

Pulp survival and periodontal healing of autotransplanted teeth: a retrospective study

Sobrevivência pulpar e cicatrização periodontal de dentes autotransplantados: um estudo retrospectivo

Supervivencia pulpar y curación periodontal de dientes autotrasplantados: un estudio retrospectivo

Received: 12/11/2022 | Revised: 12/21/2022 | Accepted: 12/22/2022 | Published: 12/26/2022

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Abstract

Aim: The aim of this retrospective study was to evaluate the post-surgical results of autotransplanted teeth, considering the pulp survival rate and periodontal healing. *Methodology:* Records of 43 patients with 50 autotransplanted teeth were analysed. Demographic, clinical and radiographic data were verified. The time between autotransplantation surgery and the date of endodontic access was considered to assess the pulp survival rate. Periodontal healing was observed through gingival morphology and the presence of root resorption. Pulp survival was verified and the influence of Nolla stage on the survival rate was analysed. *Results:* The pulp survival rate was 72%, and the stage of root development influenced the survival rate in autotransplanted teeth ($p = 0.001$). The pulp survival rate in autotransplanted teeth in Nolla stages 6 and 7 was 100%; the pulp survival rate for teeth in stages 8 and 9 was 90% and 75%, respectively. Regarding periodontal analysis, no tooth was observed in the presence of periodontal pockets and mobility above grade I. Replacement resorption was diagnosed in 20% and external inflammatory resorption in 4%. *Conclusions:* Dental autotransplantation was a safe treatment, showing satisfactory results. The pulp survival rate was considered high, especially in teeth with incomplete rhizogenesis.

Keywords: Dental pulp; Transplant; Regeneration.

Resumo

Objetivo: O objetivo deste estudo retrospectivo foi avaliar os resultados pós-cirúrgicos de dentes autotransplantados, considerando a taxa de sobrevivência pulpar e a cicatrização periodontal. *Metodologia:* Foram analisados prontuários de 43 pacientes com 50 dentes autotransplantados. Dados demográficos, clínicos e radiográficos foram verificados. O tempo entre a cirurgia de autotransplante e a data do acesso endodôntico foi considerado para avaliar a taxa de sobrevivência pulpar. A cicatrização periodontal foi observada pela morfologia gengival e pela presença de reabsorção radicular. A sobrevivência da polpa foi verificada e a influência do estágio de Nolla na taxa de sobrevivência foi analisada. *Resultados:* A taxa de sobrevivência pulpar foi de 72%, e o estágio de desenvolvimento radicular influenciou a taxa de sobrevivência em dentes autotransplantados ($p = 0,001$). A taxa de sobrevivência da polpa em dentes autotransplantados nos estágios 6 e 7 de Nolla foi de 100%; a taxa de sobrevivência da polpa para os dentes nos estágios

8 e 9 foi de 90% e 75%, respectivamente. Com relação à análise periodontal, nenhum dente foi observado com presença de bolsas periodontais e mobilidade acima do grau I. Reabsorção por substituição foi diagnosticada em 20% e reabsorção inflamatória externa em 4%. *Conclusões:* O autotransplante dentário mostrou-se um tratamento seguro, apresentando resultados satisfatórios. A taxa de sobrevivência pulpar foi considerada alta, principalmente em dentes com rizogênese incompleta.

Palavras-chave: Polpa dentária; Transplantes; Regeneração.

Resumen

Objetivo: El objetivo de este estudio retrospectivo fue evaluar los resultados posquirúrgicos de dientes autotrasplantados, considerando la tasa de supervivencia pulpar y la cicatrización periodontal. *Metodología:* Se analizaron los expedientes de 43 pacientes con 50 dientes autotrasplantados. Se verificaron datos demográficos, clínicos y radiográficos. Se consideró el tiempo entre la cirugía de autotrasplante y la fecha del acceso endodóntico para evaluar la tasa de supervivencia pulpar. Se observó cicatrización periodontal a través de la morfología gingival y la presencia de reabsorción radicular. Se verificó la supervivencia pulpar y se analizó la influencia del estadio de Nolla en la tasa de supervivencia. *Resultados:* La tasa de supervivencia pulpar fue del 72%, y la etapa de desarrollo radicular influyó en la tasa de supervivencia en los dientes autotrasplantados ($p = 0,001$). La tasa de supervivencia pulpar en dientes autotrasplantados en estadios 6 y 7 de Nolla fue del 100%; la tasa de supervivencia de la pulpa para los dientes en las etapas 8 y 9 fue del 90% y 75%, respectivamente. En cuanto al análisis periodontal, no se observó ningún diente con presencia de bolsas periodontales y movilidad superior al grado I. Se diagnosticó reabsorción por reemplazo en el 20% y reabsorción inflamatoria externa en el 4%. *Conclusiones:* El autotrasplante dental fue un tratamiento seguro, mostrando resultados satisfactorios. La tasa de supervivencia pulpar se consideró alta, especialmente en dientes con rizogénesis incompleta.

Palabras clave: Pulpa dental; Trasplantes; Regeneración.

1. Introduction

Use Dental autotransplantation or autogenous dental transplantation is an efficient alternative method of oral rehabilitation in cases of agenesis, ectopias and premature loss of permanent teeth as a consequence of accidental dental trauma or caries. The procedure is defined as the extraction of a tooth or more teeth from one site to be implanted into another site of the dental arch in the same individual (Akhlef, et al., 2018; Andreasen, et al., 1990; Kafourou, et al 2017; Kristerson, L. & Lagerstrom L (1991). The donor tooth can potentially induce bone formation and re-establishment of a normal alveolar process without the need for special care. Protheses and implants are contraindicated for young patients due to ongoing bone growth and maturation (Czochrowska, et al., 2002; Thomas, et al., 1998). Low costs, the possibility of aesthetic restoration and orthodontic movement without damage to adjacent teeth are important considerations when autotransplantation is indicated (Paulsen, et al., 1995; Schatz, & Joho, 1994).

Survival rate has often been the primary outcome parameter in studies on dental autotransplantation. High survival rates have been reported, especially with premolar autotransplantation (Candeiro, et al., 2015; Kristerson, 1985; Ninomiya, et al., 2002). However, the greatest challenge with autotransplanted teeth is pulp and periodontal healing due to several factors such as age, general health status, the stage of root development of the tooth to be transplanted, the health of periodontal and alveolar tissue of the recipient bed, strict control of infections and the health of the patient. Among the potentially unfavourable results are pulp necrosis, substitution resorption and lack of root development (Kristerson, 1985; Schwartz, et al., 1985)

Studies on autotransplantation have great clinical relevance, because the identification of factors that can interfere with pulp and periodontal healing help in achieving more predictable results that further validate this treatment modality. This retrospective study aimed to evaluate the post-surgical results of autotransplanted teeth, considering the pulp survival rate and periodontal healing.

2. Methodology

This study was approved by the Research Ethics Committee of Federal University of Espírito Santo.

This retrospective study followed the Strengthening Reporting Observational Studies in Epidemiology (STROBE)

guidelines (Vandenbroucke, et al., 2007; Von Elm, et al., 2007). The study sample was selected from the clinical records of patients treated at the Endodontics Clinic of Endodontics Clinic of UFES between 1993 and 2003 who underwent dental autotransplantation. The inclusion criteria were as follows:

- Patients with completed clinical and radiographic records;
- Patients who were followed up for at least 6 months after autotransplantation;
- Patients who signed the informed consent form.

All information was collected from the patients' medical records. Data on gender, age of the patient at the time of autotransplantation, date of autotransplantation, cause of tooth loss, donor tooth and stage of root development, site of the recipient alveolus and date of endodontic treatment after autotransplantation, if it occurred, were verified. The results of cold (Endo-Frost Roeko-Wilcos do Brasil, Rio de Janeiro, RJ, Brazil) and electrical (digital pulp tester, model RD101-NTC, ODOUS COML Ltda and Gesund Bio Engenharia, Belo Horizonte, MG, Brazil) pulp tests were recorded, as well as the presence of sensitivity to palpation, percussion, fistulas or oedema.

The periodontal evaluation comprised analysis of the level of periodontal insertion, the presence of gingival bleeding, mobility and gingival morphology, as registered in the medical records. The insertion level was classified into three categories: 0–3 mm, 3–5 mm and >5 mm; mobility was classified as grade I, II and III; and gingival morphology was classified as normal, retracted or swollen (Andreasen, et al., 1990; Borring-Møller, & Frandsen, 1978).

Radiographic analysis

Radiographic analysis was performed by three radiologists. Radiographs were taken using a previously calibrated Dabi Atlante Spectro 70x radiographic device (Dabi Atlante, São Paulo) and analysed using a magnifying glass and a negatoscope. The following parameters were analysed.

Pulp chamber

- Normal: morphological aspects of normality without change in size or shape;
- Partially calcified: presence of diffuse calcifications not fully obliterating the inside of the pulp chamber;
- Fully calcified: dentin deposition fully occupying the space.

Root canal

- Normal: Morphological aspects of normality without alteration in size or shape;
- Partially calcified: presence of pulp calcification occupying up to two thirds of the duct space;
- Fully calcified: presence of pulp calcification occupying up to two thirds of the duct space;
- Internal inflammatory resorption: radiographic aspect of alteration in root canal path continuity in any third of the dental root;
- Endodontic treatment performed: root canal filled with obturator material.

Periapical

- Normal;
- Thickening of the apical periodontal ligament: indicated by an increase in the radiolucent line located between the root and the hard blade in the apical third;
- Presence of a periapical lesion: area of bone rarefaction, indicated by diffuse or circumscribed radiolucent image at the root apex;

- Presence of condensing osteitis: indicated by the presence of a radiopaque, dense and uniform alteration near the apex of the tooth.

Stage of root development at autotransplantation

The Nolla stages were used to determine the stage of root development. The radiographic image of the tooth was compared with Nolla schemes, and each tooth was given a representative value correlated to the stage of root development at the time of the transplantation and at the last follow-up consultation.

Pulp survival analysis

The time elapsed between autotransplantation surgery and the date of endodontic access was considered to assess the pulp survival rate. In all cases, access was performed on the day pulp necrosis was diagnosed. The diagnosis of necrosis was characterized by the absence of response to the pulp and electrical tests, associated with the presence of at least one other clinical or radiographic criterion: presence of sensitivity to palpation, percussion, fistulas or oedema, coronary darkening and periapical radiolucency. The pulp was considered vital when the radiographic analysis showed partial or total presence of root canal obliteration, continuation of root development and absence of clinical and radiographic signs of necrosis.

Statistical analysis

The results of the clinical and radiographic analysis are presented by descriptive statistics. Pulp survival was verified using the Kaplan-Meyer test. The influence of the Nolla stage on the survival rate was analysed using the log rank test. A 5% significance level was adopted. The SPSS program (IBM, Armonk, NY, USA, version 24) was used for the analyses.

3. Results

A total of 43 patients were examined, 23 men and 20 women, with 50 autotransplanted teeth. The age of the patients at the time of autotransplantation ranged from 10 to 22 years and the follow-up period ranged from 8 months to 9 years. The 50 autotransplanted teeth included 40 premolars (39 lower premolars and 1 upper premolar), 1 supernumerary upper lateral incisor, 6 molars (4 third upper molars and 2 lower molars) and 3 upper canines. The 40 premolars, 3 canines and the incisor were transplanted to the region of upper central incisors lost by dental trauma. The 6 molars were transplanted to the region of other molars lost due to caries disease.

Clinical data

Fourteen teeth underwent endodontic treatment (3 canines, 6 premolars, 4 molars and 1 incisor); 10 were transplanted after complete root development (Nolla stage 10), 2 were transplanted in stage 9 and 2 in stage 8 (Table 3). Of the 36 teeth that had not yet undergone endodontic treatment, 5 responded positively to the cold test and 31 did not respond. No teeth responded positively to the electrical test. All five teeth that showed a positive response to the cold test had not completed 1 year since surgery. Although most teeth did not respond to pulp tests, they were considered vital, because no other clinical and radiographic signs of necrosis were identified. Regarding the periodontal analysis, no teeth presented periodontal pockets and mobility above grade I (Figure 1). The gingival aspect was classified as normal in 78%. The clinical parameters are presented in Table 1.

Radiographic data

Table II shows the results of the radiographic analysis. Of the 36 teeth without endodontic treatment, 34 presented calcifications of both the chamber and the root canal. The periapex was considered normal in 76% of the total sample.

Replacement resorption was diagnosed in 10 teeth and external inflammatory resorption in 2. No cases presented internal inflammatory resorption.

Pulp survival analysis

The mean pulp survival was 72% and the Nolla stage influenced the survival rate in autotransplanted teeth ($p = 0.001$). The survival rate of autotransplanted teeth in Nolla stages 6 and 7 was 100%, and the survival rate for teeth in stages 8 and 9 was 90% and 75%, respectively. No teeth in stage 10 remained vital after autotransplantation.

Table 1 - Descriptive analysis of the clinical results after dental autotransplantation.

Clinical analysis	Autotransplanted teeth, <i>n</i> (%)
Cold test	
Negative	45 (90)
Positive	5 (10)
Electrical test	
Negative	50 (100)
Positive	0 (0)
Palpation tests	
Negative	50 (100)
Positive	0 (0)
Percussion test	
Negative	50 (100)
Positive	0 (0)
Fistula	
Absent	50 (100)
Present	0 (0)
Oedema	
Absent	50 (100)
Present	0 (0)
Gingival bleeding	
Absent	45 (90)
Present	5 (10)
Gingival morphology	
Normal	39 (78)
Retracted	6 (12)
Swollen	5 (10)
Periodontal insertion	
0–3 mm	50 (100)
3–5 mm	0 (0)
>5 mm	0 (0)
Mobility	
I	50 (100)
II	0 (0)
III	0 (0)

Source: Authors.

Table 2 - Descriptive analysis of the radiographic results after dental autotransplantation.

Radiographic analysis	Autotransplanted teeth, n (%)
Pulp chamber	
Normal	2 (4)
Partially calcified	9 (18)
Fully calcified	25 (50)
Root canal	
Normal	2 (4)
Partially calcified	19 (38)
Fully calcified	15 (30)
Internal inflammatory resorption	0 (0)
Endodontic treatment	14 (14)
Periapical	
Normal	38 (76)
Thickening of the ligament	8 (16)
Periapical lesion	4 (8)
Condensing osteitis	2 (4)
Periodontium	
External inflammatory resorption	2 (4)
Resorption by substitution	10 (20)

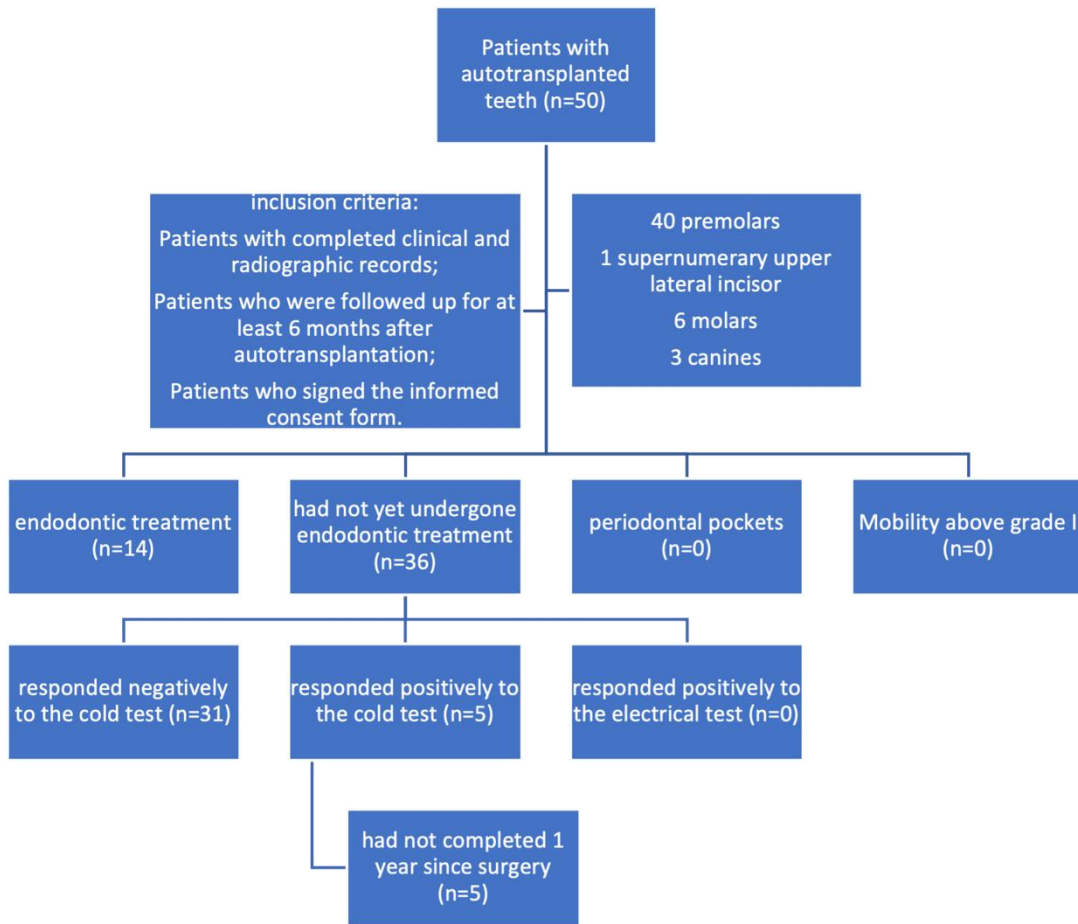
Source: Authors.

Table 3 - Survival rate of autotransplanted teeth and the relationship with the Nolla stage.

Nolla stage	No.	Pulp vitality		Pulp survival (%)
		Yes	No	
6	2	2	0	100
7	10	10	0	100
8	20	18	2	90
9	8	7	2	75
10	10	0	10	0
Mean				72

Source: Authors.

Figure 1 - Flow chat describing clinical data.



Source: Authors.

4. Discussion

This study aimed to evaluate the post-surgical results of autotransplanted teeth in a sample of 43 patients and 50 teeth. Different dental groups were included because the main indications for autotransplantation involve transplantation of premolars to the region of missing central incisors, third molar transplants for the region of missing first or second molars and transplants of retained canines. Supernumerary tooth transplants are also indicated in cases of agenesis or loss of upper incisors (Andreasen, et al., 1990; Kafourou, et al., 2017; Schatz, & Joho, 1994; Candeiro, et al., 2015; Xu, et al. 2021).

Caries and dental trauma are the main causes of tooth loss in permanent dentition (Schatz, JP & Joho, JP, 1994). In this study, 44 teeth were transplanted as a result of dental trauma and 6 due to caries lesions.

Autotransplantation success rates are considered high. Two recent systematic reviews reported a survival rate greater than 95% (Akhlef, et al., 2018; Rohof, et al., 2018). In this study, all autotransplanted teeth remained in the mouth after the follow-up period. However, one of the main objectives of this study was not to evaluate the survival of the transplanted tooth but rather pulp survival, which, in these cases, is associated with canal obliteration and continuation of root development (Rohof, et al., 2018).

Root canal obliteration is one of the main criteria used to verify if the pulp remains vital after autotransplantation, because the presence of viable cells in the pulp space is a marker of deposition of mineralized tissue. Radiographic signs of partial or total obliteration of the root canal were identified in 34 cases (94.4%) among the 36 who did not receive endodontic treatment. These results corroborate previous investigations that reported radiographic signs of pulp canal obliteration within 6

months after surgery (Andreasen, et al., 1990; Paulsen, et al., 1995; Jonsson, & Sigurdsson, 2004). Plakwicz et al. (2013) reviewed 23 cases and reported pulp healing in most of their sample, with continuous root development and pulp canal obliteration in several cases.

The time elapsed between autotransplantation surgery and the date of endodontic access was considered to determine the pulp survival rate. In all cases, access was performed on the day pulp necrosis was diagnosed. The pulp survival rate was 72%, and the stage of root development at the time of transplantation influenced the pulp prognosis. No autotransplanted teeth with closed apex remained vital. The survival rate of teeth in Nolla stages 6 and 7 was 100%; the pulp survival rate of teeth in stages 8 and 9 was 90% and 75%, respectively.

The length of stay outside the alveolus and root maturation influence pulp necrosis of autotransplanted teeth. Furthermore, autotransplantation interrupts the vascular and nervous supply to the pulp. Thus, serious damage to pulp tissues occurs during the surgical procedure (Andreasen, et al., 1990; He, et al., 2017; Skoglund, & Hasselgren, 1992). Healing occurs by revascularization of the blood and nerve supply, therefore teeth with incomplete root formation have a better chance of revascularization due to increased vascularization related to wider open apices². This corroborates with a systematic review reporting that the stage of root development correlated with pulp survival (Almpiani, et al., 2018). Pulp necrosis in autotransplanted teeth with complete rhizogenesis is common (Andreasen, et al., 1990), which also agrees with the results of our study.

The maintenance of viable periodontal ligament cells in transplanted teeth is considered the most critical factor for the success of periodontal healing (Clokie, et al., 2001; de Freitas Coutinho, et al., 2021; Hupp, et al., 1998; Lee, et al., 2001). Thus, donor teeth should remain outside the alveolus for a minimum period or be preserved in a storage medium capable of maintaining periodontal ligament vitality. In this study, we inserted the teeth into a new alveolus shortly after exodontia, without using storage medium.

Periodontal ligament healing was considered satisfactory; few cases presented root resorption, 2 teeth with external inflammatory resorption (4%) and 10 teeth with replacement resorption (20%). These findings are similar to those in several other studies (Kafourou, et al 2017; Kristerson, & Lagerstrom 1991; Czochrowska, et al., 2002; Plakwicz, et al., 2013; Tsukiboshi, 2002). Even though some teeth developed replacement resorption, they may play an important role in maintaining bone in this location. Bone atrophy in edentulous sites is inevitable, often requiring bone grafting before implantation. Even if the autotransplantation fails in the future, a good amount of bone structure can be preserved for planning an implant (Kafourou, et al., 2017).

In general, the condition of gingival tissues was considered adequate. Bleeding was observed in only 5 teeth, but was related to accumulation of plaque. Minimal gingival retraction was found in 6 teeth and no periodontal pockets or associated bone loss were verified. In a recent study that considered gingival aesthetics as one of the criteria for evaluating autotransplanted teeth, the authors observed good aesthetic success; the results were considered good or excellent in 65% of the evaluations and poor and in only 7.5% (de Freitas Coutinho, et al., 2021).

One of the methodological limitations lies in the retrospective nature of this study. Clinical and radiographic data were collected from the patients' clinical records. In some cases, we noticed that the patients missed follow-up consultations, which were then rescheduled for another date. This may have delayed the diagnosis of pulp necrosis and, therefore, the onset of endodontic treatment. Even so, studies on autotransplantation are important to validate and disseminate this treatment modality among dentists. Autotransplantation has been shown to be a safe and predictable therapeutic option, especially in cases of early tooth loss.

5. Conclusion

Dental autotransplantation is a safe and viable treatment option, showing satisfactory results for clinical and radiographic procedures. The pulp survival rate was considered high, especially in teeth with incomplete root formation.

Conflict of Interest

We declare no financial or personal relationships with other people or organizations that could inappropriately influence our work.

References

- Akhlef, Y., Schwartz, O., Andreasen, J. O., & Jensen, S. S. (2018). Autotransplantation of teeth to the anterior maxilla: a systematic review of survival and success, aesthetic presentation and patient-reported outcome. *Dental Traumatology*, 34, 20–27.
- Almpani, K., Papageorgiou, S. N., & Papadopoulos, M. A. (2018). Autotransplantation of teeth in humans: a systematic review and meta-analysis. *Clinical Oral Investigations*, 19, 1157–1179.
- Andreasen, J. O., Paulsen, H. U., & Yu (1990). A long-term study of 370 autotransplanted premolars: part I—surgical procedures and standardized techniques for monitoring healing. *European Journal of Orthodontics*, 12, 3–13.
- Borring-Møller, G., & Frandsen, (1978). A. Autologous tooth transplantation to replace molars lost in patients with juvenile periodontitis. *Journal of Clinical Periodontology*, 5, 152–158.
- Candeiro, G. T., Alencar-Júnior, E. A., Scarparo, H. C., Furtado-Júnior, J. H., Gavini, G., & Caldeira, C. L. (2015). Eight-year follow-up of autogenous tooth transplantation involving multidisciplinary treatment. *Journal of Oral Science*, 57, 273–276.
- Clokie, C. M., Yau, D. M., & Chano, L. (2001). Autogenous tooth transplantation: an alternative to dental implant placement? *Journal (Canadian Dental Association)*, 67, 92–96.
- Czochrowska, E. M., Stenvik, A., Bjercke, B., & Zachrisson, B. U. (2002). Outcome of tooth transplantation: survival and success rates 17–41 years post-treatment. *American Journal of Orthodontics and Dentofacial Orthopedics*, 121, 110–119.
- de Freitas Coutinho, N. B., Nunes, F. C., Intra, J. B. G., Roldi, A., de-Jesus-Soares, A., Coelho, M. S., et al. (2021). Success, survival rate, and soft tissue esthetic of tooth autotransplantation. *Journal of Endodontics*, 47, 391–396.
- He, L., Kim, S. G., Gong, Q., Zhong, J., Wang, S., Zhou, X., et al. Regenerative endodontics for adult patients. *Journal of Endodontics*, 43, S57–S64, 2017.
- Hupp, J. G., Mesaros, S. V., Aukhil, I., & Trope, M. (1998). Periodontal ligament vitality and histologic healing of teeth stored for extended periods before transplantation. *Dental Traumatology*, 14, 79–83.
- Jonsson, T., & Sigurdsson, T. J. (2004). Autotransplantation of premolars to premolar sites. A long-term follow-up study of 40 consecutive patients. *American Journal of Orthodontics and Dentofacial Orthopedics*, 125, 668–675.
- Kafourou, V., Tong, H. J., Day, P Houghton, N., Spencer, R. J., & Duggal, M. (2017). Outcomes and prognostic factors that influence the success of tooth autotransplantation in children and adolescents. *Dental Traumatology*, 33, 393–399.
- Kristerson, L. (1985). Autotransplantation of human premolars: a clinical and radiographic study of 100 teeth. *International Journal of Oral Surgery*, 14, 200–213.
- Kristerson, L., & Lagerstrom, L (1991). Autotransplantation of teeth in cases with agenesis or traumatic loss of maxillary incisors. *European Journal of Orthodontics*, 13, 486–492.
- Kugelberg, R., Tegsjo, U., & Malmgren, O. (2002). Autotransplantation of 45 teeth to the upper incisor region in adolescents. *Swedish Dental Journal*, 18, 165–172, 1994.
- Lee, S. J., Jung, I. Y., Lee, C. Y., Choi, S. Y., & Kum, K. Y. (2001). Clinical application of computer-aided rapid prototyping for tooth transplantation. *Dental Traumatology*, 17, 114–119.
- Ninomiya, M., Kamata, N., Fujimoto, R., Ishimoto, T., Kido, J. I., Nagayama, M., et al. (2002). Application of enamel matrix derivative in autotransplantation of an impacted maxillary premolar: a case report. *Journal of Periodontology*, 73, 346–351.
- Paulsen, H. U., Andreasen, J. O., & Schwartz, O (1995). Pulp and periodontal healing, root development and root resorption subsequent to transplantation and orthodontic rotation: a long-term study of autotransplanted premolars. *American Journal of Orthodontics and Dentofacial Orthopedics*, 108, 630–640.
- Plakwicz, P., Wojtowicz, A. , & Czochrowska, E. M. (2013). Survival and success rates of autotransplanted premolars: a prospective study of the protocol for developing teeth. *American Journal of Orthodontics and Dentofacial Orthopedics*, 144, 229–237.
- Rohof, E. C., Kerdijk, W., Jansma, J., Livas, C., & Ren, Y. (2018). Autotransplantation of teeth with incomplete root formation: a systematic review and meta-analysis. *Clinical Oral Investigations*, 22, 1613–1624.

- Schatz, J. P., & Joho, J. P. (1994). Indications of autotransplantation of teeth in orthodontic problem cases. *American Journal of Orthodontics and Dentofacial Orthopedics.*, 106, 351–357.
- Schwartz, O., Bergmann, P., & Klausen, B. (1985). Autotransplantation of human teeth: a life-table analysis of prognostic factors. *International Journal of Oral Surgery.*, 14, 245–258.
- Skoglund, A., & Hasselgren, G. (1992). Tissue changes in immature dog teeth autotransplanted to surgically prepared sockets. *Oral Surgery, Oral Medicine, Oral Pathology.*, 74, 789–795.
- Thomas, S., Turner, S. R., & Sandy, J. R. (1998). Autotransplantation of teeth: is there a role?. *British Journal of Orthodontics.*, 25, 275–282.
- Tsukiboshi, M. (2002). Autotransplantation of teeth: requirements for predictable success. *Dental Traumatology.*, 18, 157–180.
- Vandenbroucke, J. P., Von Elm, E., Altman, D. G., Gøtzsche, P. C., Mulrow, C. D., Pocock, S. J., et al. (2007). Strengthening the Reporting of Observational Studies in Epidemiology (STROBE): explanation and elaboration. *Annals of Internal Medicine.*, 146, 1500–1524.
- Von Elm, E., Altman, D. G., Egger, M., Pocock, S. J., Gøtzsche, P. C., & Vandenbroucke, J. P. (2007). The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *PLoS Medicine.*, 4, 1623–1627.
- Xu, L., Gu, H., Zou, G., Yuan, H., & Zhou, J. (2021). Autotransplantation of a completely developed impacted maxillary canine: a 7-year follow-up case report. *Journal of the American Dental Association.*, 152, 763–769.