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Pulp and periodontal tissue repair - regeneration or tissue metaplasia after dental trauma. A review

REVIEW ARTICLE

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Abstract – Healing subsequent to dental trauma is known to be very complex, a result explained by the variability of the types of dental trauma (six luxations, nine fracture types, and their combinations). On top of that, at least 16 different cellular systems get involved in more severe trauma types each of them with a different potential for healing with repair, i.e. (re-establishment of tissue continuity without functional restitution) and regeneration (where the injured or lost tissue is replaced with new tissue with identical tissue anatomy and function) and finally metaplasia (where a new type of tissue replaces the injured). In this study, a review is given of the impact of trauma to various dental tissues such as alveolar bone, periodontal ligament, cementum, Hertvigs epithelial root sheath, and the pulp.

The healing after traumatic dental injuries has long been known to be very complex and often unpredictable (1). This complexity relates primarily to the large variations in injury types, which may involve six luxations and nine fracture types each resulting in a unique injury to hard and soft tissue (1). When it is further considered that fractures and luxations are often combined, i.e. 54 (6×9) healing scenarios exist (2). These injuries affect the dental organ that consists of at least 19 cellular systems, most with a different healing potential.

The multitude of trauma scenarios combined with the many cell types involved may explain why so many variations in healing may occur such as repair- and infection-related root resorption, cervical invasive root resorption, loss of marginal bone support, and ankylosis-related resorption, all related to periodontal ligament (PDL) healing events (1). In regard to the pulp, pathological healing events may include *pulp canal obliteration* (PCO), *root canal resorption*, (repair and infection related), and *tissue metamorphosis* where PDL structures such as bone PDL and cementum are found inside the pulp. Altogether, at least 13 deviations in healing (1, 3) are present. The purpose of the present article is to present a survey of the experimental and clinical studies which may to a certain extent explain this marked variation in the healing of the dental structures after trauma. In this aspect, the following types of traumas will be described: *tissue ischemia*, *tissue crushing,* and *tissue loss* (1). In this study, the following healing terminology will be used: *regeneration* is used for a biologic process whereby the continuity of the disrupted or lost tissue is regained by new tissue which restores structure and function, whereas *repair* or scar formation is a biologic process whereby the continuity of the disrupted or lost tissue is regained by new tissue which does not restore structure and function (4). The term tissue metaplasia is used when tissue of one type (e.g. pulp) is replaced by another type (bone, cementum, and PDL). In this analysis, the alveolar bone injuries and PDL injuries will be the first to be described followed by pulp injuries.

In the pulp and periodontium tissue, a number of specific cells, located in the pulp, PDL, and alveolar bone, are found which each has a certain capacity of healing (5).

The type of healing is determined upon the stem cell capacity in the given location (Fig. 1). Furthermore, a race between different tissue compartment cells whereby a damaged PDL area can be occupied by bone cells and a pulp space may become invades by PDL cells, PDL, and bone cells or bone cells alone. These facts complicate significantly the healing after trauma and surgery.

Alveolar bone

Alveolar bone loss

The healing events after surgical removal of the labial bone plate have shown that this structure will be completely reformed (6, 7). This is explained by the bone-inducing capacity of vital PDL residing on the root surface (11) (Fig. 2).

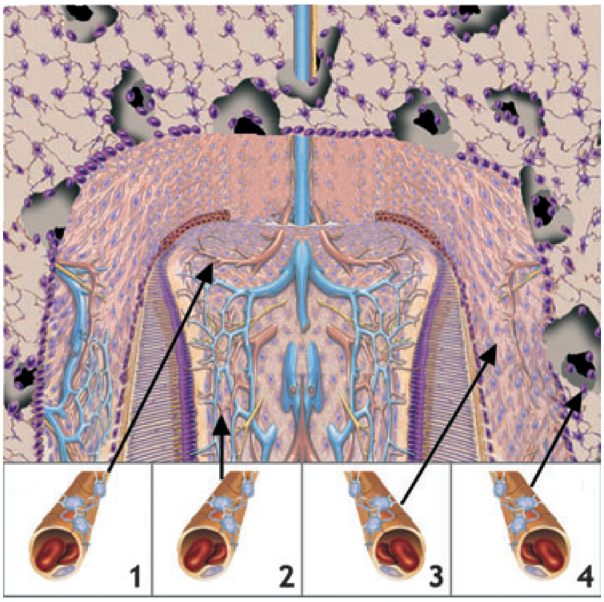

Fig. 1. In a tooth with immature root formation four different stem cell populations have been isolated. 1: Apical papilla stem cells; 2: Dental pulp stem cells; 3: Periodontal ligament stem cells; and 4: Bone marrow stem cells.

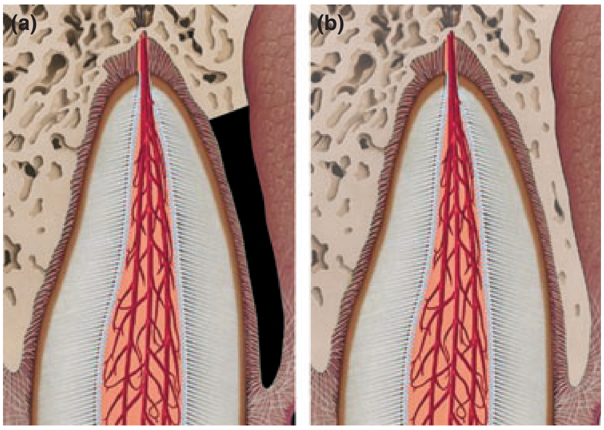

Fig. 2. (a) Isolated removal of the labial bone plate. (b) Regeneration of this structure.

Alveolar bone ischemia and crushing

This event has been examined in intrusion cases, and the general feature is that the bone regeneration is good especially in children with immature root formation, whereas in cases with mature root formation, transient or permanent loss of bone may occur (12, 13).

Periodontal ligament

Periodontal ligament loss facing the alveolar bone

One study has examined the role of this structure and it appears that the loss does not prevent regeneration of the PDL (9) (Fig. 3).

Periodontal ligament ischemia or contusion

In several experiments, it has been found that this may lead to repair-related resorption or resorption ankylosis (10, 14, 15) (Fig. 4).

Periodontal ligament loss facing the cementum

In several experimental and clinical studies, it has been shown that this leads to ankylosis (3, 6, 10, 14, 16). However, a size factor exists; in animal experiments, defects less than 4mm^2; showed either complete healing or a transient ankylosis site which was later resorbed and repair-related root resorption developed in these sites (14) (Fig. 5). In larger sites (i.e. exceeding 4 m^2), a permanent ankylosis site was formed (14) (Fig. 6).

Cementum

Cementum loss

This event is created in case of an osteotomy affecting the root surface (20–24) (Fig. 7) or apicoectomy (17, 18) (Fig. 8) and in relation to a root fracture (19). In these cases, new cementum will be found on the exposed dentin (9, 17, 18) (Fig. 8). This process apparently starts from existing cementoblasts next to the tissue loss (17, 18, 20, 24).

Hertvig's epithelial root sheath

Loss of Hertvig's epithelial root sheath (HERS)

This event may occur during avulsion and extrusion where a separation zone may occur at the level of the pulpal papilla (1). If the tooth is not replanted the isolated apical papilla plus, the HERS may continue its activity and form a root tip (25–27). Under experimental conditions, it has been found that partly removal of the HERS may lead to a compromised root development and invasion of PDL and bone into the pulp canal (28) (Fig. 9).

HERS and ischemia damage

This event may occur because of marked inaccurate reposition where the revascular process becomes delayed whereby the HERS becomes avital. This leads to invasion of bone, PDL and cementum in the pulp canal and lack of further root formation (28, 29) (Fig. 9).

HERS and contusion damage

This event may occur after lateral luxation, intrusion, and avulsion with subsequent replantation (1, 12, 13). The healing event appears to be similar to HERS ischemia.

Pulp

Pulp loss

This may occur as a therapeutic measure. Experiments in monkeys have shown that in mature teeth a pulp

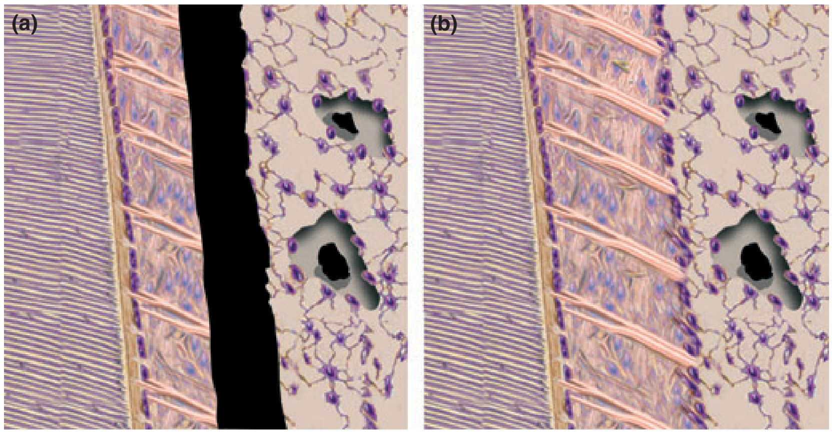

Fig. 3. (a) Isolated removal of the alveolar part of the periodontal ligament (PDL). (b) Healing of the entire PDL.

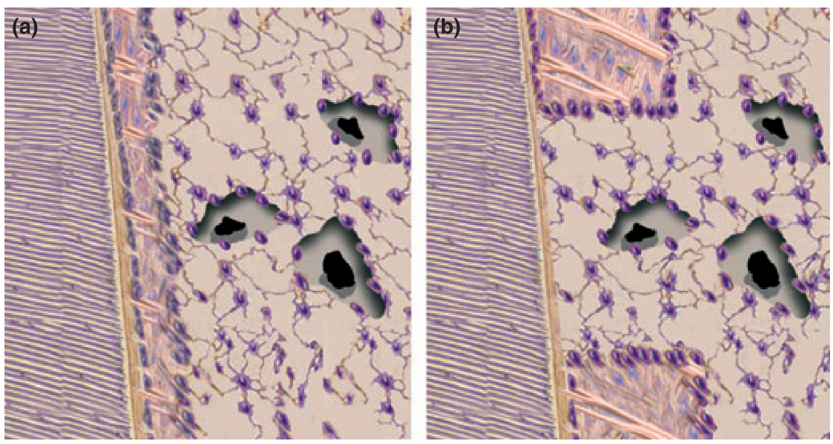

Fig. 4. (a) Contusion or ischemia of the entire periodontal ligament. (b) This may lead to ankylosis.

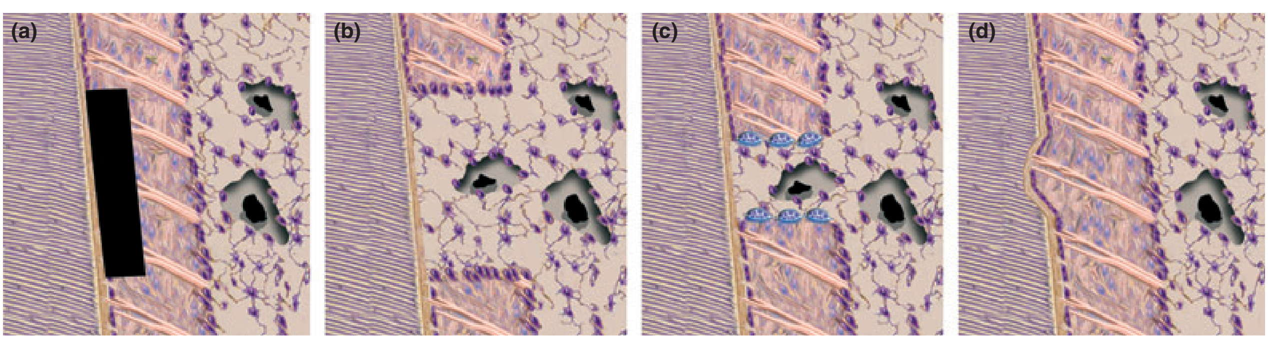

Fig. 5. (a) Isolated removal of the cemental part of the periodontal ligament. (b) This may lead to transient ankylosis (c and d).

revascularization process becomes arrested (8, 30, 31). In teeth with immature root formation, pulp revitalization will occur, although at a slower rate compared with a situation where the ischemic pulp is preserved (32–34).

Pulp ischemia

This event happens in all tooth displacement injuries where the vascular supply is damaged or ruptured (1). Such events lead to severe changes in the pulp chamber, ranging from pulp regeneration, pulp repair with accelerated dentin formation (PCO) (1), or pulp metaplasia where PDL ± bone invade the pulp and finally a sterile or infected pulp necrosis may occur (1) (Fig. 10). The revitalization process appear to be very dependent upon the size of the apical foramen, being very frequent with apical diameters above 1.0 mm and infrequent with diameters below 0.3 mm (35).

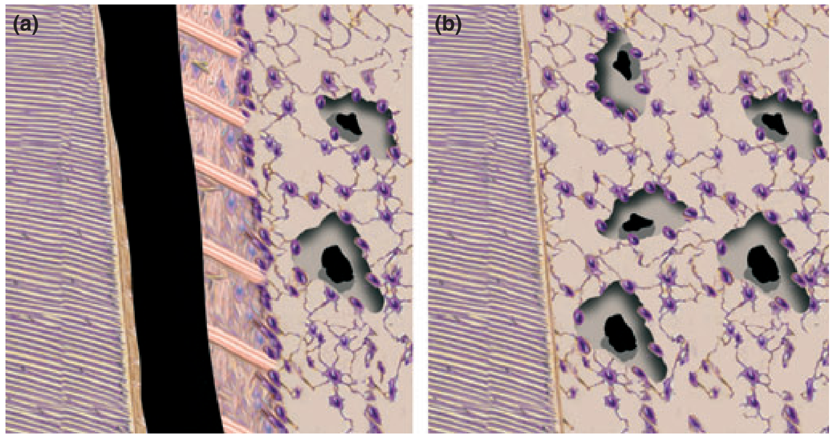

Fig. 6. (a) Larger injury to the cemental part of the periodontal ligament has taken place. (b) A permanent ankylosis is formed.

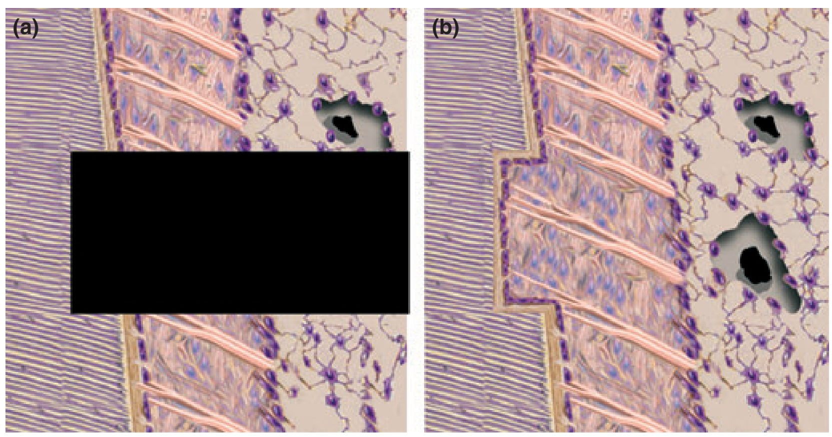

Fig. 7. (a) Small osteotomy plus removal of periodontal ligament (PDL) and cementum. (b) Reformation of a functional PDL with new cementum.

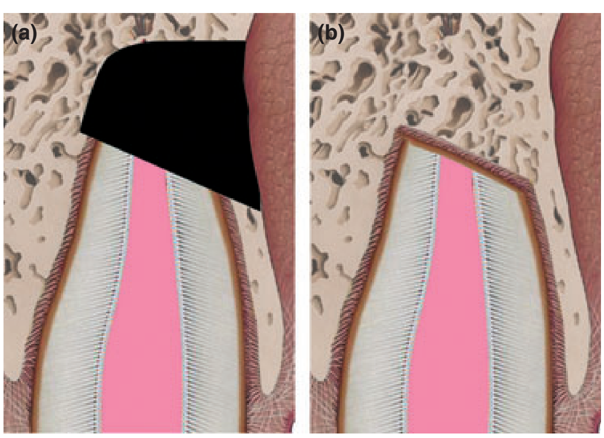

Fig. 8. (a) Apicoectomy. (b) Reformation of a functional periodontal ligament with new cementum.

Pulp contusion damage

This injury may occur subsequent to intrusion into the bone of teeth with immature roots (12, 13). Statistics have shown that this event represents a high risk of infected pulp necrosis as well as a risk of PCO or PDL plus bone invasion. This addiction arrested root development is a frequent finding (12, 13). All of these events possibly relate to the damage or loss of HERS whereby invasion of periodontal structures (cementum periodontal ligament and bone) obtain a preference to invade the pulp chamber (1).

Conclusion

This survey of the healing responses in the pulp and periodontium after trauma strongly indicates that the survival of the cell layer next to cementum appears to be crucial for PDL healing including alveolar bone. The survival of HERS appears to be decisive for further root development. Finally, the presence of ischemic but intact pulp tissue appears to be strongly related to survival or regeneration of tertiary dentin. However, the latter will only occur of the ischemic pulp tissue do not become infected, and the apical foramen has a certain critical width allowing the revitalization of the ischemic pulp tissue.

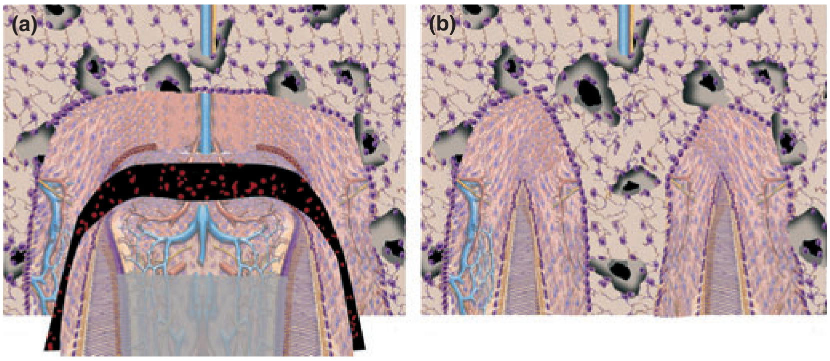

Fig. 9. (a) Hertwigs epithelial root sheath is damaged. (b) Bone and periodontal ligament invasion may take place in the root canal.

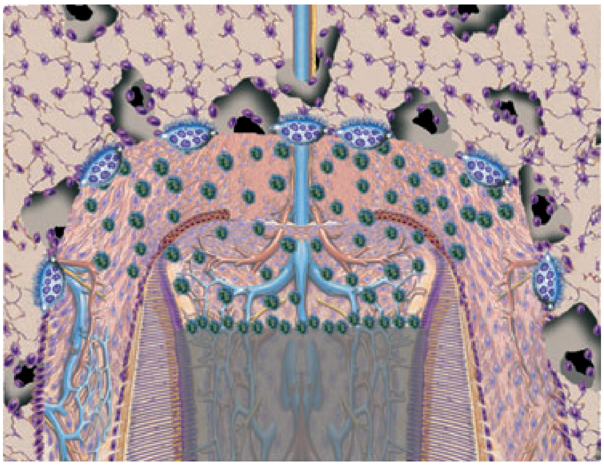

Fig. 10. Infected pulp necrosis.

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