ABSTRACT

Autotransplantation is the technique of transplanting embedded, impacted or erupted teeth from one site into another in the same individual. Despite current scientific evidence indicating that autotransplantation has favourable long-term survival rates, autotransplantation is still not generally regarded as mainstream practice outside of Scandinavian countries.

Successful autotransplantation can offer many advantages in a growing patient, including a normally functioning periodontium, proprioception and preservation of alveolar bone volume. In the event that the autotransplantation eventually fails, the bone and soft tissue conditions would still be likely to be favourable for subsequent implant treatment.

This review article will identify and discuss the factors that influence case selection, the ideal timing for autotransplantation and the critical determinants for achieving a successful outcome. The limitations of the technique and alternative treatment options will be discussed. It is hoped that through greater awareness and recognition by the dental profession, autotransplantation will become another viable treatment option in the management of compromised teeth in patients with significant remaining growth potential.

INTRODUCTION

Autotransplantation is a controlled, sterile avulsion and re-implantation of a tooth into a distant site in the same person. It is still a controversial treatment option, however, it has been suggested as the treatment of choice in selected cases.

Proponents of autotransplantation emphasise its ability to maintain and permit...
continuation of alveolar bone growth. A successfully transplanted tooth erupts with growth and can also be moved orthodontically. If a transplant fails at a later stage, a well maintained ridge can be prepared for an implant when most appropriate. For a successful outcome, preservation of the periodontal ligament of the transplanted tooth is the key to successful autotransplantation through prevention of ankylosis. An appreciation and respect for the biology of the periodontal ligament and the pulp is essential when considering this procedure. The critics of autotransplantation point to the lack of quality research and the dependence of the technique on surgical skill.

HISTORICAL BACKGROUND

Tooth autotransplantation began as allotransplantation, which is between two different people. Historical documentations date back to 1594 through the works of surgeon Ambroise Paré where royal families had teeth transplanted. In 1772, a surgeon, John Hunter successfully transplanted a tooth from one person to another. At this time there was no consideration or knowledge of disease transmission and immune compatibility. Later work focused on autografts, which are now termed autotransplantation.

The technique of autotransplantation has existed for several centuries, however, the first clinical case reports appeared in the dental literature during the 1950’s. Research in this field started with surgical enucleation of unerupted or partially erupted third molars that were used to replace decayed molars.4,5 Autotransplantation research began during the 1970’s on monkeys. This research investigated biological principles that are critical to success. These included the influence of extra-alveolar time, periodontal ligament cell survival, damage to the follicle and Hertwig’s epithelial root sheath and the effect of tooth position in relation to the socket and splinting methods.5-8 In 1973, a large prospective study started at the University Hospital in Copenhagen on patients aged seven to 35 years investigating various healing parameters following autotransplantation of 370 premolars.1,9-11 These early human and animal studies contributed to a sound appreciation of the biology and importance of periodontal ligament preservation with careful atraumatic extractions.

CLINICAL DECISION-MAKING

Autotransplantation can be successfully performed in both the anterior and posterior regions of the dentition. Although the overall surgical technique and clinical management is very similar, anterior and posterior tooth autotransplantation should be considered as separate entities, each with their own specific indications, advantages and disadvantages (Table 1).

Autotransplantation for Anterior Tooth Replacement

Missing teeth either due to agenesis and/or trauma are the two most common reasons for considering autotransplantation in the anterior region for a young patient (Fig. 1,2). Treatment options depend on multiple factors and may include no intervention, space closure or space opening with orthodontic appliances to facilitate prosthodontic restoration and finally autotransplantation.12-14
Regardless of the aetiology, the overall management is complicated by the unique requirements of the individual patient’s growth and development stage. Therefore the treatment planning is often decided on a case-by-case basis at an interdisciplinary orthodontic and restorative clinic.

Figure 1. The developing 45 was transplanted into compromised 21 extraction site for this 13-year-old patient. The 12 and 22 were also congenitally missing. Note that the 45 was intentionally placed with a 90 degree rotation to resemble the mesiodistal width of the extracted 21 and thus facilitate future restorative procedures.

Figure 2. The autotransplanted 45 was subsequently restored with composite resin. Ceramic restoration is planned in the future to provide ideal aesthetics when the gingival margin heights are stable.

Table 1

<table>
<thead>
<tr>
<th>Anterior Region (Incisors)</th>
<th>Posterior Region (Molars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indications</td>
<td></td>
</tr>
<tr>
<td>Severe compromise</td>
<td>Severe compromise</td>
</tr>
<tr>
<td>(e.g. trauma, dilaceration)</td>
<td>(e.g. caries, hypomineralisation, pathology)</td>
</tr>
<tr>
<td>Ideal Timing</td>
<td></td>
</tr>
<tr>
<td>8-14 years of age</td>
<td>12-16 years of age</td>
</tr>
<tr>
<td>(donor tooth – premolar)</td>
<td>(donor tooth – third molar)</td>
</tr>
<tr>
<td></td>
<td>root</td>
</tr>
<tr>
<td>Prosthodontic</td>
<td></td>
</tr>
<tr>
<td>Almost always required</td>
<td>Generally not required</td>
</tr>
<tr>
<td>(e.g. composite build-up, veneer)</td>
<td>Requirements</td>
</tr>
</tbody>
</table>

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Treatment of the anterior region of the mouth often involves challenging requirements. The overall aesthetics are dependent upon the alveolar ridge volume, soft tissue thickness and the quality and appearance of the restorations, also known as the “aesthetic triangle”. In addition, the lip position upon smiling or upper lip line is also important for some patients. Careful attention to the gingival margin architecture becomes a critical aesthetic factor for patients with a high lip line and increased gingival display upon smiling.

Autotransplantation with successful periodontal ligament preservation represents a unique opportunity with an aesthetic advantage because of its inherent potential for bone induction and re-establishment of a normal alveolar process, which in turn contributes to soft tissue preservation. Successful autotransplantation can therefore be viewed as a long-term temporary option during the growth period to preserve the alveolar ridge and keep future options open for the growing, adolescent patient.

Many case reports have been published which demonstrate the success of autotransplantation for the replacement of severely compromised anterior teeth.

**Autotransplantation for Posterior Tooth Replacement**

In contrast to anterior autotransplantation, there are relatively few articles that have discussed the rationale and successful outcomes for posterior tooth (i.e. molar) autotransplantation. Despite this, it could be argued that the presence of severely compromised molar teeth is a far more common clinical scenario. The first permanent molar has been reported to be the most caries prone tooth in the permanent dentition. More than 50% of children over the age of 11 years have some caries experience in this tooth. In addition to caries, the first permanent molar is also commonly found to be significantly hypomineralised. The reported prevalence of molar hypomineralisation is 3-40%. In Australia, Arrow and co-workers reported a 22% prevalence of hypomineralised first permanent molars.

Many studies have demonstrated an increased caries rate in hypomineralised molar teeth. A study by Arrow demonstrated that hypomineralised first permanent molars are 14 times more likely to experience occlusal caries compared to unaffected molars. Reduced tooth brushing due to pain, post-eruptive breakdown and rapid progression of caries through the poor quality enamel can lead to severe structural compromises and pain.

Fortunately, molar autotransplantation does not generally require any prosthodontic procedures to enhance dental aesthetics. Carefully selected patients can also have this procedure without the need for comprehensive orthodontic treatment if such treatment is not desired or indicated. If the surgical procedure is performed well and at the ideal time, autotransplantation can provide an excellent outcome from the cost-benefit perspective. The compromised molar tooth is removed, which avoids the classic restorative cycle and the third molar, which is commonly non-functional and impacted, is placed into the donor site. This form of treatment represents cost-effective and appropriate dental recycling.

For a variety of reasons, some adolescent patients with compromised molars may not be willing or able to undergo comprehensive orthodontic treatment. Such reasons may include poor oral hygiene and/or low motivation for orthodontic treatment, or be financial or geographical in nature. Third molar autotransplantation may be a very reasonable option.
for such patients. In contrast to anterior autotransplantation cases, no further cosmetic restorative procedures are generally required, thus improving the cost-benefit perspective of this treatment modality.

Reich\textsuperscript{29} presented data on a sample of 44 molar autotransplantations performed in patients aged between 11 and 25 years. The overall success rate was 95.5\% with a mean follow-up period of 19 months. The two failures were attributed to subsequent infection with no ankylosis, root resorption or malocclusion noted in any of the cases. Endodontic treatment was not required for any of the 44 autotransplants. The author estimated that autotransplantation was 87\% less costly than a restorative dental implant in private practice and proposed autotransplantation as a fundamentally sound treatment option for teenage patients with a compromised first permanent molar and impacting immature third molars.

A recent paper by Nagori et al\textsuperscript{30} presented their experience with 57 cases of immediate autotransplantation of third molars with both open and closed apices, of which 40 involved mandibular molars. All of the patients had grossly decayed or non-restorable root stumps, with 20 patients having signs of periapical infection at the time of transplant. Thorough curettage of the infected periapical region immediately prior to the transplantation is recommended. The overall success rate was 86\% after a mean follow-up period of 20 months. Pulp revascularisation was noted in all successful cases with open apices, again demonstrating the advantages of this procedure when the donor tooth is immature. For closed apices, it was recommended that recommended endodontic treatment commence within two to four weeks to avoid failure.

**Comparison of Autotransplantation and Other Treatment Options**

The survival and success rates of tooth autotransplantation, especially with an immature root-formation donor tooth, are comparable to the most common tooth replacement alternatives, which include fixed bridges, resin-bonded bridges, and single unit implants.\textsuperscript{31}

Fixed bridges have been reported to have a 10-year survival rate of 80-85\%, decreasing to 65\% at 25 years.\textsuperscript{32} A subsequent systematic review recorded a survival rate of 76\% after five years and 60\% after 10 years. It is important to note that the results depend on the prosthetic design, operator experience and the definitions of survival and success, which can vary between studies\textsuperscript{33} (Table 2).

Dental implants have varying rates of success with an expected 10-year survival rate of 90\%.\textsuperscript{34} In contrast to an osseointegrated dental implant in a growing individual, a successful autotransplant maintains a vital periodontium, can be moved orthodontically and is compatible with continuous skeletal growth (Table 3).
Table 2
Comparison of Autotransplantation and Traditional Treatment Options for Missing Anterior Teeth

<table>
<thead>
<tr>
<th>Studies</th>
<th>Survival Rate</th>
<th>Follow-Up</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autotransplantation - Long-term Observational</td>
<td>90%</td>
<td>17-41 years</td>
</tr>
<tr>
<td>Czochrowska et al (2002)</td>
<td></td>
<td>Mean: 26 years</td>
</tr>
<tr>
<td>Single Tooth Implants - Systematic Review</td>
<td>94.5%</td>
<td>5 years</td>
</tr>
<tr>
<td>Jung et al (2008)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fixed Partial Dentures - Systematic Review</td>
<td>89.1%</td>
<td>10 years</td>
</tr>
<tr>
<td>Resin Bonded Bridge - Systematic Review</td>
<td>87.5%</td>
<td>5 years</td>
</tr>
</tbody>
</table>

Table 3
Advantages of Autotransplantation in Comparison to Restorative Implants

1. Suitable Option for Adolescent Patients (continue to erupt with ongoing vertical facial growth)
2. Normal Proprioception and Thermal Feedback
3. Can be Moved Orthodontically
4. Preserves Alveolar Bone Volume (even in the event of failure, the autotransplant can be replaced with an osseointegrated implant when facial growth is complete)

CASE SELECTION
Despite its many advantages, tooth autotransplantation is undoubtedly a very technique sensitive procedure. Carefully considered individual case selection and surgical skill are the critical determinants for success. Inappropriately selected cases will undermine the success of this treatment modality, which highlights the need for strict selection criteria when considering autotransplantation for a patient.

Medical History
The patient must be in good general health with an uncomplicated medical history. Smoking must be avoided, as this will reduce the vascularity and wound healing potential post-transplantation. Uncontrolled diabetes is also a significant contraindication.

Donor Tooth Selection
The donor tooth ideally should have incomplete root formation, be healthy and have normal morphology that matches the recipient site without complicating the occlusion. It should also be in a position where it can be removed as atraumatically as possible. Recent advances in three-dimensional imaging techniques have the potential to enhance the success rate of the autotransplantation procedure. Such imaging can assist in the selection
of an appropriate donor tooth through the accuracy of pre-surgical morphological measurements and also facilitate the planned atraumatic extraction.

**The Importance of Root Development Stage for Autotransplantation**

The stage of root development has been shown to be one of the primary factors affecting the prognosis of an autotransplanted tooth. The average autotransplantation success rate is reported to be more than 80% if the root of the transplant is immature at the time of surgery or at one-half to three-quarters of the normal root length using the Moorrees root classification. For autotransplantation cases, continued root development most likely depends on the health of Hertwig’s epithelial root sheath. If Hertwig’s root sheath is damaged, future root growth is likely to be limited or inhibited.

According to Andreasen, a half to three-quarter root length, or between seven and nine millimeters with a wide open apical foramen is highlighted to be the most important factor for achieving the objectives of ongoing root development with periodontal ligament and pulpal healing.

Revascularisation will usually occur for an immature tooth. Pulp obliteration is a common and normal sequence following revascularisation, which can be seen radiographically within three to six months. Seven to 27 percent of teeth with pulpal obliteration may develop pulp necrosis with radiographic signs of periapical disease. This represents a significant advantage when transplanting immature teeth because subsequent endodontic treatment is generally not required.

It appears that the most successful transplants are the lower first and second premolars and upper second premolars, due to their favorable root morphology. The highest success rates seem to be transplantation of immature premolars to the maxillary incisor region.

**Autotransplantation of Teeth With Complete Root Formation**

Less reliable revascularisation occurs if the apex is smaller than one millimeter. Despite this, autotransplantation with a closed apex may still be an option in some cases, where high quality endodontic procedure and restoration can be performed. An 87% survival rate and a 63.1% success rate was recorded in mature teeth with a closed apex with a follow up of an average of 10 years. The authors found a 10% risk of ankylosis, which is less problematic for an adult patient. Although the survival rates appear to be high, this data must be interpreted with caution due to the heterogeneous sample, which included incisors, premolars and molars. Endodontic treatment is best initiated as soon as possible, preferably within two weeks post-transplant to prevent inflammatory root resorption. A systematic review and meta-analysis reported that root resorption was two times higher in studies where the endodontic treatment was performed beyond 14 days post-transplant. A high quality endodontic procedure and a restoration with an effective coronal seal are also critical factors for the longevity of any endodontically treated autotransplant.

**Other Important Patient-Related Factors**

The patient must avoid trauma to the transplanted tooth to minimise the risk of failure. Excellent oral hygiene is also required to facilitate health of the periodontium and reduce the likelihood of inflammation and secondary infection at the transplant site.
THE SURGICAL TECHNIQUE OF AUTOTRANSPPLANTATION

The Importance of Preservation of the Periodontal Ligament
The survival of the periodontal ligament and the absence of ankylosis are the primary objectives for a transplanted tooth in a growing individual. The viability of the periodontal ligament is compromised through extra-oral dehydration or damage. The atraumatic extraction of the donor tooth is paramount to preserve the periodontal ligament and cementum covering the root into which the periodontal ligament attaches. Histological studies show that cementum damage results in direct contact between osteoclasts of the bone and the root surface occurs which leads to replacement resorption or ankylosis.\(^6,10,45\)

Extra-Oral Time Prior to Transplantation
Autotransplantation is effectively a planned avulsion and replantation.\(^46\) It is critical to keep the extra-oral time before transplantation to an absolute minimum. It has been shown that less than one minute of extra-oral time significantly reduces the risk of pulp necrosis.\(^9,10\) The most important factor for success is the vitality of the periodontal ligament, which decreases significantly with increased extra-oral exposure (Table 4).

<table>
<thead>
<tr>
<th>Table 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Criteria for Autotransplantation Success</td>
</tr>
<tr>
<td>1. Medically healthy patient</td>
</tr>
<tr>
<td>2. Donor tooth with normal morphology that matches the recipient site without complicating the occlusion</td>
</tr>
<tr>
<td>3. One half to three quarters root formation with under-developed root apex (over 1 mm wide open apex)</td>
</tr>
<tr>
<td>4. Atraumatic extraction technique preserving Hertwig’s epithelial root sheath, periodontal ligament and the apical portion of the developing tooth bud</td>
</tr>
<tr>
<td>5. Keeping extra-oral time for the donor tooth to an absolute minimum (preferably less than one minute)</td>
</tr>
<tr>
<td>6. Transplanted tooth is placed into a fresh socket, rather than an artificially prepared socket</td>
</tr>
<tr>
<td>7. Avoid trauma post-transplantation and maintain excellent oral hygiene</td>
</tr>
</tbody>
</table>

Andreasen postulated that optimum healing is more likely and more predictable when a transplanted tooth is placed into a fresh socket, rather than an artificially prepared socket. It is hypothesised that the periodontal ligament cells in the root can work synergistically with the progenitor cells in the socket wall.\(^6\) However, it would seem that careful handling and satisfactory fit of the donor tooth into the recipient site are also critically important factors.

Surgical Templates
To reduce extra-oral time and handling of the periodontal ligament, a template or a tooth replica can be used to create the recipient site.\(^19\) Sterilised premolar teeth have been used as templates in the past. Chrome cobalt tooth templates have also been utilised (Fig. 3). These templates are cast to average tooth dimensions.
Figure 3. A chrome cobalt tooth template is being used to facilitate the autotransplantation of an immature upper premolar into the ankylosed 75 extraction space. The 35 is congenitally missing and orthodontic space closure in the lower arch is not indicated due to multiple other missing teeth, nor is an immediate implant replacement possible for this growing, adolescent patient. After the template was tried in, the immature premolar tooth was extracted and placed into the extraction site. The extra-oral time was less than a minute.

Three-dimensional printing has the potential to provide customised pre-surgical tooth templates from a segmented cone beam image. Some studies reported a reduction of extra-oral time to less than minute as compared to a historical control method of three to 10 minutes. The first Cone Beam Computed Tomography (CBCT) assisted template reported an extra-alveolar time of seven minutes, which is similar to the time reported for the traditional techniques. This highlights that surgical technique and a well-developed surgical protocol are the critical factors. Additional studies to compare the accuracy of customised three-dimensional templates with other conventional template techniques would also be beneficial.

In the search for increasing predictability of periodontal ligament and pulpal survival, novel research on animal models has been published in the field of tissue engineering and cellular biology.

One case report investigated the application of orthodontic force for up to 14 days prior to extraction with the goal to increase periodontal ligament space to facilitate the ease of extraction and reduce the potential damage to the periodontal ligament. It is clear that further research in this area is required before clinical recommendations can be made.

There is absolutely no question that the autotransplantation procedure is extremely technique sensitive, with the surgeon's skill, experience and careful handling of the transplanted tooth being vital for success. Unfortunately, many surgeons to date have not received the requisite experience in performing this procedure. Clinicians in Europe, particularly in Scandinavia and Poland, appear to be very proficient in this surgical technique and demonstrate excellent success rates. It is hoped that greater awareness of the significant advantages of autotransplantation will lead to the appropriate recommendation.

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of this procedure for carefully selected patients with an expectation of significant remaining facial growth. Such patients have the most to gain from this procedure and the least to lose if the autotransplant fails in the short, medium or long term. Future improvements in 3D radiology and rapid prototyping are likely to greatly facilitate the surgical technique, hopefully leading to better predictability and success rates. If the evidence base regarding this technique continues to expand, it is hoped that clinicians worldwide will begin to acknowledge, consider, recommend and perform this very worthwhile procedure for appropriately selected adolescent patients.

**Stabilisation Post-Transplantation**

Various methods of splinting stabilisation post-surgery methods have been proposed. The fixation method should be determined by the initial stability of the transplant. If the transplanted tooth fits well within the socket and between the adjacent teeth is adequate, a mattress suture is generally all that is required (Fig. 4). A recent evidence-based appraisal of the literature indicated that type of splint was not a significant factor in healing.\(^{53}\) Despite the lack of evidence-based guidelines with respect to the duration of splinting, it has been hypothesised that prolonged splinting duration and rigid splinting materials may contribute to the development of ankylosis and therefore should be avoided.\(^{54-57}\) It is also recommended that the transplant be taken out of traumatic occlusion post-surgery.\(^2\)

![Figure 4. The same patient as shown in Figure 3. The autotransplanted tooth stabilised with a mattress suture. The transplant was taken out of occlusion by the use of compomer bite ramps on 36 and 46 and the orthodontic wire bypassed the transplanted tooth.](image)
This series of photographs demonstrate extraction of the compromised 36, harvesting of the developing 38 and autotransplantation of the 38 into the 36 extraction site. No orthodontic treatment was desired by this patient.

**POST-AUTOTRANSPLANTATION MANAGEMENT AND OUTCOMES**

**Follow-Up Protocol**

The recognised follow up protocols for autotransplantation have been adapted from the work of Andreasen. This protocol involves regular clinical and radiographic monitoring, consisting of a baseline post-operative radiograph and continuous reassessment of the periodontal and pulpal healing.

**Pulp Testing**

Immature transplants typically regain their sensibility within 6-12 months in 90% of cases. In the presence of pulp obliteration, traditional electrical and cold pulp tests can be unreliable. Laser Doppler Flowmetry (LDF) can be used to evaluate the blood flow of autotransplanted teeth and replanted avulsed teeth and has been shown to detect...
revascularisation much earlier than standard sensitivity tests.\textsuperscript{58} LDF uses a laser beam light to detect a frequency shift caused by capillary movement of red blood cells, which are the largest moving cells within blood. Unfortunately, this type of testing can lead to false positive results, is technique sensitive and is not always readily available.\textsuperscript{59,60} It is therefore important that other clinical and radiographic diagnostic assessments are performed prior to commencing any type of root canal treatment.\textsuperscript{61}

**Potential Complications of Autotransplantation**

Root resorption can be divided into surface, inflammatory and replacement resorption.\textsuperscript{63} Unfortunately, this distinction is not found to be consistent in previous studies. The ultimate goal of autotransplantation in a growing individual is periodontal healing and avoiding ankylosis or replacement root resorption. Periapical healing, pulp survival and the absence of inflammatory root resorption are also important.\textsuperscript{36}

Replacement resorption or ankylosis may be detectable radiographically within 6 months of transplantation by infra-occlusion, visualisation of loss of lamina dura on radiographs and a “high metallic” percussive sound. Andreasen reported an incidence of 4.8%, however, the study included samples of varying extra-oral storage times.\textsuperscript{10} Ankylosis was reported to be seven percent in 162 transplanted premolars after an average of 10 years follow-up and up to 40% in 49 third molar transplantations.\textsuperscript{62} The authors also concluded that previous primary molar ankylosis leads to higher chance of ankylosis post-operatively. Therefore, premolar autotransplantation into sites without previous ankylosis of primary tooth may have a lower risk of ankylosis.

Inflammatory resorption is also known as infection-related resorption. The chance of inflammatory resorption is high if bacterial contamination occurs and when the apex diameter is smaller than one millimeter.\textsuperscript{9} Odontoclasts respond to the necrotic debris, which results in progressive dentine resorption. It can occur within one month of autotransplantation and must be arrested by eliminating the inflammatory stimulus, (i.e. the infected pulp tissue) through endodontic treatment.\textsuperscript{63, 64}

To avoid post-transplant complications, careful handling of the periodontal ligament, extra-oral time of less than a minute and an open apex of over one millimeter are required.\textsuperscript{65} Operator experience and a meticulous surgical protocol are paramount to success.

**Autotransplantation Survival and Success Rates**

Several studies have been published with varying success and survival rates, ranging from one to 41 years of follow up. It is challenging to objectively evaluate success rates of autotransplantation outcomes in published studies due to the multitude of confounding factors. These factors include retrospective study design, inconsistency in the duration of follow-up, sample size, differences in operator skill, and diverse pre-operative, surgical and post-operative parameters.

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Inconsistency of published outcomes is further confounded by studies investigating different root morphologies. For example, a heterogeneous sample, which includes impacted canines and third molars in the same group as premolars, will dilute the success rate of the premolars. Consequently this does not give a representative percentage of success.

Different studies tend to use different assessment criteria for treatment outcomes. The two definable autotransplantation outcome criteria are survival rate and treatment success rate. Survival rate can be objectively defined as presence of a viable transplanted tooth at the time of examination. Success criteria are more subjective and their definition varies between the studies. Most authors recognise the importance of factors such as tooth vitality, health of the periodontium, root development and absence of root resorption and ankylosis.

Previous studies have reported survival rates ranging from 90-100%. Czochrowska et al also recorded treatment success, which was reported to be 79%. Treatment success rate was evaluated based on the presence or absence of pathology, ankylosis and decreased root length. Their assessments included radiographic and clinical examination, photography, study models and a periodontal analysis. The recorded outcomes for teeth with incomplete root formation compared favorably with other tooth replacement options. The long-term follow-up in this study also allowed them to make an observation that ankylosis does not necessarily render autotransplantation a failure, as it is usually a slow process in adults that may take 20 years or more. Patient and clinician satisfaction with the autotransplantation procedure was also evaluated. Patients reported that the only discomfort was the procedure itself. Over 80% of patients and fellow dental professionals rated the aesthetic outcome as satisfactory or acceptable.

Despite the multiple variables and protocols from these studies, a high rate of success was still achieved, which compares favourably with other contemporary and traditional tooth replacement modalities.

Decoronation Technique in the Event of Ankylosis

Ankylosed teeth generally impede alveolar bone development in the vertical dimension, which results in more dramatic effects for a young individual. Extraction of an ankylosed tooth may result in a significant loss of bone, particularly the thin buccal plate of the maxilla. Disturbance in the vertical growth of the alveolar bone also leads to unfavourable tilting of the adjacent teeth and the cessation of ridge development, which subsequently requires ridge augmentation prior to future prosthodontic procedures.

To address tooth ankylosis in children and adolescents, a decoronation technique was developed by Malmgren and co-workers. This technique has recently become recognised as the gold standard treatment for paediatric ankyloses. The main advantage of this technique is the preservation of alveolar width and height in growing individuals. The crown is removed two to three millimetres beneath the marginal bone level with the remaining root left in situ. If the tooth has been previously endodontically treated, it is...
debrided and allowed to fill with blood coagulum. The root serves as a matrix for new bone development as it undergoes continued replacement resorption. The vertical bone is augmented during eruption of adjacent teeth via the dental-periosteal fibre complex. The patient’s age at the time of decoronation is an important factor. The most predictable vertical bone apposition is achieved before 13-16 years of age, earlier in girls, as vertical bone growth is generally at its maximum at this time.\(^7\)

In summary, should the auto-transplanted tooth become ankylosed, decoronation can be performed to provide maintenance of the alveolar bone ridge width and continuity. This will facilitate future prosthodontic requirements with minimal, if any, ridge augmentation required for subsequent implant placement.

### Reduced Root Length of Autotransplanted Teeth: Is this a Clinically Relevant Problem?

Autotransplanted teeth will generally have shorter overall root length compared to the adjacent teeth, as limited root growth is expected post-transplantation. In addition to this, third molar teeth typically have shorter root morphology than first and second permanent molars. Therefore an autotransplanted third molar is likely to have shorter roots than the first permanent molar that it replaced. This situation could be considered to be conceptually comparable to cases where a molar had undergone significant apical root resorption compared to the adjacent teeth.

Levander and Malmgren\(^7\) followed up patients with severely resorbed upper incisor teeth. The results of this study indicate that there is an enhanced risk of tooth mobility if the crown-root ratio is greater than one is to one, and the use of such teeth as prosthodontic abutments should be reconsidered. It would be reasonable to assume that these findings would also apply to posterior teeth with shortened roots.

In the absence of inflammation, mobile teeth with a complete and healthy connective tissue attachment can be maintained.\(^7\) However, in the event of alveolar bone loss, a critical stage for the residual periodontal attachment may be reached prematurely in teeth with reduced overall root length.\(^7\),\(^9\)

To reduce the likelihood of clinical mobility and the possibility of periodontal attachment loss, patients with autotransplanted teeth with shorter than average root lengths must maintain an excellent standard of oral hygiene and periodontal health.

### What is the Meaning of “Success” for an Adolescent Patient?

The definition of success of tooth replacement in an adolescent may be different to the definition of success for an adult. Success of autotransplantation is measured using specific criteria with studies publishing autotransplantation outcomes with up to 40 years of follow-up and comparing these results to outcomes of implants and other prosthodontic options. The ideal scenario for an adult would be to have a successful transplant remain in situ for many years. However, in a growing patient with missing teeth, compromised teeth or
traumatic injuries, the issue of maintenance of bone becomes critical. Therefore, a successful transplant in a growing patient may be defined as one that serves the purpose of being a ‘biological space maintainer’ and having achieved a specific patient-oriented goal. An autotransplant which survives until the majority of vertical facial growth is complete could still be considered a “success”. Such an autotransplant would have achieved a functional, biological and aesthetic goal for that particular period of time and other options can now be considered.

The key to autotransplantation in a growing patient is the absence of ankylosis. Therefore this feature can serve as the primary measure of success in a growing patient and every effort should be made to preserve the periodontal ligament. This measure of success is in contrast with that for an adult patient where no active vertical growth is expected and in whom an ankylosed tooth is of less significance.

Conclusions
This literature review intends to highlight the potential benefits of tooth autotransplantation and to increase awareness of this treatment modality for patients with significantly compromised teeth. Autotransplantation can be a viable option when orthodontic space closure is not predictable or practical in an adolescent patient, using an available or “spare” immature donor tooth rather than a prosthetic restoration.

Autotransplantation of teeth in growing patients has the potential to provide significant advantages from the cost-benefit perspective provided that the relatively strict selection criteria are met and a skilled surgeon is available. This treatment option does warrant serious consideration where the long-term prognosis of a tooth is questionable, where suitable donor teeth at the ideal stage of root development are present and where restorative implant placement is not possible due to expected future facial growth and dentoalveolar change. It is expected that the use of cone beam computed tomography data and further developments in rapid three-dimensional prototyping is likely to improve the survival and success rates of this technique, through production of a highly accurate surgical template and reducing the extra-oral exposure time for the donor tooth.

Tooth autotransplantation is not a new concept. It is hoped that through greater clinician awareness and future technological advancement, autotransplantation will become a very reasonable and viable treatment option for appropriately selected adolescent patients.

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