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Dental roots' and surrounding structures' response after contact with orthodontic mini implants: A systematic literature review

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SUMMARY

The objective of this article was to conduct a systematic literature review about the consequences and recovery of dental roots' and surrounding structures' after iatrogenic mini implant (MI) contact based on peer reviewed publications of 2008-2017 January. The Cochrane and PRISMA references were used while searching for scientific literature in six data bases. The inclusion criteria to select articles were: 1) root contact evaluation associated with the use of orthodontic MI, 2) the diameter of MI was ≤2.5 mm, 3) the research sample was ≥20 MI, 4) the extent of dental root or surrounding structures damage, the regeneration/degeneration and their progress was described, 5) the condition of dental roots and surrounding structures should be evaluated immediately after damage with MI, after longer contact with MI and after a certain period of time, 6) articles published in 2008-2017 January. Two authors independently reviewed and extracted data from the selected studies and a methodological quality assessment process was used to rank the studies classifying them as low, moderate or high quality. 13 articles met the selection criteria of the research. The success of damaged dental root or surrounding structure regeneration was influenced by the damage extent: the cementum, dentin or periodontal ligament may regenerate; the regeneration of damaged pulp is uncertain. The loss of pulp vitality, root resorption, root fracture, ankylosis or osteosclerosis are rare complications. Dental roots may resorb due to contact with MI, but the regeneration is possible after cause removal.

Key words: mini-implant, root, contact, damage, healing.

INTRODUCTION

Mini implants (MI) have become the most popular temporary skeletal anchorage devices used in orthodontics since the last decade. They can be screwed in such treatment-comfortable sites as alveolar process interdental spaces, although the risk of damaging dental roots or surrounding structures with the MI is high in these locations (1). It is known that MI should be screwed in fixed gingiva or muco-gingival junction, while the proximity between adjacent dental roots is limited in this location (for example: the root proximity is only about 3 mm between the first molar and second premolar in site 5 mm lower than alveolar process crest) (2-4) and the requirement of safe 2-2.5 mm proximity between MI-root and 1 mm between MI-periodontal ligament (5, 6) is usually difficult to achieve. Therefore, MI-root contact rate is around 20% (7). The reasons of root damaging may be: inappropriate MI insertion (low proximity and/or wrong MI insertion angle), individual anatomical root shape variations and MI or tooth migration during treatment (8-13). MI which are in contact with dental root or in low proximity usually lose their stability or can cause various alveolar bone, periodontal ligament and/or root cementum, dentin or pulp tissue damage, which may manifest as an inflammation, external root resorption, the loss of pulp vitality, osteosclerosis or ankylosis (14, 15). Although there is a variety of such case reports, there is still a lack of scientific researches analyzing iatrogenic MI complications. The majority of such articles has analyzed the impact of MI on animal teeth (*in vivo*), so it is still unknown, what is the human teeth's and surrounding structures' response to contact with MI. The most reliable scientific conclusions about root

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damage and healing may be found in articles which analyze the use of surgical mini screws in jaw bones fractures' and orthognathic surgeries, but such mini screws are usually not screwed in between adjacent teeth roots. Based on periodontologic study it is known, that root cementum or periodontal ligament regenerates in 2-3 months after damage and alveolar bone regenerates even faster (16). The damaged tooth usually remains vital, with no increased mobility and only rarely gets infected or has to be extracted (17, 18). There are only a few articles in which human dental roots' damage, which occurred during MI insertion or after a certain time of contacting MI, was analyzed. Another published articles are case reports and several case series, where the samples were small, therefore it is unknown, what are the histological changes after root damage and what self-healing occurs after MI-root contact.

The lack of scientifically based literature does not allow the orthodontists to properly inform their patients about possible complications while using MI during treatment. The PICO (*Patient problem or population, Intervention, Comparison and Outcomes*) question is still unanswered: what histological changes occur after MI-root contact, can these changes cause external root resorption, ankylosis or pulp necrosis and is self-healing of periodontal ligament possible? The purpose of this study was to systematically review the current literature researching on root and surrounding structures response after contact with MI.

MATERIAL AND METHODS

The Cochrane Handbook for Systematic Reviews of Interventions and the PRISMA statement guidelines were used as the framework for this article. The electronic databases *Cochrane Library*, *Scirus*, *ScienceDirect*, *Medline* and *PubMed Central* were used to search original articles from 2008 to 2017 January. The key words and their combinations used for articles' search were: mini-implant, microimplant, miniscrew, miniscrew implant, orthodontic anchorage screws, temporary skeletal anchorage devices, temporary anchorage devices, orthodontics, implant, mini implant, micro implant, micro screw, miniscrew, teeth, root, contact, damage, healing. Furthermore, the following journals were searched manually: "American Journal of Orthodontics and Dentofacial Orthopedics", "Angle Orthodontist", "Journal of Dental Sciences" and "Clinical Oral Implants Research"

The article selection criteria were determined according to the object of research, type and method of study, sample size, analysis of the results and research duration:

1. Articles analyzing dental root damage during MI insertion or teeth migration, clinical cases or controlled studies in human/animal dental root-MI contact. The exclusion criteria were technique articles, case reports, opinion articles and review articles;
2. Random sampling clinical trials had priority against controlled sample clinical researches, even though they were evaluated as well;
3. The diameter of MI used in research was ≤2.5 mm. Articles with no MI characteristics given were rejected;
4. Sample size ≥20 MI;
5. Articles with determined damage extent and described regeneration/degeneration progress;
6. The condition of dental roots and surrounding structures should be evaluated immediately after damage with MI, after longer contact with MI and after a certain period of time.

All titles and summaries of found publications were reviewed in order to exclude all inadequate articles by two readers (G. G. and G. K.). The full versions of remaining, possibly appropriate, articles were reviewed. The full texts of articles', which eligibility could not be evaluated by reviewing their summaries, were read on purpose to avoid incorrect exclusion. The process of articles' selection is presented in the PRISMA diagram (Figure 1).

All inclusion criteria matching articles were analyzed and their quality was evaluated based on modified Alves *et al.* (19) suggested method under five criteria: 1) sample size, 2) research method, 3) research object description, 4) diagnostic methods, 5) study design (Table 1). Adding up the score of five variables, each study could maximally score 10 points and be categorized as low (0-5 points), moderate (6-7 points) or high (8-10 points) methodological quality.

RESULTS AND DISCUSSION

Searches of the electronic databases identified 594 titles and abstracts on MI and root damage, which were entered into a PRISMA flow diagram (Figure 1). Among these, 335 titles were duplicated and were therefore removed. All remaining titles and abstracts (259) were analyzed and 239 were found inappropriate and were excluded. The full texts of 20 articles were assessed and 7 articles were excluded because there was no analysis of root damage, even though the MI-root contact was mentioned in articles'

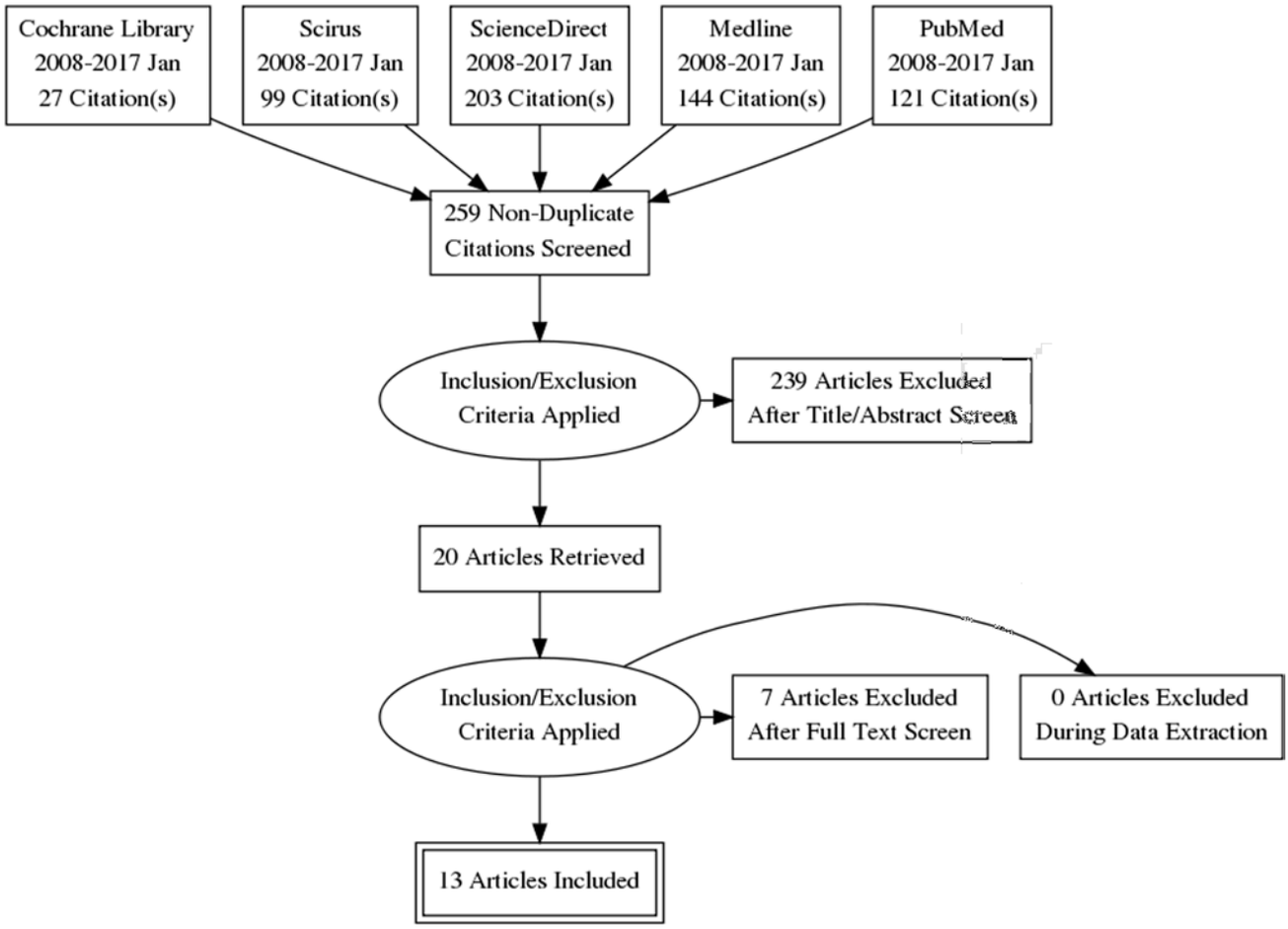

Figure 1. The operationalisation of the study variables and their scales of measurement

abstracts. Overall 13 articles (2, 8, 20-30) were left after applying inclusion/exclusion criteria.

The majority of analyzed articles were studies in animals (2, 20-26, 28, 29) and only in three researches humans were involved (8, 27, 30). The characteristics of analyzed studies are given in the table (Table 2).

Almost all analyzed studies were controlled clinical trials (2, 8, 20-26, 28-30) and only one research was a study of clinical cases with humans (27). The results of majority analyzed studies and description of damaged roots healing process were similar, although several articles' authors (2, 27, 29) submitted different results and underlined encountered complications.

Overall 40 animals (2, 20-26, 28, 29) and 77 humans (8, 27, 30) were included in analyzed studies and 707 MI were used (diameter was 1.5-2 mm, length – 6-11 mm). 218 self-tapping MI were used, 163 MI of them had contact with roots. MI contact with periodontal ligament of 3 roots were described only in Hebree *et al.* (23) research. The damage of dental roots with pulp injury was mentioned in latter and Briscenko *et al.* (22) articles. The root healing

Table 1. Quality assessment description according to a modified version described by Alves *et al.* (2013)

Component	Definition	Classification
Sample size	The number of affected teeth	0-10 = 0 pt.; 11-20 = 1 pt.; ≥21 = 2 pt.
Research method	The research method used for damaged dental roots examination	Radiographic = 1 pt.; histological analysis or scanning electron microscopy = 2 pt.
Research object description	Description of the evaluated teeth and the characterization of MI (diameter, length)	Teeth or MI description = 1 pt.; teeth and MI description = 2 pt.
Diagnostic methods	The analysis of iatrogenic MI-root contact impact, consequences and healing after MI removal	Analysis undone – 0 pt.; 0-10 weeks – 1 pt.; ≥11 weeks – 2 pt.
Study design	Controlled studies in humans, clinical cases and controlled studies in animals	Controlled studies in humans – 2 pt.; clinical cases or controlled studies in animals – 1 pt.

Table 2. Characteristics of included studies *(continued on next page)*

References	Diagnostic methods	Number of animals/subjects	Number and type (SD – self-drilling, ST –self-tapping, n/d – no data) of MI	Diameter /length (mm)	MI contact with periodontium	MI contact with dental root	Root perforation with pulp damage by MI	Root injury duration (weeks)	Root healing duration (weeks)	Research duration (weeks)	Outcomes
Lee *et al.* [2]	Histological analysis	4 Beagles dogs	46, ST	1.6/6.0	7	8	7	16	0	16	Root resorption was detected in the majority of MI-periodontal ligament contact cases. Secondary cementum replaced the resorbed dentin. Root resorption was detected in all MI-root contact cases. Ankylosis was observed in root perforation group; root resorption was detected in opposite MI insertion site.
Kadioglu *et al.* [8]	Scanning electron microscopy	10 humans	20, n/d	1.5/8.0	0	20	0	4; 8	4; 8	8	After 4 week MI-root contact and 4 weeks healing immature organic fibers were observed in resorptive crater. After 8 week MI-root contact and 8 weeks healing the reorganization of collagen fibers and new fibers were observed in resorptive crater. The reorganization of collagen fibers and covering of damaged sites was evident.
Chen *et al.* [20]	Histological analysis	6 half-breed dogs	72, n/d	2.0/11.0	0	47	0	3; 12; 24	12	24	24 weeks after root damaging the majority of sites was filled with bone tissue and cementum. After 12 weeks healing a rapid defect covering with bone tissue was observed.
Kang *et al.* [21]	Histological analysis	3 Beagles dogs	48, ST	1.8/8.5	0	24	0	8	1-7	8	MI with root contacts were lost after 7 days after insertion. The failure rate of MI with root contacts was 79.2%. The regeneration of periodontal ligament and damaged root healing by injured sites replacement by cementum was observed after MI precipitated. No inflammatory cells were detected.
Brisceno *et al.* [22]	Histological analysis	7 Beagles dogs	56, ST	1.8/8.0	0	49	7	0	6; 12	12	Under favourable conditions (no infection or pulpal invasion), root healing occurred in 64.3% of the teeth after damage with MI. After 6 and 12 weeks of healing a new layer of cementum, new attached periodontal ligament and regenerated alveolar bone were observed. 9% of damaged teeth had bone degeneration in furcation site. Teeth with pulp damage (12.5%) had non-specific inflammatory tissue and no periodontal ligament or cementum regeneration was observed.
Hembree *et al.* [23]	Histological analysis	7 Beagles dogs	42, ST	1.8/8.0	3	19	6	0; 6; 12	0	12	Periodontal ligament damage was detected in 3 teeth (7.2%), cementum – 8 (19.0%), dentin – 11 (26.2%). Bone loss in furcation site was observed in 3 (7.2%) teeth, major pulp damage – 6 (14.2%). Periodontal ligament healing and fibrotic connective tissue migration towards MI was evident in long-term observation group where only periodontal ligament was damaged.

Table 2. Characteristics of included studies *(continued from previous page)*

References	Diagnostic methods	Number of animals/subjects	Number and type (SD – self-drilling, ST –self-tapping, n/d – no data) of MI	Diameter /length (mm)	MI contact with periodontium	MI contact with dental root	Root perforation with pulp damage by MI	Root injury duration (weeks)	Root healing duration (weeks)	Research duration (weeks)	Outcomes
Renjen *et al.* [24]	Histological analysis	3 Beagles dogs	60, SD	2.0/10.0	0	11	5	12	0	12	Reparative cementum was present along the periphery of each injured root. Ankylosis was observed only when root fragment dislocation occurred. No external root resorption, inflammatory process or pulp necrosis were detected.
Kim *et al.* [25]	Histological analysis	4 mini pigs	80, SD	1.6/8.0	13	11	6	4; 8; 12	4; 8; 12; 16	16	No ankylosis was detected. Root resorption was observed when MI-root proximity was <1.0 mm. No cementum regeneration was examined when MI was left in contact with root. After MI removal, cementum regenerated in the damaged site during healing process. A partial cementum layer regeneration was observed at the 4 week. Cementum regenerated in all affected sites by the 8-16 week. The damage was irreversible when the MI ruptured through thicker areas of dentin and into pulp tissue.
Huang *et al.* [26]	Histological analysis	2 half-breed dogs	20, n/d	2.0/11.0	0	3	0	12; 18	6	18	The majority of MI were stable. No root resorption was evident. A successful regeneration with cementum formation was observed when dentin by the pulp chamber was damaged.
Shinohara *et al.* [27]	Computed tomography	50 humans	147, ST	1.6/8.0	0	29	0	6 months	0	4	MI failure rates with and without root contacts: 20.7% and 1.7% respectively. MI-root contact rate: 20.0%
Dao *et al.* [28]	Histological analysis	3 Beagles dogs	60, SD	2.0/10.0	0	11	5	12	0	12	The regeneration of continuous cementum layer was observed in all damaged sites. No root resorption, pulp necrosis or inflammation were detected.
Chen *et al.* [29]	Histological analysis	1 half-breed dog	8, ST	2.0/11.0	0	7	0	0; 9; 12; 18; 21; 23	1; 3; 6; 12; 15; 24	24	All MI screwed into the roots on purpose became mobile and obvious inflammation reaction was observed. Active bone reorganization and inflammation were evident when MI were in contact with roots and later were lost due to increased mobility. After 6 weeks healing a chronic inflammation was observed. After MI removal and 24 weeks healing the alveolar bone regeneration was detected.
Ahmed *et al.* [30]	Histological analysis	17 humans	48, SD	1.6/8.0	0	48	0	0	4; 8; 12	12	Almost 50% patients' dental roots regeneration was higher than 50% by the 4 and 8 weeks. The major regeneration occurred by the 8 week. The periodontal ligament thickness increased from 4 to 8 week, but by the 12 week the thickness decreased. The regeneration of cementum layer was 59.6% by the ending of 4 week and was 73.1% by the ending of 12 week.

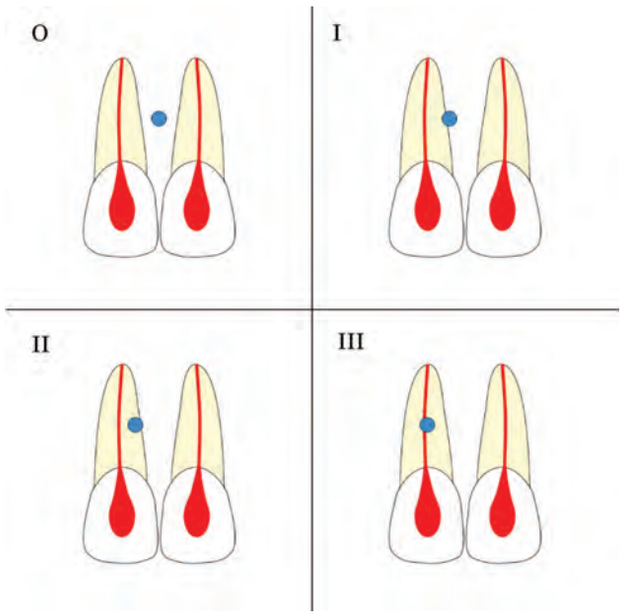

Figure 2. Categorization of dental root damage: 0 – no lesion; I – tangential contact to the root, cementum damage; II – dentin lesion without pulp damage; III – dentin lesion with pulp damage (31).

analysis was carried out after MI removal in a 4-12 weeks period.

The authors discussed these types of dental roots' damage in their articles: the damage of periodontal ligament, cementum and dentin without or with pulp damage (Fig. 2). These dental root damages were done in two ways: 1) during MI insertion (2), 2) after moving the root to MI direction (8, 20-24, 25-30).

Four articles (20, 22, 23, 30) had high methodological quality. The authors of these articles chose the same method of dental roots damaging (MI were screwed in directly to the roots on purpose) and the evaluation of their healing process.

Three articles' authors (20, 22, 23) carried out researches with animals (with 7, 6, 7 dogs respectively) and another article's (30) – with 17 humans, when the MI were screwed in premolars' roots, which were planned to be removed during orthodontic treatment.

Seven articles (2, 8, 21, 24, 25, 27, 29) had moderate methodological quality. Two researches (8, 27) were in humans. Kadioglu *et al.* (8) analyzed root damage after moving the roots towards inserted MI. 10 humans were included in this research. MI contact with the first premolar lasted for 4 and 8 weeks, later the roots were allowed to heal for 4 and 8 weeks. After healing the teeth were extracted and analyzed by scanning electron microscopy method. Shinohara *et al.* (27) analyzed 50 patients' clinical cases, where 29 self-tapping MI had contacts with roots. The research was less accurate and informative because the MI-root contacts were analyzed only by computed tomography and the root healing after MI removal was not evaluated. Other five researches (2, 21, 24, 25, 29) were based on trials involving animals. Kang *et al.* (21) analyzed 3 Beagles dogs root damages made with 48 self-tapping MI: 24 MI were screwed into the roots, 24 MI – near the roots, confirming the insertion site by histological analysis. The root healing was evaluated after 4-7 weeks after MI stability was lost. Renjen *et al.* (24) also carried out a research with 3 Beagles dogs using 60 self-drilling MI. The aim of this research was to identify the influence of deeper root damage on pulp tissue and surrounding structures. After histological analysis 11 MI-root contacts and 5 pulp tissue injuries were identified. The duration of root regeneration was 12 weeks. Lee *et al.* (2) research was on 4 Beagles dogs with 46 MI. After histological analysis 8 MI-root and 7 MI-periodontal ligament and pulp tissue contacts were detected. The roots were analyzed after 16 week duration contact. Kim *et al.* (25) carried out a research on 4 mini pigs with 80 MI: 11 MI had contacts with roots, 13 – with periodontal ligament and 6 – with pulp. The root tissue healing was examined during 4-16 week period by histologic analysis. Chen *et al.* (29) examined the reaction of root tissue after contact with MI. 1 dog with 8 MI (7 MI had contacts with roots) was examined. The histologic investigation of roots' regeneration was carried out at the 1, 3, 6, 8 and 24 week.

Two articles (26, 28) included in this review had low methodological quality. Huang *et al.* (26) carried out a research in two dogs. The authors examined root damage after moving them towards 20 MI. Only 3 MI had direct contact with roots. The trial duration was 18 weeks including 6 weeks of healing. Dao *et al.* (28) evaluated the direct root damage with MI by histological analysis. 60 MI were screwed in 3 dogs; during insertion 11 MI had contact with roots, 5 MI – with pulp tissue. The trial duration was 12 weeks without healing evaluation.

In all articles the MI-root contacts were analyzed, root perforations were described in six studies (2, 22-25, 28) and periodontal ligament injuries were investigated only in three researches (2, 23, 25).

There is no accurate description of dental and surrounding structures' tissue histological alterations after MI-root contact, MI removal and the influence of MI-root contact duration on it in the scientific literature, therefore the comparison of this systematic literature review results with other scientific researches' cannot be conducted and only information of articles included in this review is analyzed.

Due to the limitation of analyzed articles' samples, the evaluation of successful dental root healing progress after contact with MI is complicated. The given

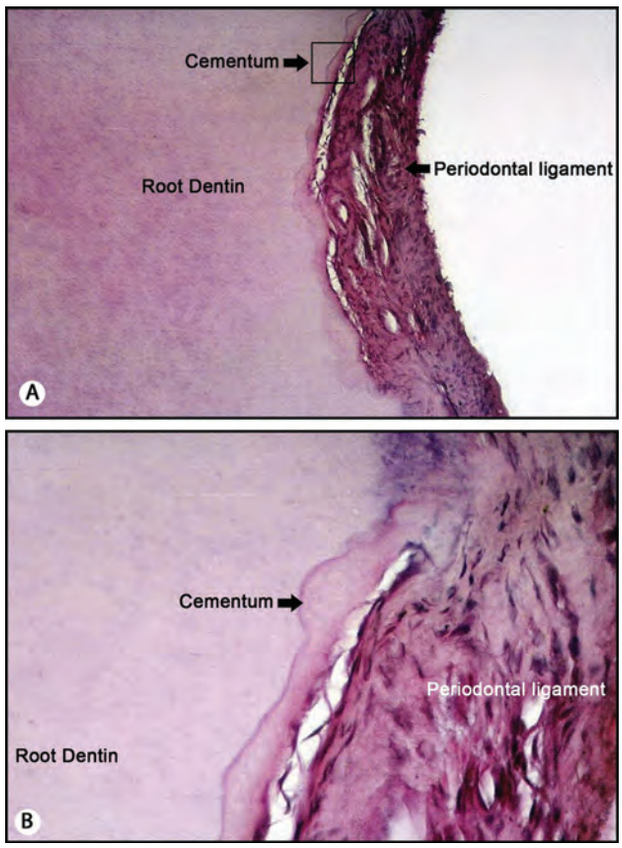

Figure 3. Damaged root surface section of healing after week 4: A) a break in the continuity of the mature cementum and early sign of repair with reattachment of the periodontal ligament fiber to the root dentin after root contact with the temporary anchorage device, with an increase in the thickness of the periodontal ligament fibers (10 times original magnification); B) fibers of the periodontal ligament inserted perpendicularly into a thin layer of newly formed reparative cementum (40 times original magnification) (30).

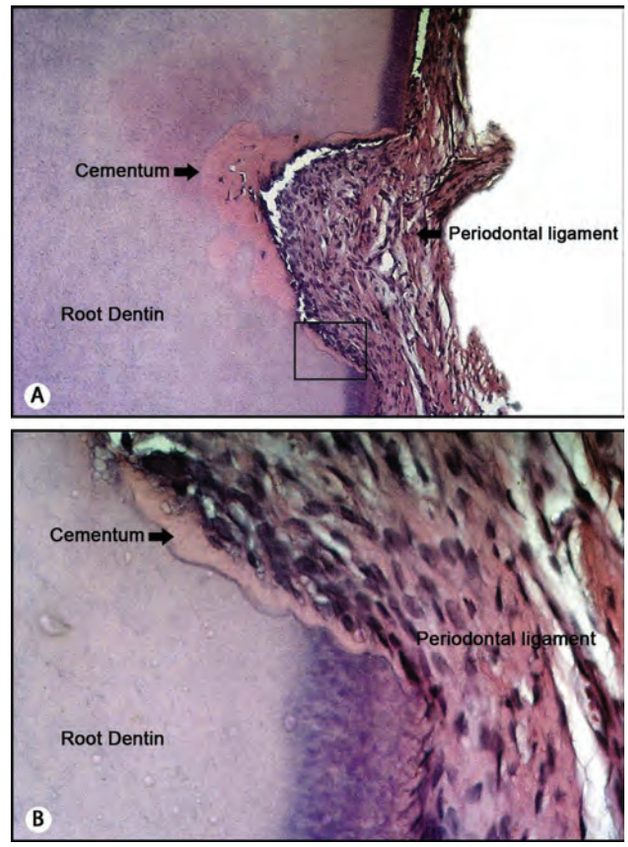

Figure 4. Damaged root surface section of healing after week 8: A) periodontal ligament fiber reorganization is taking place at the bottom of the resorptive crater, and newly formed reparative cementum (eosinophilic material laid between the periodontal ligament and the denuded root dentin) (10 times original magnification); B) newly formed reparative cementum is continuous with existing immature and mature cementum crater (40 times original magnification) (30).

description of MI contact influence on dental root was similar in the majority of articles, although in several researches (2, 27, 29) the results were controversial. Usually the results were examined at the 4, 8 and 12 week of healing. All high quality articles (20, 22, 23, 30) described successful regeneration of damaged roots: Ahmed *et al.* (30) examined the initiation of root regeneration process at the 4 week, and the main regeneration was investigated by the 8 week (Fig. 3).

The ordinary healing process of cementoblasts rearranging and periodontal ligament covering the damaged area was examined in all analyzed teeth. The healing periodontal ligament thickness increased from the 4 to the 8 week (Fig. 4). The main regeneration process was examined until the 8 week, and by the 12 week the observed healing process had lower intensity and the periodontal ligament thickness was thinner (Fig. 5.), although the thickness of cementum layer increased from 59.6% to 73.1% from the 4 week. The authors detected statistically significant difference between histological analysis of damaged root regeneration between the 4 and 8 week, although there was no statistically significant difference between the 8 and 12 week.

Hembree *et al.* (23) examined the healing of periodontal ligament and migration of fibrotic connective tissue around the MI even when MI was not removed. Although the prognosis of dental roots healing after injury with MI is high, two articles' authors (22, 23) specified the degeneration of bone tissue at furcation site.

The identified possible iatrogenic injuries with MI in analyzed articles were: 1) injury of periodontal ligament, 2) injury of periodontal ligament and cementum, 3) injury of cementum and dentin up to 50% MI width, 4) injury of cementum and dentin more than 50% MI width, 5) root perforation with pulp injury. The adverse effects and slower healing usually occurred when there was pulp damage or root fracture or root fragment dislocation. The points of ankylosis were observed in two articles (2, 24) and usually root resorption was examined.

The authors of the majority articles where MI were inserted directly into the roots identified that the insertion torque when the MI was screwed into the root

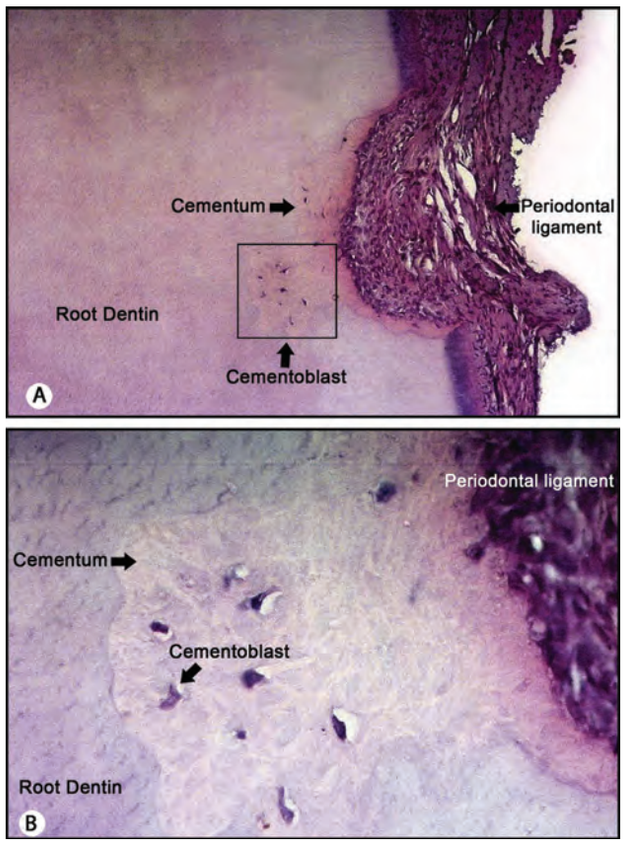

Figure 5. Damaged root surface section of healing after week 12: A) advanced stage of reparative cementum formation. The cementum thickness has increased, and a mineralization front demarcates the repaired mineralized cementum from the root dentin (10 times original magnification). B) Hemotoxyphilic nucleated cells embedded in the mineralized structure suggest cementoblasts with their processes directed toward the cellular periodontal ligament (40 times original magnification) (30).

was considerably higher than screwing into the alveolar bone. The standard of MI insertion torque is 5-10 Ncm, although Brisceno *et al.* (22) specified that the insertion torque when MI contacts the root was around 50.7 Ncm (the values were in the range 36.4-65.2 Ncm).

Several articles' authors analyzed MI stability when they were left in contact with roots. In two articles (20, 29) the loss of MI was described because of decreased stability. The regeneration of damaged roots processed without complications in Chen *et al.* (20) article, although other article's authors (29) described the inflammation in MI-root contact site, due to which the root began to resorb and the MI was lost. After continuing the observations and allowing the roots to heal for 6 weeks, the further inflammation development was inspected, which later became chronic. The successful healing was examined just after immediate MI removal in this study.

CONCLUSIONS

Based on the evidence of the reports found, this systematic review suggests:

1. The histological sequence of events during time after root damage with MI, MI removal and the influence of MI-root contact duration on altering processes are still not fully investigated;
2. The scientific and statistically significant evaluation of regeneration/degeneration process success and percentage is controversial because of low number of researches on this topic and different research objects, methods, different primary results' description, different research duration and lack of clarity of some studies;
3. The success of damaged human roots' regeneration depends on the damage extent: the periodontal ligament/cementum/dentin injuries may regenerate fully, although the success of regeneration is uncertain after pulp damage;
4. Human/animal roots contacting MI may resorb, but after quick reason removal (unscrewing the MI) the regeneration occurs without further consequences. The regeneration may be observed after 4-12 weeks;
5. The loss of pulp vitality, ankylosis, root resorption or osteosclerosis are rare complications after root fracture or pulp damage. It is still unknown when it occurs;
6. The root damage may develop even when the MI is close to the root. The risk of pathology increases when the MI-root proximity decrease (critical proximity is 1 mm);
7. MI-root contact may cause the loss of MI stability.

STATEMENT OF CONFLICT OF INTERESTS

The authors state no conflict of interest.

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