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Review Article

Alveolar bone dimensional changes of post-extraction sockets in humans: a systematic review

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Abstract

Objective: To review the literature to assess the amount of change in height and width of the residual ridge after tooth extraction.

Material and Methods: MEDLINE-PubMed and the Cochrane Central register of controlled trials (CENTRAL) were searched through up to March 2009. Appropriate studies which data reported concerning the dimensional changes in alveolar height and width after tooth extraction were included. Approximal height change, mid-buccal change, mid-crestal change, mid-lingual change, Alveolar width change and socket fill were selected as outcome variables. Mean values and if available standard deviations were extracted. Weighted mean changes were calculated.

Results: Independent screening of the titles and abstracts of 1244 MEDLINE-PubMed and 106 Cochrane papers resulted in 12 publications that met the eligibility criteria. The reduction in width of the alveolar ridges was 3.87 mm. The mean clinical mid-buccal height loss was 1.67 mm. The mean crestal height change as assessed on the radiographs was 1.53 mm. Socket fill in height as measured relative to the original socket floor was on an average 2.57 mm.

Conclusion: During the post-extraction healing period, the weighted mean changes as based on the data derived from the individual selected studies show the clinical loss in width to be greater than the loss in height, assessed both clinically as well as radiographically.

Key words: bone loss; bone resorption; dimensional height and width changes; post-extraction socket; residual ridge resorption; systematic review; tooth extraction

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The alveolar process is a tooth-dependent tissue that develops in conjunction with the eruption of the teeth. The tooth is anchored to the jaws via the bundle bone into which the periodontal ligament fibres invest. The volume as well as the shape of the alveolar process is determined by the form of the teeth, their axis of eruption and eventual inclination (Schroeder 1986). Subsequent to the removal of teeth, the alveolar process will undergo atrophy (e.g. Atwood 1957, Hedegård 1962, Tallgren 1972). The bundle bone at the site obviously will lose its function and disappear (Botticelli et al. 2004, Araújo & Lindhe 2005, Araújo et al. 2008).

Tooth extraction is one of the most common dental procedures. Generally, the extraction socket heals uneventfully. However, even with uneventful healing, the alveolar defect that results as a consequence of tooth removal will only become partially restored. Concurrent with bone growth into the socket, there is also well-documented, resorption of the alveolar ridges. The greatest amount of bone loss is in the horizontal dimension and occurs mainly on the facial aspect of the ridge. There is also loss of vertical ridge height, which has been described to be most pronounced on the buccal aspect (Lekovic et al. 1997, 1998, Araújo & Lindhe 2005). This resoprtion process results in a narrower and shorter ridge (Pinho et al. 2006) and the effect of this resorptive pattern is the relocation of the ridge to a more palatal/lingual position. The defect resulting from the loss of a tooth may be complicated by previous bone loss due

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to periodontal disease, endodontic lesions, or a traumatic episode. The situation becomes even more compromised when the alveolus has lost walls or height (Iasella et al. 2003). Loss of alveolar bone may have occurred before tooth extraction because of periodontal disease, periapical pathology, or trauma to teeth and bone. The size of the residual ridge is reduced most rapidly in the first 6 months, but bone resorption activity in the residual ridge continues throughout life at a slower rate resulting in the removal of large amounts of jaw structure (Jahangiri et al. 1998). Morphologic changes in extraction sockets have been described by cephalometric measurements, study cast measurement, radiographic analysis and direct measurements of the ridge following surgical re-entry procedures (Chen et al. 2004).

Except in the most dramatic cases, this ridge collapse following tooth extraction has not been a concern to most dentists or surgical specialist. Damage of the bone tissue during tooth removal may also result in bone loss (Schropp et al. 2003). However, within the past decade, as aesthetics have received more emphasis with treatment planning, resorption of the alveolar ridge following tooth extraction, especially in the anterior region has become a significant problem (Bartee 2001). After tooth removal, the dental team faces the challenge of creating a prosthetic restoration that blends with the adjacent natural dentition.

Sufficient alveolar bone volume and favourable architecture of the alveolar ridge are essential to obtain optimal functional and aesthetic prosthetic reconstructions. Therefore, knowledge about the healing process at extraction sites, including contour changes caused by bone resoprtion, is essential for treatment planning. It is the purpose of the present paper to describe – based on a systematic search of the available literature – anatomical changes of the residual ridge following tooth extraction. Attention is focused on bone dimensional changes of height and width, as evaluated by clinical or radiographic means.

Material and Methods

Focused question

What are the dimensional changes of height and width of the alveolar bone following tooth extraction?

Search strategy

Two internet sources were selected in the search for papers satisfying the study purpose: The National Library of Medicine, Washington, DC (MEDLINE-PubMed) (1965 up to March 2009) and the Cochrane Central register of controlled trials (CENTRAL) (up to March 2009). All reference lists of the selected studies were screened for additional papers that could meet the eligibility criteria of the study. The databases were searched using the following search term:

PubMed & Cochrane CENTRAL search

Intervention:
(<[MeSH terms/all subheadings] ''Tooth Extraction''>
OR
<[text words] Tooth Extraction OR Dental Extraction OR Tooth Removal OR Tooth Pulling>
OR
<[text words] Tooth AND Extraction>)
AND
Outcome:
(<[MeSH terms/all subheadings] ''Bone Resorption'' OR ''Alveolar Bone Loss''>
OR
<[text words] Bone Defect OR Bone Resorption OR Alveolar Bone Loss>)

This search strategy attempted to be inclusive for any study that evaluated the effect of diverse varieties of post extraction healing. In various trials, the undisturbed healing group (frequently the control group) served to provide data with regard to healing following extraction, thus being randomly collected.

The eligibility criteria were:

- randomized-controlled clinical trials, or,
- controlled clinical trials, or,
- prospective clinical studies, or,
- case series,
- conducted in human subjects $\geqslant 18$ years,
- subjects in good general health (no systemic disorders),
- intervention: tooth extraction.
- outcome parameters: clinical and/or radiographic alveolar bone dimensions (height and/or width)

Only papers written in English language were included. Letters and narrative or historical reviews were not included in the search. Papers without abstracts but with titles related to the objectives of this review were selected so that the full text could be screened for eligibility.

Screening and selection

The papers were screened independently by two reviewers (F. D. A. and G. A. W.), first by title and abstract. Then, as a second step, full-text papers were selected that fulfilled the eligibility criteria for inclusion according to the study aim. After the search, all reference lists of selected studies were screened for additional papers that might meet the eligibility criteria of the study. Any disagreement between the two reviewers was resolved after an additional discussion.

Assessment of heterogeneity

Factors that were recorded in order to evaluate the heterogeneity of the primary outcome across studies were as follows:

- Study design.
- Duration of follow-up.
- Number, age, range of subjects.
- Tooth type.
- Reason for extraction.
- Smoking status.
- Intervention.
- Evaluation parameters.
- Evaluation method (radiographical or clinical).

Quality assessment

Assessment of methodological study quality was performed combining the proposed criteria of the RCT-checklist of the Dutch Cochrane Center (2009), the CONSORT statement (2001) Moher et al. (1999, 2001), MOOSE statement (Stroup et al. 2000), STROBE statement (Von Elm et al. 2007), and Esposito et al. (2001) and Needleman et al. (2000). This combination resulted in the quality criteria as mentioned in Box 1. When random allocation, defined inclusion/exclusion, blinding to patient and examiner, balanced experimental groups, an identical treatment between groups except for intervention and report of follow-up was described, the study was classed as at a low risk of bias. When missing one of these five criteria, the study was classed as having a moderate potential risk of bias. Missing two or more of these criteria resulted in a high

Box 1. Quality assessment of the studies included

Validity	Study # / quality criteria	# I Barone et al. (2008)	# II Brägger et al. (1994)	# III Camargo et al. (2000)	# IV Crespi et al. (2009)	# V Fiorellini et al. (2005)	# VI Kerr et al. (2008)	# VII Iasella et al. (2003)	# VIII Lekovic et al. (1997)	# IX Lekovic et al. (1998)	# X Saldanha et al. (2006)	# XI Schropp et al. (2003)	# XII Serino et al. (2003)
External	Representive population group	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Eligibility criteria defined	Yes	?	Yes	Yes	Yes	?	Yes	?	?	Yes	Yes	Yes
Internal	Random allocation	Yes	Yes	?	No	Yes	Yes	Yes	?	Yes	NA	NA	?
	Allocation concealment	?	?	?	?	?	?	?	?	?	NA	NA	?
	Blinded to the patient	?	Yes	?	?	Yes	?	?	?	?	NA	NA	?
	Blinded to the examiner	?	Yes	?	Yes	Yes	Yes	Yes	?	Yes	NA	NA	?
	Blinding during statistical analysis	?	?	?	?	?	?	?	?	?	?	NA	?
	Reported loss to follow-up	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	?	Yes	Yes
	# (%) of drop-outs	0	0	0	0	0	0	0	3 (30%)	0	?	2 (4%)	9 (20%)
	Treatment identical, except for intervention	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	NA	NA	Yes
Statistical	Sample size calculation and power	?	?	?	?	?	?	Yes	?	?	?	?	?
	Point estimates presented for primary outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	Measures of variability for the primary outcome	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
	Intention to treat analysis	?	?	?	?	Yes	?	?	?	?	?	?	?
Clinical aspects	Study design	Parallel	Parallel	Split-mouth	Split-mouth	Parallel	Split-mouth	Parallel	Split-mouth	Split-mouth	Cohort	Cohort	Parallel and split mouth
	Validated measurement	?	?	?	?	?	?	?	?	?	?	?	?
	Calibration examiner	?	?	?	?	?	?	?	?	?	?	?	?
	Reproducibility data shown	No	No	No	No	Yes	No	No	No	No	No	Yes	No
	Reason for extraction	Requiring extraction	Scheduled for extraction	Requiring extraction	Requiring extraction	Requiring extraction	Requiring extraction	Requiring extraction	Requiring extraction	Requiring extraction	Requiring extraction	Root fractures, periodontal problems, endodontic failures, advanced caries	Compromised teeth
	Estimated potential risk of bias	Moderate	Low	High	Moderate	Low	Low	Low	High	Low	Moderate	Low	High
	Level of evidence CEBM	1B-	1B-	1B-	1B-	1B	1B-	1B-	2B	1B-	2B	2B	2B

NA, not applicable; CEBM, Centre for Evidence Based Medicine.

potential risk of bias. In addition, the Centre for Evidence Based Medicine (CEBM) document for ''Levels of Evidence'' (2009) was used to assess the methodological quality.

Data extraction

From the selection of papers that met the criteria, data were processed for analysis. Mean values and standard deviations were extracted by the three reviewers (D. E. S., F. D. A., G. A. W.) with regard to dimensional changes of height and width on the alveolar bone after tooth extraction reported from clinical or radiographical evaluations. Approximal height change, mid-buccal change, mid-crestal change, mid-lingual change, alveolar width change and socket fill were selected as outcome variables.

Data analysis

A weighted mean change and standard deviations of the weighted mean change for each outcome variable were calculated using the SPSS Inc. (Chicago, IL, USA) statistical package. If necessary and possible, data for the outcome variables as presented in Tables 3 and 4 were calculated by the authors based on the data as provided by the individual selected studies. Some of the papers provided standard errors (SE) of the mean. The SDs were calculated based on the sample size ($SE = SD/\sqrt{N}$). Ninety-five percent confidence intervals were calculated based on the SE × 1.96 (as upper bound) and SE × −1.96 (as lower bound).

Results

Search results

The PubMed search resulted in 1244 papers. The Cochrane search resulted in 106 papers, which provided 36 additional papers to the PubMed search (Table 1). The screening resulted in 42 full-text articles. After full reading, 31 studies were excluded because these did not report on bone dimensional changes. The remaining 11 papers that fulfilled the selection criteria were processed for data extraction. One additional paper (# XI) from the reference list of study # X was included and processed for data extraction

Table 1. Search results

Selection	PubMed	Cochrane	Identical
Search	1244	106	70
Titles and abstracts		1280	
Excluded by title and abstract		1238	
All selected for full-text reading		42	
Excluded after full reading		31	
Included after full reading		11	
Included from reference list		1	
Final selection for data extraction		12	

Assessment of heterogeneity

After a preliminary evaluation of the selected papers, considerable heterogeneity was observed. Information regarding the study characteristics is presented in Table 2.

Study design and duration of follow-up

Of the selected studies, six were randomized-controlled clinical trials (# I–VII) and four studies were controlled clinical trials (# III, IX, X, XII). One study (# VIII) was a case-series and study # XI was a prospective clinical trial. Studies # III, IV, VI, VIII and IX had a split-mouth design. The evaluation period varied between the studies from 3 to 12 months.

Subjects, age, tooth types, reason for extraction, smoking status

The studies included between 7 and 46 subjects. Only study # V did not report the age of the participants. Nine out of twelve studies involved regular patient whereas study # II, IX and XII involved patients treated for periodontal disease. Most studies evaluated the effect of tooth extraction at anterior and premolar sites. Three studies also included molars (# IV, VI, XI). Most papers did not describe the reasons for extraction. Two studies extrated compromised teeth such as root fractures, periodontal problems, endodontic failures and advanced caries (XI, XII). Seven studies did not report about the smoking status of the participants. Two studies (# IV, VI) particularly excluded smokers whereas study # I included three smokers out of the 20 subjects monitored. Study # X purposely compared the results following extraction in smokers and non-smokers.

Intervention

Most of the extracted data concerned control groups/teeth in studies that evaluated the effect of different therapies on the post-extraction outcome. The exceptions are studies # II and # X that compared two groups both of which are included in this review. Study # II evaluated the effect of rinsing with chlorhexidine during 1 month following extraction and # X evaluated smoking status in relation to healing. Study # XI evaluated only one group prospectively during a 12-month interval. Studies # II, IV,VI, and XI allowed spontaneous healing following extraction. In the other studies, flaps were raised. Studies # III, VII, X and XII did not attempt to close the extraction wound while in studies # I, V, VIII and IX flaps were raised and eventually sutured and secured to completely close the extraction socket.

Evaluation parameters

Studies # I, VII, XI and XII assessed the bone change at the mesial and distal aspect of the extraction site. For the purpose of this review, an average approximal height change was calculated. Studies # I, VI and VII measured the change at the mid-buccal and mid-lingual aspect of the extraction site whereas studies # III, VIII, IX and XII only assessed the mid-buccal aspect. In the radiographical studies, the crestal height change was measured relative to the most coronal aspect of the ridge. Only three studies (# III, VIII, IX) assessed socket fill. Five out of the six clinical studies assessed change in width (# I, III, VII, VIII, IX) while only two out of the six radiographic studies measured alveolar width change (# VI, X).

Evaluation method

Studies # II, IV, V, VI, X and XI performed a radiographical evaluation of the alveolar bone in the socket site Study # II, IV, and XI compared two peri-apical intra-oral radiographs. Bite blocks were used for standardization. Study # X used linear tomography and

Table 2. Overview of the studies processed for data extraction

ID#	Author	Title	Design and follow-up time	Mean age in years (SD) and gender	Group(s)	Measures	Random	Flap raised
# I	Barone et al. (2008)	Xenograft *versus* extraction alone for ridge preservation after tooth removal: a clinical and histomorphometric study	RCT 7 months	> 18 (range 26–69) ?	Control: antibiotics for 4 days, chlorhexidine for 21 days and anti-inflammatory drugs for 3 days	*Clinical* Reference: acrylic stent Height bucally Height lingually Width Height mesial and distal	Yes	Yes closure
# II	Brägger et al. (1994)	Effect of chlorhexidine (0.12%) rinses on periodontal tissue healing after tooth extraction	RCT 6 months	? ?	Control: placebo rinse for 30 days Test: chlorhexidine rinse for 30 days Start of rinsing 2 days after tooth extraction	*Radiographs* On standardized radiographs using acrylic bite blocks Parameters: crestal alveolar bone mesial and distal to extraction site	Yes	No
# III	Camargo et al. (2000)	Influence of bioactive glass on changes in alveolar process dimensions after exodontia	Clinical trial split-mouth 6 months	44.0 (15.9) 8 ♀/8 ♂	Control: antibiotics for 7 days chlorhexidine for 21 days and analgesics as needed	*Clinical* Reference: titanium pins External vertical measure Internal vertical measure Horizontal measure	?	Yes No closure
# IV	Crespi et al. (2009)	Magnesium-Enriched hydroxyapatite compared with calcium sulfate in the healing of human extraction sockets: radiographic and histomorphomeric evaluation at 3 months	RCT split-mouth 3 months	51.3 (range 28–72) 7 ♀/8 ♂	Control: antibiotics for 1 week	*Radiographs* Reference: occlusal stent vertical ridge height	Yes	No
# V	Fiorellini et al. (2005)	Randomized study evaluating recombinant human bone morphogenetic protein-2 for extraction socket augmentation	Multi-centre placebo-controlled-randomized clinical trial, 4 months	? ?	Control: antibiotics for 7–10 days chlorhexidine for? days	*Radiographs* (CT scan) Reference: ? alveolar height	Yes	Yes Closure
# VI	Kerr et al. (2008)	The effect of ultrasound on bone dimensional changes following extraction: a pilot study	RCT split-mouth 3 months	53.3 (range 36–72) 14♀/10 ♂	Control: spontaneous healing	*Cone beam volumetric tomography* Reference: metalic plate Height buccal Height lingual Width at crest	Yes	No
# VII	Iasella et al. (2003)	Ridge preservation with freeze-dried bone allograft and a collagen membrane compared with extraction alone for implant side development: a clinical and histological study in humans	RCT 6 months	51.5 (13.6) (range 28–76) 14♀/10 ♂	Control: antibiotics for 2 weeks chlorhexidine for? days and analgesics for 1 week	*Clinical* Reference: acrylic stent Horizontal ridge width Vertical ridge height at mid-buccal, mid-lingual, mesial, distal points	Yes	Yes No closure

# VIII	Lekovic et al. (1997)	A bone regenerative approach to alveolar ridge maintenance following tooth extraction. Report of 10 cases	Case series split-mouth 6 months	49.8 6 ♀/4 ♂	Control: antibiotics for 7 days, chlorhexidine for ? days and analgesics as needed	*Clinical* Reference: titanium pins External vertical measure Internal vertical measure Horizontal measure	?	Yes Closure
# IX	Lekovic et al. (1998)	Preservation of alveolar bone on extraction sockets using bioabsorbable membranes	Clinical trial split-mouth 6 months	52.6 (11.8) 6♀/10 ♂	Control: antibiotics for 7 days, Chlorhexidine for 15 days and analgesics as needed	*Clinical* Reference: titanium pins External vertical measure Internal vertical measure Horizontal measure	Yes	Yes Closure
# X	Saldanha et al. (2006)	Smoking may affect the alveolar process dimensions and radiographic bone density in maxillary extraction sites: a prospective study in humans	Clinical study 6 months	? (range 22–67) 9 ♀/12 ♂	Test: smokers (at least 20 cigarettes per day for at least 5 years) Control: non-smokers Chlorhexidine for 1 month and analgesics as needed	*Radiographs* Reference: acrylic stent with metal sphere On lineair tomogram Parameters: alveolar process height and alveolar process width at crest	?	Yes No closure
# XI	Schropp et al. (2003)	Bone healing and soft tissue contour changes following single-tooth extraction: a clinical and radiographic 12-month prospective study	Prospective clinical trial 12 months	45 (range 20–73) 31♀/15 ♂	Test: spontaneous healing	*Radiographs* Reference: ? height at mesial and distal of neighbouring tooth height buccally; height orally; width	□	No
# XII	Serino et al. (2003)	Ridge preservation following tooth extraction using a polylactide and polyglycolide sponge as space filler: a clinical and histological study in humans	Clinical trial 6 months	? (range 35–64) 31 ♀/14 ♂	Control: chlorhexidine for 2 weeks and analgesics as needed	*Clinical* Reference: acrylic stent Alveolar process height between three landmarks: -mesio-buccal; -mid-buccal; -disto-buccal	?	Yes No closure

an acrylic stent with a fixed reference point (metal sphere). Study # V used computer tomography (CT) scans. These scans were examined by three independent reviewers. However, no reference guide was used. Study # VI used cone beam volumetric tomography scans (CBTV) with a metallic reference plate. Studies # I, III, VII, VIII, IX and XII performed clinical assessments of the healing processes following extraction. Studies # I, VII and XII used a stent guide for the measurements whereas studies # II, VIII and IX placed titanium pins immediately following extraction, which then served as reference points.

Assessment of quality

Quality assessment is presented in Box 1. The estimated risk of bias is considered to be low for six studies, for three moderate and for three high. Study # V is considered to have the highest level of evidence with an estimated low risk of bias and a score 1B (CEBM 2009). Seven studies receive a score 1B – as they lacked confidence intervals. Two studies had a drop-out rate of $>20\%$ and were given score 2B (# VIII, XII). Two were cohort studies with a 2B score (# IX, X).

Loss to follow-up

From study # XII in total, nine of the original 45 subjects dropped out of the study for reasons unrelated to the treatment provided. However, the paper did not provide information how many of these nine subjects belonged to the control group. In study # VIII at the 3-month re-evaluation visit, three out of the 10 subjects presented with exposed membranes (test teeth). Therefore, these subjects were prematurely exited from this split-mouth study, which had an effect on the number of control sites in the study. From study # XI, two patients withdrew after the 6-month visit and were therefore not included in the 12-month evaluation. The assessments in study # VI involved the measurement of the ridge relative to a reference plate. At the most coronal level, only the lingual ridge provided data for all 12 sites whereas the buccal ridge at this coronal level was absent in six out of the 12 sites.

Study outcome

The study outcomes are presented in Tables 3 and 4. The clinical data involved anterior and pre-molar sites. The weighted mean changes at the approximal aspect of the neighbouring teeth show a mean loss of 0.64 mm ($N = 45$) (95% CI $-0.699 < > -0.585$). The mid-buccal change was 1.67 mm (95% CI $-1.910 < > -1.428$); including all extracted data ($N = 84$). The loss at the mid-lingual aspect was 2.03 mm ($N = 32$) (95% CI $-2.486 < > -1.564$). For a proper comparison also a weighted mean for the mid-buccal loss was also, calculated using the data as extracted from the same studies (SD = I, VII) that provided mid-lingual data, which showed a mean loss of 2.59 (1.85) mm ($N = 32$). Socket fill in height as measured relative to the original socket floor was on average 2.57 mm (95% CI 2.446 < > 2.707). The reduction in width of the alveolar ridges was 3.87 mm.

This clinically observed change in width is much larger than what is observed on the radiographs, which is 1.21 mm. However, these data were extracted from different studies and the radiographical data involved apart from the anterior and pre-molar teeth also from the molar teeth. The mean crestal height change as assessed on the radiographs (Table 4) is 1.53 mm ($N = 111$) (95% CI $-1.696 < > -1.364$), which is in line with the clinical observation at the mid-buccal aspect ($N = 84$) being 1.67 mm (Table 3).

The approximal bone height change was on average 0.7 mm being similar to what was clinically assessed. One of the studies included (# II) particularly assessed the effect of a post-extraction therapy of 30 days rinsing with chlorhexidine mouth rinse and showed that this significantly reduced approximal bone loss.

Discussion

The results from this review with respect to socket fill are presented in Table 3. It shows that on average approximately 2.57 mm of fill in bone height may be expected. The crestal height changes as based on radiographic measurements is approximately 1.59 mm, which can be subdivided based on the clinical assessment as loss on the buccal aspect (1.67 mm) and the lingual aspect (2.03 mm). These data do not support the results as reported by Araújo & Lindhe (2005). These authors concluded that as the crest of the buccal bone wall in their dog model was comprised solely of bundle bone, the modelling resulted in substantial vertical reduction of the buccal crest (Araújo & Lindhe 2005). The average difference between buccal and lingual crest in their dog model experiment was approximately 2 mm. Even if in the present review for the weighted mean changes (Table 3), the outcome of the same studies ($N = 32$) was used, comparing the buccal and lingual changes, the reduction would be 2.59 ($\pm$ 1.85) and 2.03 ($\pm$ 1.78), respectively. Although this difference (0.56 mm) is being more pronounced on the buccal aspect, it is still not as prominent as reported by Araújo & Lindhe (2005).

A study conducted by Nevins et al. (2006) determined the fate of a thin buccal bone plate at the prominent roots of maxillary anterior teeth following extractions. Using CT scans, they assessed the height of the crest where the width was 6 mm. Using this parameter, they observed a reduction in height (relative to the 6 mm width) of 5.24 mm. The illustration provided with this paper demonstrated that this was mainly the result of resorption of the buccal wall. These data are in support of the dog model data (Araújo & Lindhe 2005). However, the observed clinical weighted mean changes as calculated in the present review do not substantiate this finding (Table 3). Moreover, the current clinical data are supported by the CBVT scan data (Table 4) as presented in study # VI, where the buccal and lingual changes were more or less comparable. The most likely explanation is that the buccal plate in humans is on average equally prone to resoprtion as the lingual aspect of the ridge. Both showed a reduction of approximately 2 mm following extraction.

This study does not provide data on soft tissue loss that is an additive with hard tissue loss, and the combined effect of both tissues on total ridge width must be considered.The cohesive relationship between the gingiva and its underlying osseus tissue support has significance in the aesthetic zone.

Heterogeneity

Data were pooled in a meta-analysis calculating a WMD. Although the meta-analysis is now well established as a method of reviewing evidence, one common problem is the sources of heterogeneity, in particular clinical differences between studies included. Heterogeneity was investigated to increase the clinical relevance of the conclusions drawn (Thompson 1994). It was attempted to explore some of the possible causes of heterogeneity that could be related to the quality of trial design, accuracy of the outcome measures, population and length of the follow-up. Considerable clinical heterogeneity was observed among the selected studies (Table 3), which shows that the studies are not all estimating the same quantity. This does not necessarily suggest that the true intervention effect varies. The heterogeneity of the data reflects different behaviours of the study populations, differences in study designs and all other factors that may influence the outcomes. Heterogeneity may also be caused by publication bias. Last but not the least, heterogeneity may also be due to chance. In case of considerable heterogeneity, the WMD value should be interpreted with caution. The reader should not quote the WMD as the exact measure for the effect (Higgins & Green 2008). On the other hand, the heterogeneity observed most likely reflects what the dentist encounters in his/her practice population. Not one patient is or behaves the same. The results presented in this review give guidance in what may be clinically expected following tooth extraction. For this purpose, the confidence intervals have also been added that indicate the (im)precision of the study estimates. These provide an indication of how much greater or smaller the true effect is likely to be (Guyat et al. 2008)

Smoking

Post-extraction wound healing is dependent on molecular and cellular events to occur appropriately. Therefore, it seems logical to assume that the final healing outcome after tooth extraction may be influenced by factors that affect such events (Bartee 2001). A variety of factors may be of influence such as systemic factors including the patient's general health and habits (e.g. smoking). Local factors include the reasons for extraction, the number and proximity of teeth to be extracted, the condition of the socket before and after tooth extraction, the influence of tissue biotype on healing, local differences between sites in the mouth and the

Table 3. Clinical outcomes in millimetres (standard deviation in parenthesis) and 95% convidence intervals (CI)

#	study	# of subjects	# of teeth and type	Clinical outcomes (in mm)				
				aproximal height change ○	mid-buccal change	mid-lingual change	alveolar width change	socket fill
# I	Barone et al. (2008)	20	20 A/P	Mesial: − 0.4(1.2) Distal: − 0.5 (1.0) Average: − 0.45▲	− 3.6 (1.5)	− 3.0 (1.6)	− 4.5 (0.8)	□
# III	Camargo et al. (2000)	16	16 A/P	□	− 1.00 (9▲)	□	− 3.06 (9.64▲)	+3.00▲
# VII	Iasella et al. (2003)	12	12 A/P	Mesial: − 1.0 (0.8) Distal: − 0.8 (0.8) Average: − 0.9▲	− 0.90 (1.60)	− 0.4 (1.0)	− 2.63 (2.29)	□
# VIII	Lekovic et al. (1997)	10	10 A/P	□	*N* = 7* − 1.00 (0.00▲)	□	*N* = 7* − 4.43 (5.03▲)	*N* = 7* +1.92▲
# IX	Lekovic et al. (1998)	16	16 A/P	□	− 1.50 (1.04▲)	□	− 4.56 (1.32▲)	+2.44▲
# XII	Serino et al. (2003)	12	13 A/P	Mesial: − 0.6 (1.0) Distal: − 0.8 (1.5) Average: − 0.7▲	− 0.8 (1.6)	□	□	□
All M_w(SD)		64	A/P	− 0.64 (0.19)▲ (*N* = 45)	− 1.67 (1.11) ▲ (*N* = 84)	− 2.03 (1.28) ▲ (*N* = 32)	− 3.87 (0.82) ▲ (*N* = 71)	+2.57 (0.40) ▲ (*N* = 39)
95% CI				− 0.699 < > − 0.585	− 1.910 < > − 1.428	− 2.486 < > − 1.564	− 4.059 < > − 3.673	2.446 < > 2.707

*Three patients in the test group presented with exposed membranes at the 3-month re-evaluation and were therefore prematurely exited from this split-mouth study.

dental arches and the type of interim prosthesis used (Chen et al. 2004).

The findings of a 6-month prospective study selected for this review suggest that smoking may significantly affect healing after tooth extraction. Thus, Saldanha et al. (2006) showed that smoking may lead to an enhanced dimensional reduction. The precise mechanisms by which tobacco smoke interferes with healing is not understood. Part of the negative influence of smoking has been attributed to nicotine, which is one of the major constituents of the particulate phase of tobacco smoke. It is one of the most cytotoxic and vasoactive substance. Based on observations by Saldanha et al. (2006), one may expect 0.5 mm more bone crest reduction following tooth extraction in smokers than in non-smokers.

Chlorhexidine

Another study selected for this review assessed the influence of a 30-day period of chlorhexidine digluconate (CHX) rinse on the healing activity of the periodontal tissues adjacent to an extraction wound (Brägger et al. 1994). The CHX group demonstrated an increase in bone density in the apposition phase between 1 and 6 months. The patients rinsing for 1 month with a placebo solution lost almost 1 mm of bone height over the 6 months following tooth extraction, while in the CHX group, practically no change (0.06 mm) was observed. This is in agreement with a previous report in which the healing of periodontal tissues around teeth located adjacent to an extraction wound were assessed. A tendency for less recession and shallower probing pocket depths were observed in the CHX group (Lang et al. 1994). Studies # I, II, V, VII, VIII, IX, X and XII all provided chlorhexidine rinse for post-extraction healing. Studies # I, III, IV, V, VII, VIII and IX even prescribed antibiotics. These post-extraction therapies may have influenced the study outcomes in a positive manner (Brägger et al. 1994, Bystedt et al. 1997).

Positive effect

In some cases, the healing extraction can also be considered to provide a beneficial effect. A reduction in pocket probing depth following tooth extraction in addition to that obtained by scaling and root planing has been demonstrated

Table 4. Radiographical outcomes in millimetres (standard deviation in parenthesis) and 95% convidence intervals (CI)

#	study	# of subjects	# of teeth & type	Radiographic outcomes (in mm): approximal height change ○	mid-buccal change	mid-lingual change	crestal height change	alveolar width change
# II	Brägger et al. (1994)	23 test: 11 control: 12	16 16 type?	− 0.06 (0.89) − 0.93 (0.74) Average: − 0.7▲	□	□	□	□
# IV	Crespi et al. (2009)	15	15 P/M	□	□	□	− 3.75 (0.63)	□
# V	Fiorellini et al. (2005)	20	20 A/P	□	□	□	$N = 19$ − 1.17 (1.23)	□
# VI	Kerr et al. (2008)	12	12 A/P/M	□	$N = 12$ − 0.95 (1.34▲)	$N = 12$ − 1.12 (0.98▲)	$N = 12$ Average: − 1.04▲	$N = 6$ − 2.20 (1.99▲)
# X	Saldanha et al. (2006)	21 SM:10 NSM: 11	10 11 A (upper jaw)	□	□	□	SM: − 1.5▲ NSM : − 1.0▲ Average: − 1.24 ▲	SM: − 1.3▲ NSM: − 0.6▲ Average: − 0.93▲
# XI	Schropp et al. (2003)	46	46 P/M	$N = 44$ Mesial: − 0.9 Distal: − 0.5 Average: − 0.7▲	□	□	$N = 44$ − 1.2	□
All M_w (SD)		125	A/P/M	− 0.7 (0.0)▲ ($N = 60$)	□	□	− 1.53 (0.88) ▲ ($N = 111$)	− 1.21 (0.54) ($N = 27$)
95% CI				not relevant			− 1.696 < > − 1.364	− 1.425 < > − 0.999

Subscript to the Tables 3 and 4:
A, incisor/canine; P, pre-molar; M, molar; N, number of teeth extracted; ▲, Calculated by the authors; □, data not provided; ○, crestal alveolar bone height change at teeth adjacent to extraction sites; M_w, weighted mean; SM = smoker; NSM, non-smoker.

at sites adjacent to an edentulous area. This reduction was the result of gingival shrinkage and was greatest at sites of deep pocket probing depths. The beneficial effects of tooth extraction to adjacent periodontium may be considered when patients with advanced periodontal disease are treated comprehensively (Grassi et al. 1987).

Surgical intervention

In studies # I, III, V, VII, VIII, IX, X and XII, buccal flaps were raised before tooth extraction. In some studies, primary closure of the extraction socket was accomplished (# I, V, VIII, IX). This primary closure requires the advancement of a large, full-thickness flap. It is well established in the periodontal literature that the elevation of a full-thickness flap (muco-periostal flap) may cause loss of attachment and resorption of bone (for a review, see Heitz-Mayfield et al. 2002). The reported crestal bone loss after a full-thickness flap elevation is approximately 0.6 mm (Wood et al. 1972). Flap elevation is believed to compromise the vascular supply of the site, contributing to soft-tissue recession and possibly limiting future regenerative potential (Sclar 1999). The direct contact between gingival connective tissue with the socket area may favour alveolar bone resorption. This additional osteoclastic resorption will occur on the external aspect of the buccal bone plate. Tavtigian (1970) showed a mean loss of 0.47 mm of the facial radicular alveolar crest after full-thickness flap procedures. In recent animal models, additional volumetric shrinkage of 0.5–0.7 mm could be observed (Blanco et al. 2008, Fickl et al. 2008). The data from Araújo and Lindhe (2009) suggest that the difference between the flap and the flapless group may disappear after longer (≥6 months) healing periods.

Evaluation time

The studies included in this review had evaluation periods, which varied from 3 to 12 months. Johnson (1969) reported that the process that resulted in tissue reduction seemed to be more pronounced during the initial phase of wound healing than during later periods following tooth removal. Most of the dimensional alterations – horizontal as well as vertical – of the alveolar ridge took place during the first 3 months of healing (Johnson 1969, Schropp et al. 2003). Therefore, this review provides a summary of data that reflect what can clinically be expected by the practioner to occur following tooth extraction.

Conclusion

During the post-extraction healing period, the weighted mean changes as based on the data derived from the individual selected studies show the clinical loss in width (3.87 mm) to be greater than the loss in height, assessed both clinically (1.67–2.03 mm) as well as radiographically (1.53 mm).

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Clinical Relevance

Scientific rationale for the study: Loss of teeth is such a frequent condition that it is easy to forget how it will invariably transform the natural configuration of the basal alveolar bone complex. Dependent on the healing pattern this may pose a problem for the clinician. It creates a challenging aesthetic problem in the fabrication of an implant-supported restoration or a conventional prosthesis. Generally, extraction sockets heal uneventfully. However, even with uneventful healing, the alveolar defect that results as a consequence of tooth removal will only achieve partial bone fill. In order to have an ideal aesthetic outcome, a sufficient ridge volume and a stable soft tissue margin is needed.

Principal findings: The weighted mean changes following extraction based on the data derived from the individual studies show clinically a loss in width of 3.87 mm and a loss in height of 1.67–2.03 mm.

Practical implications: Understanding about the healing process at extraction sites, including contour changes caused by bone resorption, is essential for treatment planning. Concurrent with bone growth into the socket, there is also well-documented resorption of the alveolar ridge. This knowledge of the amount of hardsoft tissue change following tooth extraction may help clinicians to prevent possible clinical problems in the aesthetics zone.