dehiscences) noted for TR-treated ($n = 4$ sites, corresponding to 26.7%) and AB- treated sites ($n = 0$) are basically within the range of the weighted mean incidence of 26.1% (95% CI: 7.2–45.0) previously reported for AB onlay grafts (Urban et al., 2019). These outcomes are also in agreement with the complication rates noted for TR and AB grafts following lateral grafting, with none of the sites investigated revealing any signs of primary or secondary soft tissue dehiscences or graft exposures (Schwarz et al., 2018).

Nevertheless, the stability of the augmented TR and AB sites after loading and its influence on implant survival and success in the long term need to be carefully addressed in follow-up observations. In this context, it is important to emphasize that previous pre-clinical studies provided the histological proof for a gradual resorption and replacement of TR grafts by newly formed bone, thus supporting the osseointegration process following staged implant placement on a level equivalent to that noted at AB grafted sites (Schwarz, Golubovic, Becker, et al., 2016; Schwarz, Golubovic, Mihatovic, et al., 2016; Schwarz, Mihatovic, et al., 2019).

Potential limitations of the present study are related to the limited sample size and achieved post hoc power, the lack of patient randomization (e.g., confounding effect of defect distributions), the inability to mask the surgeons and examiners due to the apparent structural difference noted between AB and TR grafts, as well as the missing analysis of wound healing at the respective donor sites. The lack of patient-reported outcome measures did not allow an evaluation on how both surgical approaches have been tolerated. Furthermore, the external validity needs to be further evaluated in future studies.

5 | CONCLUSION

In conclusion and within the aforementioned limitations, the present clinical study indicated that up to staged implant placement, both TR and AB grafts appeared to be associated with comparable efficacy and safety for combined vertical and horizontal alveolar ridge augmentation.

CONFLICT OF INTEREST

The authors declare no conflict of interests.

ETHICS STATEMENT

The study protocol was approved by the ethics committee of the Goethe University Frankfurt, Germany.

AUTHOR CONTRIBUTIONS

Conceived the ideas: Frank Schwarz and Robert Sader. *Collected and analysed the data*: Karina Obreja, S. Mayer, Ausra Ramanauskaite, Puria Parvini, and Frank Schwarz. *Led the writing*: Frank Schwarz and Karina Obreja. All authors critically revised the manuscript and agreed to the final version.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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