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Flapless Piezotome-Enhanced Vertical Alveolar Crest-Split and Horizontal Distraction of Alveolar Crests (FPeCSWT) of Less than 2 mm Width: Results of a Prospective Comparative 3-Year Clinical Multicenter-Study with 239 Patients, 261 Crest-Split Sites and 488 Inserted Dental Implants

Angelo Troedhan[1], Andreas Kurrek[2], Marcel Wainwright[3], Izabela Schlichting[1]

[1]Center for Facial Aesthetics Vienna, Vienna, Austria
[2]Implantology Clinic Oberkassel, Dusseldorf, Germany
[3]Implantology Clinic Kaiserswerth, Dusseldorf, Germany
Email: dr.troedhan@gmail.com

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Abstract

Alveolar crest-splitting and horizontal distraction is an established surgical technique to enable implant insertion into the narrow, lateral atrophic alveolar crest. This surgical technique is challenging for the oral surgeon and restricted to crest-widths of 3 - 5 mm: significant procedural bone loss at osteotomy, the need to prepare a full thickness mucoperiostal flap and milling a baseline-osteotomy to weaken the bone for distraction inhere significant risks of accidental fractures. Aim of the study was to investigate if the recently developed novel Flapless Piezotome enhanced Crest-Splitting and Widening Technique (FPeCSWT) could safely narrow down the indication for this procedure to narrow alveolar crests of widths of even less than 2 mm in a three-year survey-period. 239 patients underwent 261 FPeCSWT-surgeries and 488 implants were inserted simultaneously in the upper and the lower jaw and clinical parameters such as intrasurgical complications, patient morbidity, implant loss and vertical bone loss (VBL) in the first three years after surgeries were recorded comparing sites with less than 2 mm width with sites of more than 2 mm.

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After three years a significant difference (p = 0.24) of VBL could be observed between the group with less than 2 mm crest-width (mean: 0.97 mm, max: 2.0 mm/min: 0.0 mm; SD: 0.41) compared with the group with more than 2 mm crest-width (mean: 0.69 mm, max: 1.5 mm/min: 0.0 mm; SD: 0.36) but was still significant lower when compared with the results of similar studies published with a mucoperiostal-flap approach and baseline bone-cut. The cumulative 3-year-implant-survival-rate was 98.8%, no accidental fracture of the distracted buccal bone-plate occurred. The results of the study suggest that the FPeCSWT narrows safely down the indication for crest-splitting to also crest-widths of only 1 mm. The procedure is highly predictable and significantly reduces the challenge of surgical skills and leads to negligible patient-morbidity. The higher VBL in crest-widths of less than 2 mm can easily be compensated by subcrestal placement of implants.

Keywords

Dental Implantology, Bone-Management, Guided Bone Regeneration, Piezosurgery, Ultrasonic Surgery, Crest-Split, Ridge-Split, Distraction Osteogenesis, Biomaterials, Dental Implants

1. Introduction

The alveolar crest in the upper and lower jaw is the result of growth of the permanent dentition and loses its biological function when teeth are removed, resulting in a typical atrophy pattern [1] [2]: in a first phase of 5 - 12 months a significant centripetal reduction of crest-width up to 50% but only little loss of crest-height can be observed (**Figure 1**) with a concomitant reduction of vascularization and is only later followed by vertical atrophy. Furthermore this lateral loss of alveolar bone can be massively reinforced iatrogenic when non-tissue-preserving methods are used, or by pre-existent periodontal disease [3], resulting in a knife-blade-like alveolar crest and can be avoided by application of alveolar-ridge-preservation techniques only to a certain extent [4].

To enable implant insertion, a sufficient restoration of the alveolar crest-width can be achieved by various

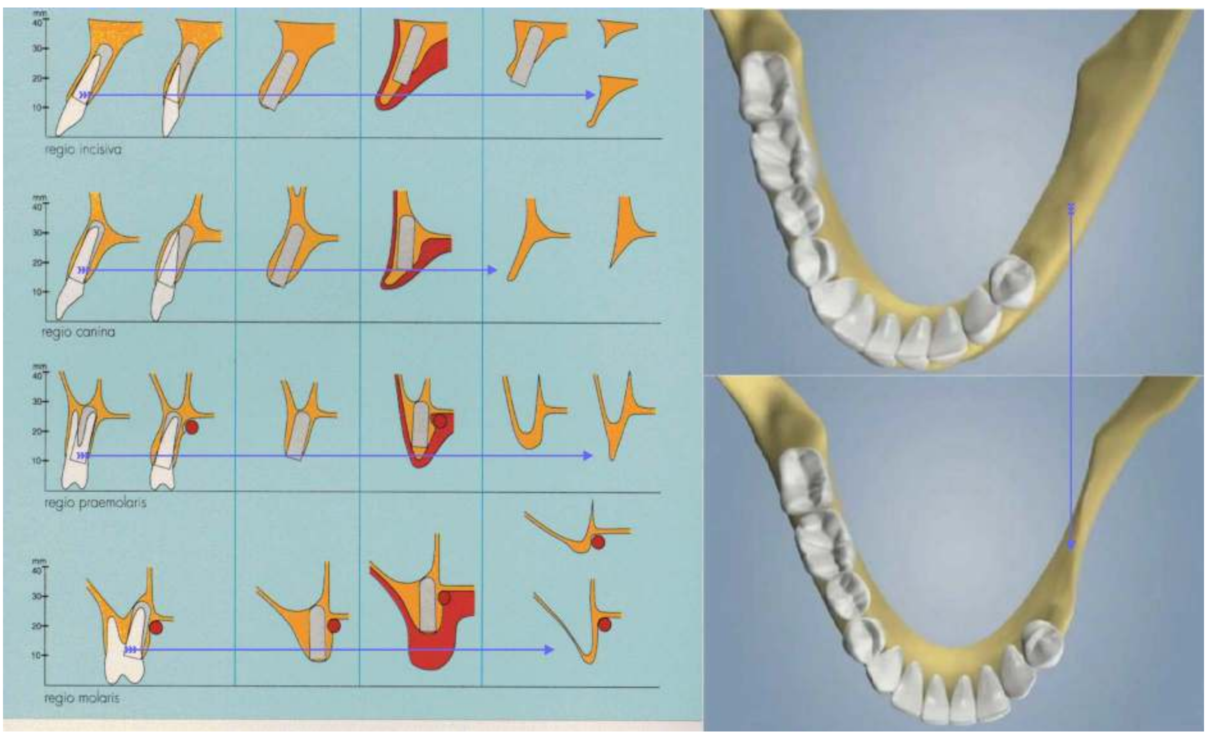

Figure 1. Atrophy pattern of the maxillary and mandibular alveolar crest.

traditional surgical techniques such as lateral appositional autologous, allogenic and xenogenic bone-block grafting [5] [6] as well as guided bone regeneration with use of synthetic biomaterials [7] or—lately described—the more promising flapless Piezotome enhanced Subperiostal Tunnel Technique (PeSTT) [8].

Nevertheless, a more biologic approach to restore an implant-sufficient alveolar crest-width can be achieved by utilizing the bone-innate fracture-healing process described as horizontal alveolar crest callus-distraction-osteogenesis [9] [10] or vertical alveolar crest-splitting with immediate horizontal distraction and immediate/delayed implant placement [11] [12].

Various tools and methods are described to achieve a sufficient mesio-distal vertical osteotomy (rotary burs, rotary diamond coated discs, oscillating saws, bone chisels) and immediate horizontal distraction of the narrow alveolar crest (cylindrical osteotomes, flat chisels, widening screws, horizontal distractors) [13] [14] which limit the applicability by their innate procedural bone loss to alveolar crest-widths of a minimum of 3 - 4 mm and demand a very high level of surgical skills [12].

With the introduction of ultrasonic surgical instruments ("Piezotomes") the applicability of the crest-split technique was narrowed down to crest-widths of 2 mm by the more bone-conserving primary osteotomy but still demanded the highly invasive preparation of a full-thickness mucoperiostal flap and comprised the significant risk of accidental iatrogenic vertical fractures or total baseline-fractures of the distracted buccal cortical bone-plate by osteotomes, chisels, widening screws or mechanical distractors [15] [16] due to the need of weakening the buccal bone-plate by milling bone-cuts into the distraction-baseline which might lead to a complete failure of the surgical procedure or at least to devitalization of the distracted buccal bone-plate and highly challenges the experience and skills or the oral surgeon [12].

Furthermore it was proven that less procedural marginal bone-resorption and better long-term results regarding preservation of the expanded crest can only be achieved when a partial-thickness (mucosal) flap is prepared to access the alveolar crest or the procedure is performed flapless [17] [18] but still is substantial with long-term marginal bone-losses of >3 mm when the alveolar crest is less wide than 3 mm [19].

After experimental analysis of the biomechanical behavior of the narrow alveolar ridge—starting with a ridge width of only 1 mm—the authors developed surgical tools for the Piezotome-device and a precise surgical protocol to allow flap- and bone-lossless osteotomies and horizontal widening of the split crest up to 4 mm avoiding the need of apical distraction-baseline bone-cuts with their innate significant risk of accidental total fractures or vertical fractures by mechanical distractors by full utilization of the jawbones innate elasticity. The experimental studies on fresh cow-ribs—which are comparable in their biomechanical behavior to human alveolar bone—and human cadaver-heads demonstrated a distraction-angle of the buccal bone-plate of up to average 30˚ to be safe against accidental distraction-baseline- or vertical fractures [20] (**Figure 2**).

Aim of the prospective multicenter-study was to determine the long-term vertical bone loss with the Flapless Piezotome-enhanced Crest-Split and Widening-Technique (FPeCSWT) and immediate implant insertion when this new Piezotome-technique and surgical protocol is applied to very narrow alveolar crests of a width of 1 - 2 mm compared to crest-widths of more than 2 mm distracted by the same technique in the first three years after surgery to investigate if this new appliance could safely narrow down the indication for crest-splitting to very narrow alveolar-crests of less than 2 mm width.

2. Material and Methods

2.1. Inclusion Criteria

Between 2009 and 2012 all consecutive patients of three implantology-clinics requesting dental-implant therapy and presenting narrow alveolar ridges of 1 - 4 mm top-crestal width and typical atrophy-pattern with width of 5 - 8 mm at the base of the crest in clinical and radiologic investigation in the upper (UJ) and lower Jaw (LJ) were elected to be treated with the Flapless Piezotome-enhanced Crest-Split and Widening-Technique (FPeCSWT) (**Figure 3**). According to the established surgical protocol by the authors the minimum alveolar crest-height above the mandibular nerve and under the maxillary sinus/nasal cavity had to be 11 - 12 mm to allow a vertical osteotomy of minimum 7 - 8 mm avoiding excess of the elastic properties of the alveolar crest in the distraction process [20], an insertion of implants 2 - 3 mm deeper than the osteotomy into non-distracted crestal bone for primary stability and an interdental space of 7 mm to allow sufficient movements of the 5 mm-wide TKW-Crest Splitting Tips (TKW-CS Tips) (**Figure 4**). Patients presenting general exclusion-criteria from implant-therapy such as uncontrolled diabetes, therapy with bisphosphonates, systemic diseases, untreated periodontitis and/or

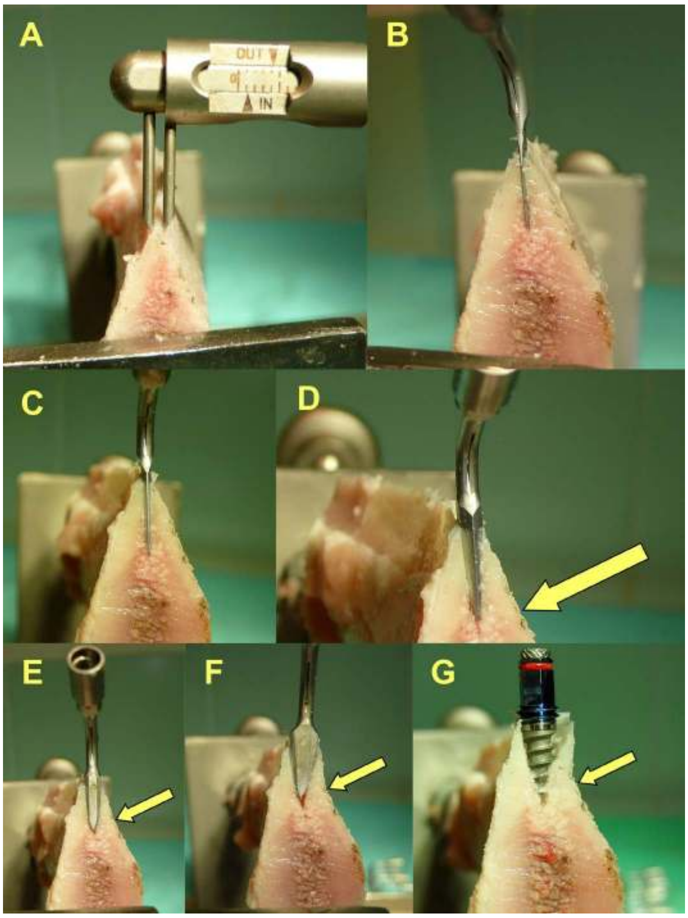

Figure 2. Experimental setup for the development of the Flapless Piezotome-enhanced Crest-Splitting and Widening-Technique (FPeCSWT) on the cow-rib model: measurement of crestal width (A), vertical osteotomy with experimental FPeCSWT-tips for Piezotome (B), initial widening (C), after mandatory buccal relief-osteotomy (not depicted) gradual widening of the split alveolar crest in 1 mm-increments (D-F) without apical bone-cut to weaken the buccal bone plate (yellow arrow), implant insertion without accidental fracture of the distracted buccal bone-plate.

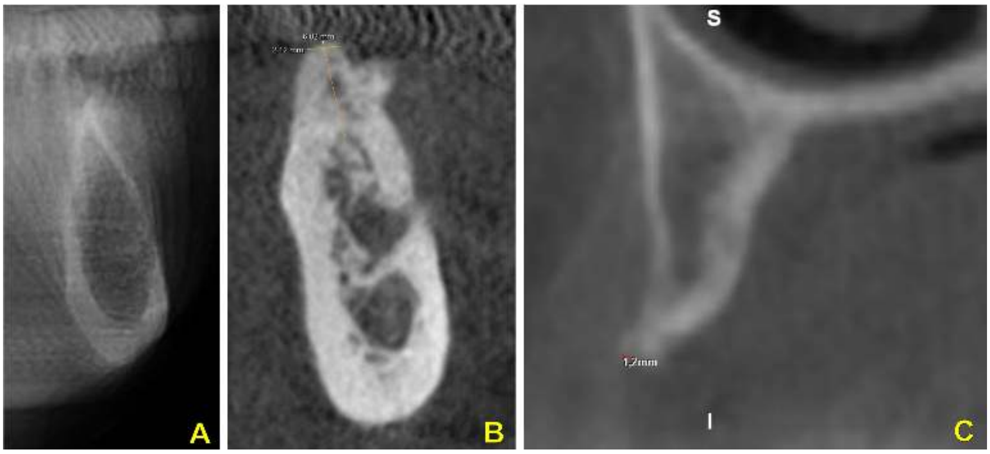

Figure 3. Presurgical CBCT of cases treated with FPeCSWT: crest-width of 1 mm in the lateral mandible (A), crest-width of 2 mm in the lateral mandible (B), crest-width of 1 mm in the upper premolar region (C), all presenting the typical atrophy pattern with 5 - 8 mm width at the base of the alveolar crest.

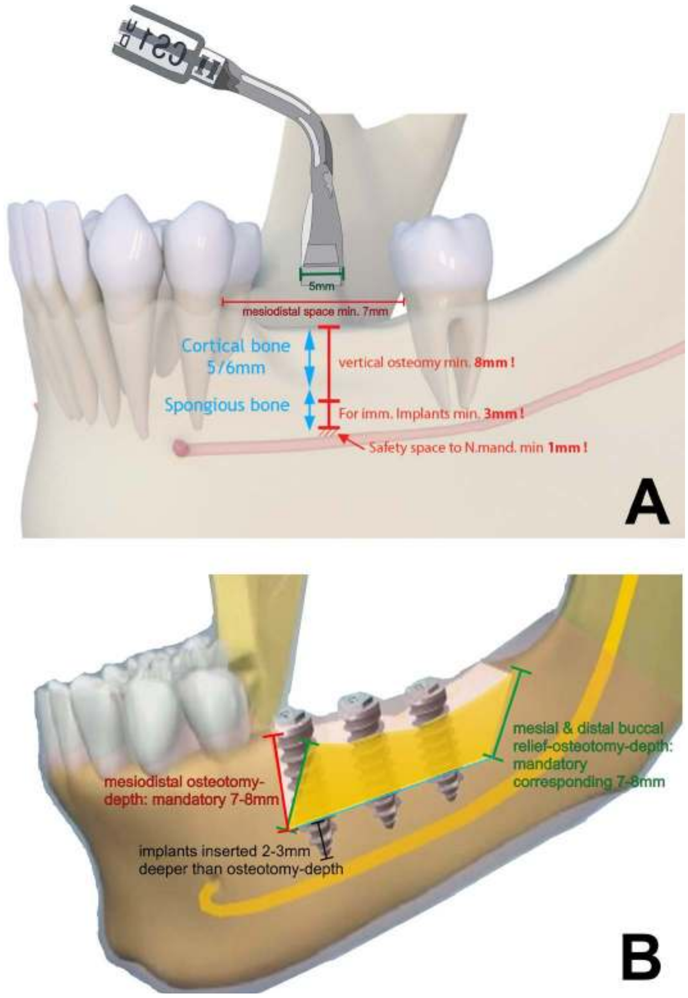

Figure 4. Surgical protocol established after experimental research and development of FPeCSWT: (A) For utmost safety a minimum height above delicate soft-tissue-structures (e.g. mandible nerve, maxillary sinus) of 11 - 12 mm is required to allow a minimum vertical osteotomy-depth of 7 - 8 mm to be within the safety-margins of the crestal-bones innate elasticity and additional 2 - 3 mm for primary stable implant-insertion into non-distracted crestal bone. A minimum distance between adjacent teeth of 7 mm is required. (B) Mandatory buccal relief-osteotomies have to correspond in their depth to the mesiodistal primary osteotomy (7 - 8 mm) and implants have to be inserted 2 - 3 mm deeper than primary osteotomy to achieve sufficient primary stability.

lack of compliance to oral hygienic home-care were excluded. All patients had to sign the legal consent regarding the FPeCSWT-procedure. Since the crest-splitting technique is a scientifically well-established and documented surgical procedure and described in the literature also for very narrow alveolar crests no approval from an ethical committee was necessary according to EMEA-guidelines for this clinical study.

2.2. Implants

For immediate implant insertion four types of CE certified implants were used in this study which represent the standard-implants used in the three clinics: Q2-implant Ø 3.75 mm, Q2-implant Ø 3.5 mm (both: TRINON Karlsruhe GmbH/Germany), SICAce Ø 3.4 mm (SIC invent AG/Switzerland) and BEGO S Ø 3.75 mm (BEGO Bremer Goldschlaegerei Wilh. Herbst GmbH & Co. KG/Germany), implant lengths varying—depending on the implant system used and the available alveolar crest height—from 9.5 - 15 mm. To fill the remaining gaps of the horizontally distracted ridge after implant insertion three different CE-certified biomaterials were used: easygraftCLASSIC (self-hardening monophasic βTCP with Polylactid-coating), easygraftCRYSTAL (self-hardening biphasic βTCP/HA with Polylactid-coating; both SUNSTAR-Degradable Solutions AG/Switzerland) and Bio-Oss Collagen (bovine xenograft; Geistlich AG/Switzerland).

2.3. Ultrasonic Surgical Device

For all surgeries the Piezotome II, Piezotome SOLO or Implant Center II (all: Satelec-ACTEON/France) were used together with the TKW-CS-Tip-set developed and designed by the authors (**Figure 5**).

2.4. Surgical Procedure

All participating surgeons had to strictly follow the surgical protocol. After applying local anaesthesia Surgery was started with a top-crestal mesio-distal incision and reversion of a minimal "booklet-flap" (**Figure 6**) [17] to measure and record intraoperatively the crest-width with a caliper (1/10th mm steps).

The initial vertical mesio-distal osteotomy then was performed with the TKW-CS 1 Tip (**Figure 7**) to the full length of the prospective implant-site (**Figure 8**) and the final length and depth of the osteotomy was recorded.

With the TKW-CS 2 Tip (**Figure 9**) the initial vertical osteotomy then was widened to allow the mandatory buccal relief-osteotomies at the mesial and distal end of the osteotomy with the TKW-CS 3 Tip from the inside of the primary osteotomy with a corresponding depth to the recorded mesiodistal primary vertical osteotomy (**Figure 4**, **Figure 10**).

Once the buccal-relief osteotomies were completed and checked for precise connection to the mesiodistal osteotomy the buccal bone plate then was distracted step by step with the TKW-CS 4 Tip (**Figure 11**), the TKW-CS 5 Tip (**Figure 12**) and the TKW-CS 6 Tip (**Figure 13**) to a resulting distraction gap of 4mm between the fully mucoperiostal-connected buccal and lingual/palatal bone-plate (**Figure 14**) without the need of milling bone-cuts at the distraction baseline to weaken the buccal bone-plate. The distracted and fully mucoperiostal-connected buccal bone-plate then was carefully checked visually and by blunt periodontal probes for perforations, fractures of the apical distraction baseline and accidental vertical fractures and results recorded.

Pilot drilling was performed then (minimum 2 - 3 mm deeper than the depth of the osteotomy) for correct anatomical positioning of the planned dental implants (**Figure 15**), the implants inserted bone level (**Figure 16**) with simultaneous recording of the Insertion Torque Value (ITV) and the remaining distraction-gap filled with stable biomaterial (**Figure 17**) followed by the final wound-closure (**Figure 18**). Remaining wound-gaps were measured with a caliper and recorded.

Figure 5. Final FPeCSWT-tips for Piezotomes: initial bone-lossless vertical osteotomy-tip (A), initial widening tip (B), tip for mandatory buccal relief-osteotomies from inside the already split crest (C), incremental widening tips for a final distraction gap of 4 mm (D)-(F).

Figure 6. Mesiodistal top-crestal incision and preparation of a minimal "booklet-flap" to identify the top of a very narrow alveolar crest of 1 mm width.

Figure 7. Initial mesiodistal osteotomy of the 1 mm wide alveolar crest with CS 1-tip for Piezotomes to a minimum depth of 7 - 8 mm.

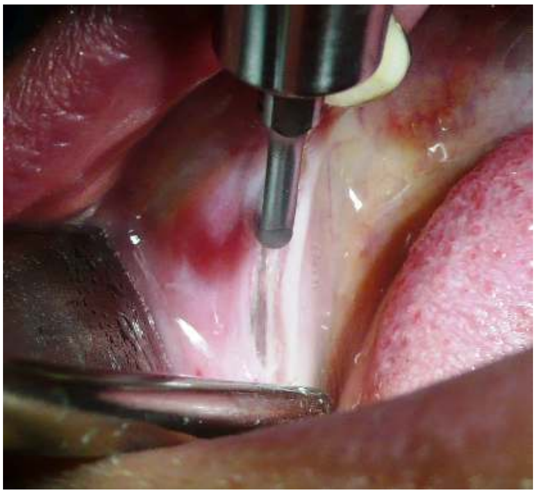

Figure 8. CS 1-tip for Piezotomes at work.

Figure 9. Crest-split site after initial widening to a 1 mm-gap with CS 2-tip as preparation for the mandatory buccal relief-osteotomies.

Figure 10. Mandatory buccal relief-osteotomies with the CS 3-tip from inside the primary mesiodistal osteotomy.

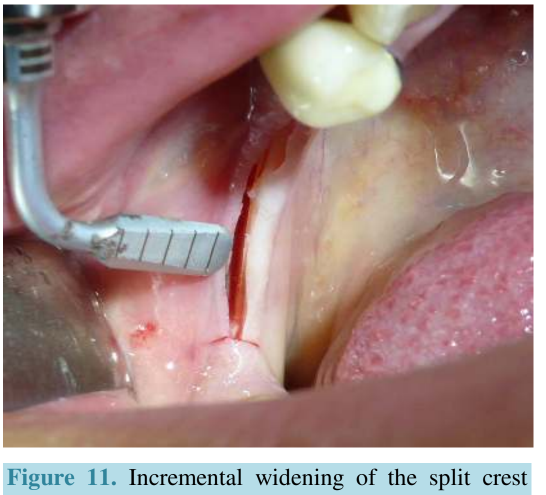

Figure 11. Incremental widening of the split crest with CS 4-tip to a gap-width of 2 mm.

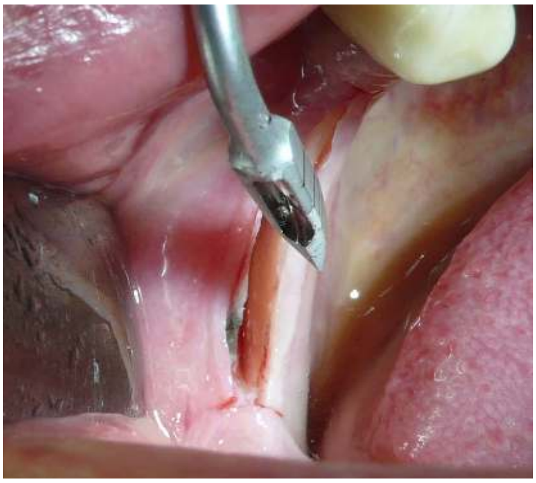

Figure 12. Incremental widening of the split crest with CS 5-tip to a gap-width of 3 mm.

Figure 13. Final widening of the split crest with CS 6-tip to a gap-width of 4 mm.

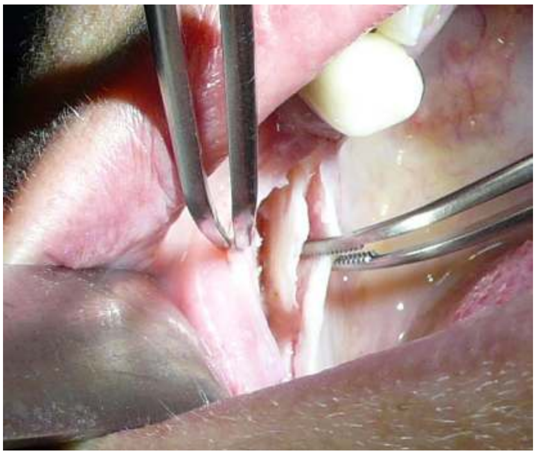

Figure 14. Final result of the FPeCSWT-surgery with the Piezotome: a fracture-free distraction of the buccal bone-plate with a resulting transversal bone-gap of 4 mm was achieved. (For better photographic demonstration of the precise and bone-lossless osteotomy and fracture-free distraction the lingual booklet-flap was slightly extended to 4 mm in this case with mesial and distal 3 - 4 mm lingual-buccal relief incisions only on the very top of the crest).

Figure 15. Check of correct anatomical placement of planned implants after pilot drilling.

Figure 16. Insertion of two Q2-implants with a diameter of 3.5 mm and 12 mm length.

Figure 17. Filling of the remaining bone-gap with self-hardening biomaterial easygraft CRYSTAL.

Sutures were removed between 10 and 14 days after surgery and all patients recurrently checked for complications in intervals of 4 weeks and adverse events recorded.

2.5. Prosthetic Treatment

An average healing period of 3 - 4 months was determined for the Lower Jaw (LJ) and 4 - 5 months for the Upper Jaw (UJ) following general accepted guidelines for two-stage dental implant insertion after tooth-removal. Before prosthetic treatment a panoramic X-ray was made, the implants uncovered by gingival-punch-technique, abutments attached with implant-system specific gingiva-formers (**Figure 19**) and after an average of one week the final prosthetic restoration completed (**Figure 20**).

2.6. Follow Up & Analysis of Vertical Bone Loss (VBL)

Patients underwent a six-monthly recall for clinical follow-up after finalized prosthetic treatment (clinical investigation, periodontal probing) and yearly panoramic X-ray investigation with a minimum of 3 years after surgery.

Full-arch Upper Jaw surgeries were classified as two different FPeCSWT-sites since the location of the nasopalatinal duct in the maxillary midline had to be spared from crest-splitting mandatorily, lower Jaw anterior osteotomies from canine to canine were classified as one site.

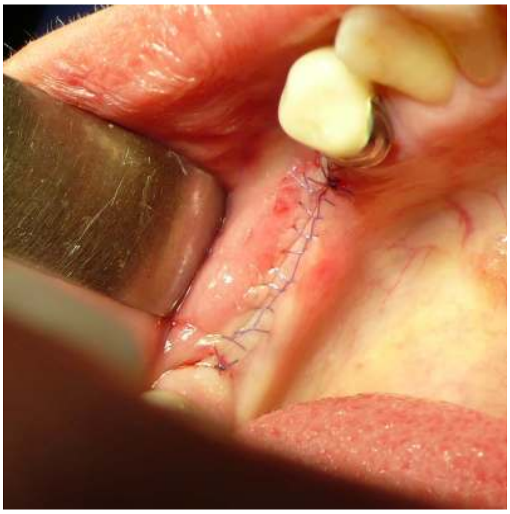

Figure 18. Tensionless wound-closure.

Figure 19. Opening of the implant-site by gingival punch, insertion of abutments and gingiva-formers.

Figure 20. Final prosthetic treatment.

The reference-plane for Vertical Bone Loss (VBL)-measurement was determined by the bone-level crestal plane of the inserted implants in the panoramic X-ray made immediately before prosthetic treatment (**Figure 21**). From this reference-plane both mesial and distal VBL of each implant was measured with the panoramic X-rays original software measure-tool (Cliniview, Galileos, Sidexis), counterchecked with the radiographic dimensional structure of the implant and the highest VBL-value for each implant recorded in an Excel-Sheet in 0.5 mm-steps. Values exceeding 0.6 mm were noted as 1 mm, values exceeding 1.1 mm as 1.5 mm respectively, to compensate too optimistic determinations of bone-margins.

All patients treated with FPeCSWT were separated into two groups defined by the intraoperative initial measurement of the original coronar alveolar crest-width: Group 1 presenting crest-widths ≤2 mm and Group 2 with crest-width above 2 mm to compare differences of VBL between these two groups. For differences between VBL-rates in the Upper Jaw (UJ) and Lower Jaw (LJ) only the upper jaw (UJ) anterior canine to canine sites were compared to Lower Jaw Lateral sites due to a too small sample for Lower Jaw anterior sites and representing the most common sites for crest-splitting and widening.

Statistical evaluation was performed by mean value, standard deviation and T-test at a significance-level of ≤0.05.

3. Results

3.1. Surgery Related Results and Complications

A total of 239 patients aged from 29 yrs to 82 yrs (mean: 63 yrs) fulfilling the inclusion criteria underwent 261 FPeCSWT-surgeries and 488 dental implants were inserted simultaneously (**Table 1**) in the upper and the lower jaw (**Table 2**).

All surgeries were performed uneventful mainly in the Upper Jaw anterior canine-to-canine and the Lower Jow lateral premolar-to-molar region (**Figure 22**) and no complications such as unintentional vertical or baseline fractures of the distracted buccal bone-plate had to be recorded, all planned implants were inserted with an average Insertion Torque Value (ITV) of 40 Ncm (min: 30 Ncm/max: 55 Ncm) both in the Upper and Lower Jaw (**Table 3**) and no adverse events or complications occurred in the immediate postsurgical phase and within the first year after surgery in both patient-groups. Pain and swelling was reported by the patients as very little compared to normal routine tooth-removal and did not interfere with normal life latest after the third day postsurgical.

Gingival wound gaps of mean 0.5 mm (max. 2 mm) were recorded in 52% of all cases and were covered by gingival secondary epithelisation on base of the iatrogenic "fracture-haematoma blood-clot" (stabilized by the biomaterials applied to the remaining distraction gaps) latest after 2 weeks occluding firmly the distraction site similar to plain tooth-extraction-site healing. In 48% of all cases a primary wound-closure could be achieved due to the 4 - 5 mm high gingival "sloppy-crest" that mostly accompanies lateral atrophic alveolar crests and is also

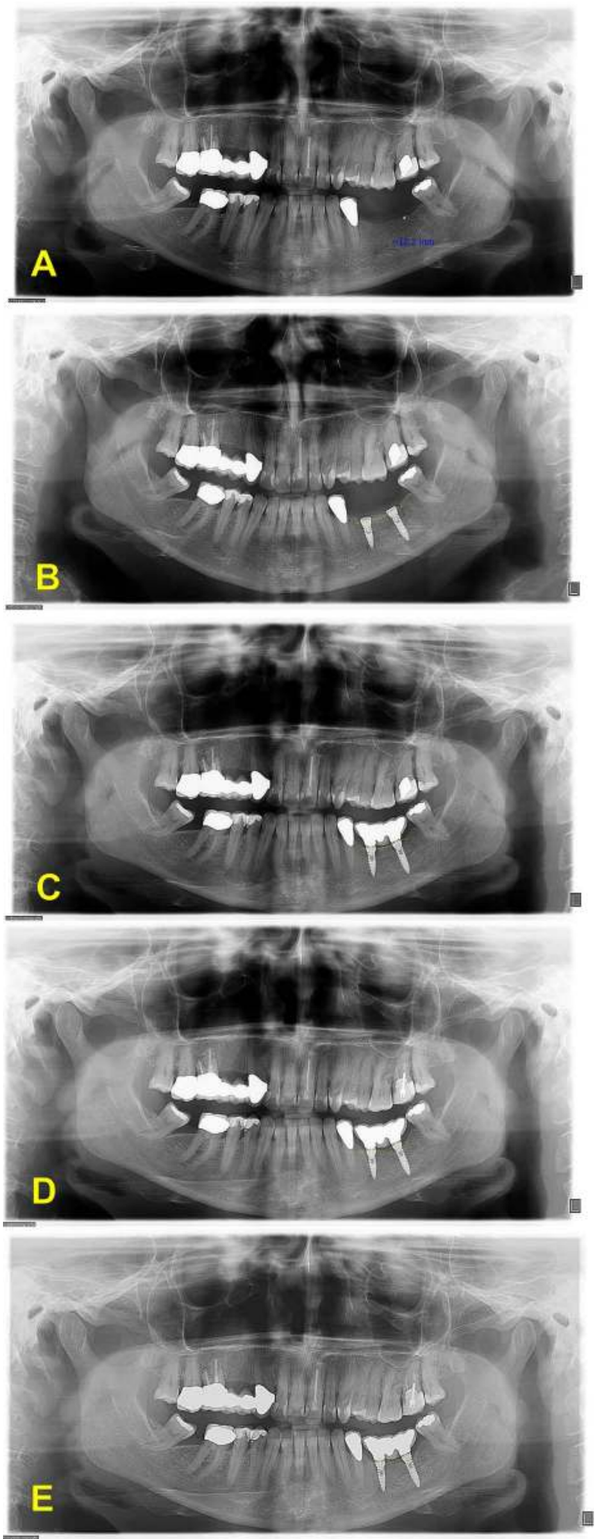

Figure 21. Radiologic follow up of case depicted in **Figures 6-20**: (A) presurgical state, (B) X-ray before prosthetic treatment, (C) X-ray after one year post surgery, (D) X-ray after two years post surgery, (E) X-ray after three years post surgery.

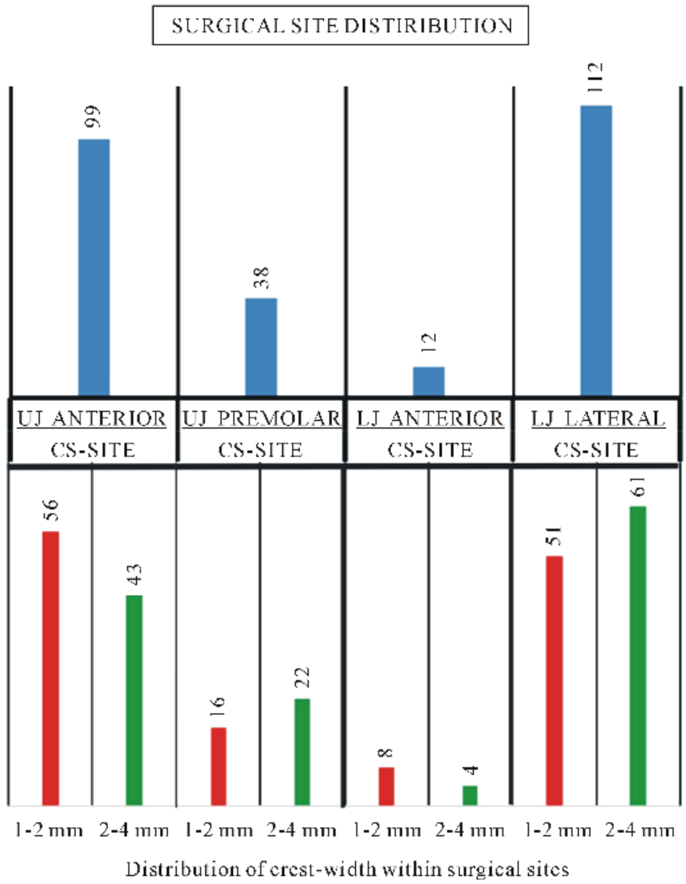

Figure 22. Cumulative and Group 1 and 2—specific surgical site distribution.

Table 1. Gender distribution of patients.

Patient number	Crest split sites	Implants
Total	Total	Total
239	261	488
Male		
61	70	139
26%	27%	28%
Female		
178	191	394
74%	73%	81%

Table 2. FPeCSWT-site and implant-number distribution.

CS-site	Implants	CS-site	Implants	CS-site	Implants	CS-site	Implants
UJ anterior	UJ anterior	UJ premolar	UJ PM	LJ anterior	LJ anterior	LJ lateral	LJ lateral
99	208	38	73	12	39	112	168
38%		15%		5%		43%	

Table 3. Mean values of measurements taken during FPeCSWT-surgeries.

Surgical protocol	Related mean values
Osteotomy depth mm	8
min UJ	6
min LJ	7
max	10
Osteotomy length mm	22
min	7
max	44
Baseline fractures	0
Vertical fractures	0
Wound-gap width mm	0.5
min	0
max	2
ITV all implants Ncm	40
min	30
max	55

split vertically with the mesiodistal mucoperiostal incision on top of the crest, leaving a keratinized surplus of gingival tissue to fully cover the distraction-site.

3.2. Prosthetic Treatment

After an average healing period of 3.5 months (±2 weeks) in the Lower Jaw (LJ) and 4.5 months (±2 weeks) in the Upper Jaw (UJ) all 488 dental implants proved to be stable osseointegrated and were treated prosthetical with crowns and bridges with a maximum of one pontic-crown for bridges (**Figure 21**).

3.3. Vertical Bone Loss (VBL)

3.3.1. Cumulative VBL All Sites Upper Jaw (UJ) and Lower Jaw (LJ) (Figure 23)

After one year all FPeCSWT-sites presented a cumulative VBL of mean 0.5 mm (max: 1.5 mm/min: 0.0 mm; Standard Deviation (SD): 0.36), Group 1 with initial crest-widths of 1 - 2 mm a mean VBL of 0.53 mm (max: 1.5 mm/min: 0.0 mm; SD: 0.39), Group 2 with initial crest-widths of more than 2 mm a mean VBL of 0.46 mm (max: 1.5 mm/min: 0.0 mm; SD: 0.32) with no significant difference between Group 1 and 2 ($p < 0.05$).

After two years the cumulative VBL of all sites was a mean of 0.68 mm (max: 2.0 mm/min: 0.0 mm; SD: 0.41) with a low significant difference ($p = 0.08$) between Group 1 (max: 2.0 mm/min: 0.0 mm; SD: 0.45) and Group 2 (max: 1.5 mm/min: 0.0 mm; SD: 0.38).

After three years a significant difference ($p = 0.24$) could be observed between Group 1 (mean: 0.97 mm, max: 2.0 mm/min: 0.0 mm; SD: 0.41) and Group 2 (mean: 0.69 mm, max: 1.5 mm/min: 0.0 mm; SD: 0.36) at a general mean VBL of all sites of 0.83 mm (max: 2.0 mm/min: 0.0 mm; SD: 0.38).

3.3.2. Comparison of VBL between Upper Jaw (Canine-to-Canine) Anterior Region and Lower Jaw Lateral (Premolar and Molar) Region (Table 4)

Comparing the cumulative mean VBL of Group 1 and Group 2 in the Upper Jaw anterior region (mean: 0.6 mm; SD: 0.41) with the cumulative VBL of Group 1 and Group 2 in the Lower Jaw lateral region (mean: 0.44 mm; SD: 0.28) higher vertical bone-resorptions can be detected with a maximum of 1.5 mm UJ anterior and 1.0 mm LJ lateral, but not significant ($p < 0.05$), and VBL increases after the third year to a mean VBL UJ anterior of 1.06 mm (max: 2 mm/min: 0.0 mm; SD: 0.47) and mean VBL LJ lateral of 0.93 mm (max: 1.5 mm/min: 0.0 mm; SD: 0.32) still showing no significant difference ($p < 0.05$) (**Table 4**).

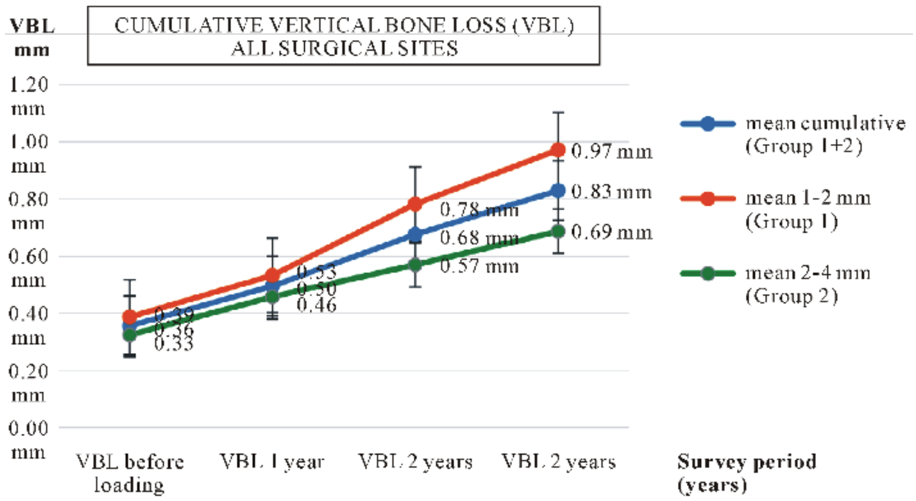

Figure 23. Cumulative and Group 1 and 2—specific Vertical Bone Loss (VBL) in the survey-period of three years.

Table 4. Results per site and patient group: 1 - 2 mm = Group 1, 2 - 4 mm = Group 2, VBL = Vertical Bone Loss.

	UJ anterior 1 - 2 mm	UJ anterior 2 - 4 mm	Cumulative	UJ Premolar 1 - 2 mm	UJ Premolar 2 - 4 mm	Cumulative	LJ anterior 1 - 2 mm	LJ anterior 2 - 4 mm	Cumulative	LJ lateral 1 - 2 mm	LJ lateral 2 - 4 mm	Cumulative
Number of CS-sites	**56**	**43**	**99**	**16**	**22**	**38**	**8**	**4**	**12**	**51**	**61**	**112**
Number of Impl. inserted	**116**	**92**	**208**	**31**	**42**	**73**	**30**	**9**	**39**	**94**	**74**	**168**
VBL bef. loading mean	**0.42**	**0.37**	**0.40**	**0.4**	**0.36**	**0.38**	**0.39**	**0.28**	**0.34**	**0.34**	**0.29**	**0.32**
min	0	0		0	0		0	0		0	0	
max	1.5	1		1.5	1		1	0.5		1	0.5	
Std. Dev.	0.39	0.32	0.36	0.37	0.28	0.33	0.39	0.25	0.32	0.26	0.2	0.23
	$p < 0.05$			$p < 0.05$						$p < 0.05$		
VBL 1 year mean	**0.61**	**0.58**	**0.60**	**0.55**	**0.48**	**0.52**	**0.48**	**0.39**	**0.44**	**0.49**	**0.38**	**0.44**
min	0	0		0	0		0	0		0	0	
max	1.5	1.5		1.5	1.5		1.5	1		1	1	
Std. Dev.	0.42	0.39	0.41	0.4	0.37	0.39	0.41	0.31	0.36	0.34	0.22	0.28
	$p < 0.05$			$p < 0.05$						$p = 0.09$		
VBL 2 year mean	**0.93**	**0.72**	**0.83**	**0.78**	**0.5**	**0.64**	**0.51**	**0.44**	**0.48**	**0.91**	**0.62**	**0.77**
min	0	0		0	0		0	0		0	0	
max	2	1.5		1.5	1.5		1.5	1		1.5	1	
Std. Dev.	0.52	0.44	0.48	0.41	0.36	0.39	0.42	0.37	0.40	0.43	0.36	0.40
	$p < 0.05$			$p < 0.05$						$p = 0.18$		
VBL 3 year mean	**1.22**	**0.89**	**1.06**	**0.82**	**0.62**	**0.72**	**0.73**	**0.5**	**0.62**	**1.12**	**0.74**	**0.93**
min	0	0		0	0		0	0		0	0	
max	2	1.5		1.5	1.5		2	1		1.5	1.5	
Std. Dev.	0.48	0.45	0.47	0.42	0.37	0.40	0.38	0.33	0.36	0.34	0.3	0.32
	$p = 0.23$			$p < 0.05$						$p = 0.24$		

3.3.3. Comparison of VBL between Group 1 (1 - 2 mm Crest Width) and Group 2 (>2 mm Crest Width) in the Upper Jaw (Canine-to-Canine) Anterior Region and Lower Jaw Lateral (Premolar and Molar) Region (Table 4)

Between Group 1 and Group 2 both UJ anterior and LJ lateral FPeCSWT-sites show significant different VBLs (UJ anterior: p = 0.23, LJ lateral: p = 0.24) after the third year with a mean VBL UJ anterior of 1.22 mm and 1.12 mm LJ lateral for Group 1 versus 0.89 mm UJ anterior and 0.74 mm LJ lateral for Group 2 (**Table 4**).

Maximum VBL-rates were higher for Group 1 in the UJ anterior region (2.0 mm) than for Group 1 in the LJ lateral region (1.5 mm) (**Table 4**).

3.4. Implant Losses

3 implants were lost in the UJ anterior region after the first year in a Group 1-patient due to an acute periimplantitis/periodontitis (3 of 3 implants lost in positions 12.11 and 21 + a second incisior 22), another single incisor implant in position 11 of a Group 1-patient was lost together with an incisior 21 due to a trauma, adding up to a loss rate for UJ anterior sites of 1.9%.

2 implants had to be removed in the LJ lateral region of a Group 2-patient after the second year due to acute periimplantitis in the general course of a severe periodontitis presenting a loss rate for LJ lateral sites of 1.2%.

Therefore the overall loss rate of inserted implants added up to six implants reducing the overall success-rate in the three year survey-period to 98.8%.

4. Discussion

Mammal bone is structural composed of ordered collagenous type 1-fibres which build the matrix for the stored inorganic calciumphosphate-components, giving bone a highly pressure-resistive yet still elastic macro- and microstructure both for cortical and trabecular bone acting as lever for muscular forces and masticatory forces introduced by loaded teeth via the periodontal ligament. In case of malformation of this basic collagenous fibre-pattern, e.g. when suffering from "osteogenesis imperfecta", bone is prone to spontaneous fractures and splinter on even smallest flexing forces [21].

On the physiologic level bone has to be absolutely viewed as a unity of periosteum, basic type 1 collagenous fibres, elastin-rich Sharpey-fibres and endosteum with concomitant vascular system, forming the "Periosteum-Sharpey-fibre-Endosteum (PSE) structural continuum" which—in case of the dentate alveolar crest—extends to the periodontal ligament [22] and undergoes constant reformation, remodelling and adaptation to introduced forces with increase or decrease of its basic collagenous fibre-pattern and inorganic calciumphosphate-components [23].

Compared to the mammal long-bones—which represent a higher evolutionary stage both in macrostructural and microstructural organization and highly matured crosslinked collagenous-fibres—the woven bone formations of ribs and jawbone show a significant greater amount of collagen-fibres which on the other hand present significant less mature crosslinks, making jawbone prone to higher rates of degradation and turnover yet "renders more flexibility to the bone and leaves it more suited to constant exercise" [24] and higher elasticity to flexing forces with only little general differences in elasticity between cortical and trabecular bone [25]. Nevertheless the elasticity of jawbones differs within the different segments of the mandible and maxilla with higher elasticity in the distal segments of the maxillary and mandibular alveolar crest [26].

This innate elasticity of the mandibular and maxillary alveolar crest enables—within specific biomechanical limits [20]—a fracture-free distraction of vertical split alveolar crests with FPeCSWT, following a precise surgical protocol without the need to perform weakening bone-cuts at the base of the buccal bone-plate (**Figure 24**, **Figure 25**). To prevent accidental fractures the elasticity of the alveolar crest must not be exceeded and demands minimum vertical osteotomy-depths of 7 - 8 mm [20].

Nevertheless, vertical alveolar crest-splitting and horizontal distraction in its use to restore a sufficient width of the lateral atrophic alveolar crest for dental implant placement mostly creates a distraction gap of 3 - 4 mm which is above the threshold of a non-critical size defect (2.7 mm) and closer to a critical-size defect (5 mm and more) [27] with reduced and prolonged bone healing of the fracture gap and increased crestal resorptions when a full-thickness mucoperiostal flap is prepared to access the surgical site [17]. By the detachment of the periosteum from the bone the physiologic unity of the PSE-structural continuum is interrupted as well as the blood-perfusion to the sparse vascularized atrophic alveolar crest obstructing the natural function of the periosteum

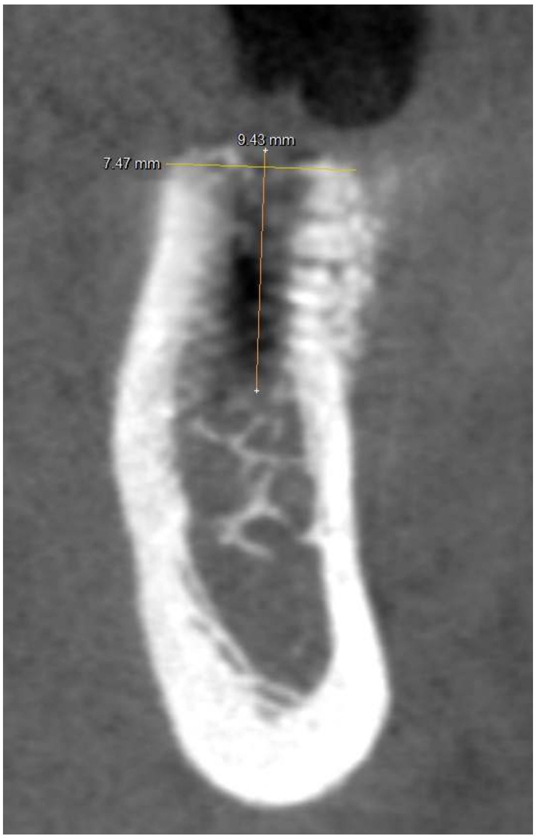

Figure 24. CBCT-scan of a mandibular distraction site after FPeCSWT.

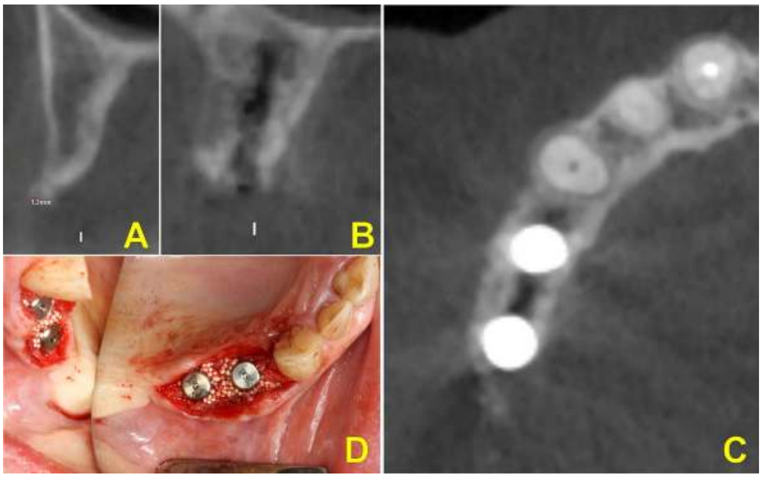

Figure 25. Sample-case of an upper premolar FPeCSWT-case: (A) presurgical state, (B) + (C) postsurgical state after FPeCSWT, (D) FPeCSWT-site with Q-Implants and esaygraft crystal inserted before wound-closure.

[28] [29] and leading to significant resorptions of the distracted buccal bone-plate [30] comparable to the physiology of bone healing in a tooth-extraction site treated with alveolar-ridge preservation-techniques [31].

As prior studies [17] and the results of the current study suggest an almost flapless approach seems to be highly preferable especially when now the indication for crest-splitting can be narrowed down to crest-width of 1 mm when FPeCSWT is used. Although FPeCSWT-sites with less than 2 mm width show a significant higher vertical bone-loss in the first three years, FPeCSWT still achieves significant better results than traditional or other ultrasonic-surgical methods of crest-splitting [15] [16] reporting buccal vertical bone loss of 3 - 4 mm in narrow alveolar crests of 2 mm. With a mean VBL UJ anterior of 1.22 mm and 1.12 mm LJ lateral for Group 1 (initial crest-width < 2 mm) versus 0.89 mm UJ anterior and 0.74 mm LJ lateral for Group 2 (initial crest width > 2 mm) with no single accidental iatrogenic vertical fracture or fracture of the distraction-baseline the FPeCSWT seems to provide more constant clinical results with calculable minimal vertical resorptions.

5. Conclusion

The results of this study suggest the Flapless Piezotome enhanced Crest Splitting and Widening Technique (FPeCSWT) to safely narrow down the indication for crest-splitting and horizontal distraction to also lateral atrophic alveolar crests of a width of only 1 mm both in the upper and lower jaw. The higher vertical bone loss of average 1.22 mm in the canine-to-canine-region of the upper front and 1.12 mm in the lateral mandible in crests of less than 2 mm width can easily be compensated by a 1 mm subcrestal (1 mm "sub-bone-level") insertion of the dental implants. An overall success-rate of 98.8% three-year-implant-survival and the negligible patient-morbidity suggests the FPeCSWT to be the therapy of choice for implant-insertion in the lateral atrophic alveolar crest. Further clinical studies have to be undertaken to investigate if the application of different bone-grafts and the addition of Platelet Rich Fibrin would allow a further enhancement of FPeCSWT in alveolar crests of <2 mm width and a further reduction of vertical bone loss.

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