9 Minimally Invasive Alternatives to Dental Extraction and Implant Placement

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9.1 Introduction to Autotransplantation of Teeth

The classic autotransplantation technique involves transplantation of an erupted or even an unerupted tooth from one site of the mouth to an extraction site or surgically prepared socket in the same person [1]. As a successfully transplanted tooth can function like a normal tooth, autotransplantation has become a viable treatment option to replace either a missing tooth or one with a poor prognosis [2].

However, the autotransplantation technique includes two additional procedures:

1. Surgical extrusion: intra-alveolar transplantation using a simple extraction to extrude teeth in a more coronal position [3].
2. Intentional replantation: a recognized endodontic procedure, used to correct a

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radiographic or clinical endodontic failure, whereby a tooth is extracted, treated outside the oral cavity, and then reinserted into its socket. This procedure is sometimes preferred over conventional apical surgery [4].

9.1.1 Clinical Examination and Diagnosis

Candidates for autotransplantation are examined and diagnosed based on their clinical and radiographic information. At present, the three-dimensional (3D) cone beam computed tomography (CBCT) radiographic assessment of teeth and their surrounding structures is desirable for planning an autotransplantation procedure [5]. Key information required includes the anatomic shape and root development of the donor tooth, bone dimension of the recipient socket, as well as the compatibility of the size of donor tooth with the size of the recipient site.

While successful autotransplantation can yield long-term results, patients should be informed that the procedure might have to be interrupted in the event of complications both in the donor tooth extraction and in the recipient site (such as insufficient alveolar bone), as well as unforeseen difficulties [6]. It is essential that the patient will be self-motivated when faced with a complex and somewhat uncertain procedure.

9.1.2 Advantages and Disadvantages

The main advantages offered by the technique are:

1. Preservation of the periodontal ligament (PDL) and the alveolar bone.
2. Ability to be performed in a growing child/adolescents as well as in adult patients.
3. Preservation of the natural shape of the attached gingiva while achieving an esthetic and optimal function.
4. Possibility, if necessary, of performing orthodontic treatment to properly position the transplanted tooth.
5. A viable alternative to dental implants, fixed bridgework, resin-bonded restorations, and removable partial dentures.

The main disadvantages are summarized thus:

1. Somewhat more aggressive and complicated surgery than conventional extraction.
2. Treatment outcome may be difficult to predict in some cases, despite digital planning.
3. Possible complications such as inflammatory root resorption, replacement root resorption, or loss of clinical attachment level, which may result in loss of the tooth.

9.2 Biological Basis

In recent decades the understanding of the wound healing process following transplantation and replantation has markedly improved the success rate of these procedures [7]. However, autotransplantation is frequently overlooked in patients with missing teeth or it is ruled out because of possible transplant-related complications. This is unfortunate because autotransplantation could become a highly relevant treatment option for single-tooth replacement, particularly since the transplanted tooth can function as a normal tooth [8]. An update of the biological basis would provide a better understanding of the high success and tooth survival rates after autotransplantation, replantation, and surgical extrusion, which would help the clinician to have in mind this procedure in specific cases.

9.2.1 Periodontal Ligament (PDL) and Bone Healing

Regardless of the procedure to be performed (autotransplantation, replantation or surgical extrusion), favorable PDL healing is the key to success [9]. Ideal PDL healing occurs when the extracted tooth is replanted in the original extraction socket in a very short extraoral time, when most of their cells are still alive. This type of healing, described as a reattachment of the PDL, consists of connecting the connective tis-

sue to the root surface [7]. However, PDL cells can be mechanically damaged during extraction or be affected by changes in pH values, osmotic pressure, dehydration, etc. Therefore, an atraumatic removal of the donor tooth is critical to successful PDL healing. Indeed, during the extraction process and extraoral storage, extreme care should be taken to protect Hertwig's epithelial root sheath (HERS) and maintain pulp vitality [10].

Since events occur quickly, by the third and fourth week post-replantation, fibroblasts and regularly aligned bundles of collagen fibers proliferate, indicating functional alignment of the PDL tissue, which, according to the literature, is the ideal healing process [11]. At 8 weeks, a near normal PDL and alignment of collagen fiber bundles are observed, meaning that if necessary, a definitive direct or indirect restoration could be performed, particularly in donor teeth with closed apex [12]. Although there is a logical variability in this time frame, the process appears to take more than 1 month. As the PDL is normally separated in the middle of the root, the reattachment of the PDL located in the gingival area occurs sooner and takes only 1–3 weeks. The PDL is severed at the center of the root during donor tooth extraction, leaving a layer of PDL containing cells (e.g., cementoblasts, fibroblasts, pericytes, epithelial cells of Malassez) on the root surface, which are essential to prevent root resorption. It is desirable to extract a tooth containing as much PDL as possible, even though the cementoblast layer by itself seems to be sufficient in preventing root resorption [13].

The most frequently performed autotransplant is done immediately after the extraction of the tooth in question. However, we sometimes encounter scenarios in which the patient presents with congenitally missing teeth or early tooth loss, implying that the recipient site destined for autotransplantation needs to be created surgically [14]. The main difference with respect to replantation and transplantation to existing sockets is the absence of PDL fibers on the walls of the surgically prepared sockets [15]. During the first weeks, the blood clot is gradually replaced by granulation tissue that supplies nutrients and sets the stage for connective tissue reattachment [16]. Over the next 2–6 months, mature bone and tooth-bone reattachment progressively replaces the granulation tissue and the immature bone [11].

One downside of autotransplantation in surgically prepared sockets is that it produces a slower revascularization and insufficient nutrition to the apical tissues. Thus, the vitality of HERS is affected by this delayed revascularization and inadequate nutrition [17, 18]. Postoperative root development dependent upon the preserved activity of HERS reduces root development after transplantation to surgically created sockets [19, 20]. The trauma triggered by preparation of a new socket induces delayed revascularization and increases the risk of thermal bone damage [15].

Clinically, however, satisfactory healing appears to take place in autotransplantation to surgically prepared alveolar sockets. In most cases no root resorption is observed, the PDL space is maintained, and physiological tooth mobility is achieved [14]. There may be situations where we encounter cases with marked buccolingual alveolar bone atrophy, where promising and optimal functional outcomes can be also achieved with guided bone regeneration [21]. Modified surgical techniques to ensure minimally traumatic removal of donor teeth help to increase the success rate of mature molar autotransplantation, especially embedded or impacted third molars. In this context, piezosurgery is beneficial in socket preparation and atraumatic extraction of third molars [22]. Nevertheless, the clinician must bear in mind that the PDL attached to the bony walls of recipient sockets plays an important healing role.

Replantation studies have demonstrated that PDL deficits on the root surface are repaired by new attachment, defined as joining connective tissue to a root surface derived from its PDL. The new attachment mechanism results from the formation of connective tissue between the exposed root surface and its surrounding tissue (bone or gingival connective tissue) by proliferating the PDL cells around the exposed root surface with the addition of cementum and Sharpey's fiber. Bone graft materials are unnecessary between bone walls and transplant roots even if the space

is wide [23]; this is a significant advantage over the use of implants. Garcia and Saffar transplanted 20 roots into surgically prepared bone cavities in the edentulous areas of 5 dogs [24]. The PDL of the roots implanted in the lower and upper right cavities remained intact, while the grafted roots in the left cavities were planed and dried. The authors of this study found that the preservation of the PDL cells benefited bone growth around the transplanted root. PDL cells are a heterogeneous cell population that can be genetically divided into three types of cells: fibroblasts, cementoblasts, and osteoblasts [25]. PDL cells induce bone regeneration in the surroundings after transplantation thanks to their high proliferative capacity, multilineage differentiation potential, capability to form PDL-like tissue, and high level of alkaline phosphatase activity [26, 27].

When donor teeth are placed into recipient sites with an insufficiently wide buccolingual space, a protrusion of the roots through bone dehiscence and a subsequent resorption of the alveolar ridge may be observed [28]. For this reason, the clinician must be able to anticipate this situation through adequate 3D planning. In such a scenario, as recommended by Imazato and Fukunishi [29], autogenous materials can be grafted over the exposed root to make way for bone regeneration. If this regeneration procedure is performed adequately, the outcome should be almost similar to that of a conventional autotransplant technique without guided bone regeneration [14]. Briefly, the narrower the recipient site is, the higher the number of failures [30].

If the area of root damage of the transplanted tooth is small, progenitor cells usually cover the area and new PDL is formed, as described by Tsukiboshi et al. [7], which is termed surface resorption or cemental healing. This transient process gives way to resorption cavities that are shallow and will heal by placement of new cementum and PDL fibers. However, in larger areas of damage, replacement resorption occurs. The damaged root surface is resorbed, leading to bone deposition and finally ankylosis. This situation is believed to be irreversible and progressive until tooth loss. The speed of the root replacement depends on the patient's age, meaning the younger the patient, the more rapid the process.

Hence, it is crucial to maintain PDL cellular viability of the donor tooth outside the mouth to ensure a long-term retention. An appropriate storage medium will preserve or improve cell viability during the extra-alveolar period, avoiding their desiccation [31]. The key factors for suitable cell growth and survival are physiologic osmolality, pH, and temperature [32]. Cellular reactions are dependent upon the pH of the environment since alterations may affect biological processes. The optimal pH and osmolality for cell growth should be in the region of 6.6–7.8 and 230–400 mosmol/kg, respectively [33]. In 1981, Andreasen [10] studied the effect of extra-alveolar time and storage media on periodontal and pulpal healing following replantation in green vervet monkeys (*Cercopithecus aethiops*). The results showed a significant relationship between the frequency of root resorption, extra-alveolar time, and storage medium, which was especially evident after dry storage. A sharp decrease in PDL survival was clearly observed after 30 min of dry storage. In sum, Andreasen demonstrated that prolonged non-physiologic storage time of the teeth was more important to prognosis than the entire extra-alveolar time.

Various storage media such as Hank's balanced salt solution (HBSS), tap water, coconut water, milk, egg white, pooled saliva, propolis, and Gatorade have been studied for their ability to preserve cell viability [34]. Osmanovic et al. [34] observed that media showing poorly conserved PDL cells after 2 h were tap water (53.4%), saliva (28.6%), and Gatorade (5.4%). HBSS is a storage medium that, thanks to its ability to provide long-term PDL, is considered the gold standard in cases of avulsion, but it is routinely unavailable in dental offices. Accordingly, the most practical choice of medium in autotransplant cases would be physiologic saline or milk because these products have also shown excellent PDL cell survival [7].

9.2.2 Pulp Regeneration and Root Development

Tooth transplantation, replantation, and surgical extrusion interrupt vascular supply to HERS. Experimental investigations have shown that after transplantation of immature teeth only a small apical part of the pulp tissue turns necrotic [35]. Skoglund et al. [36] studied revascularization of pulp of replanted and autotransplanted teeth with open apex in dogs. The transplant revascularization commenced on the fourth postoperative day with an ingrowth of new vessels, which were visible in the whole pulp at approximately 1 month. Therefore, pulp regeneration can be expected in replantation and transplantation of immature teeth. Andreasen et al. [37] have proposed that the diameter of the apical foramen should be greater than 1 mm for an autotransplanted tooth for revascularization. Pulp canal obliteration, a defense response of revascularized pulp, is frequently observed after tooth transplantation procedures, dental trauma injury, and orthodontic movement [38]. Abd-Elmeguid et al. [39] found that pulp canal obliteration was the most common outcome of pulpal healing, with 96% of healed pulps. Their study detected the first obliterations at 3–14 months with a mean time of 9.5 months. In such an event, the clinician must carry out a clinical and radiographic follow-up to check for apical periodontitis. Partial pulp canal obliteration, therefore, is a sign that the pulp is still vital during healing.

However, since revascularization and pulpal healing are far less probable in teeth with closed apex, endodontic treatment is considered a routine procedure to avoid pulp necrosis with subsequent periapical inflammation and inflammatory root resorption [40–42]. Endodontic treatment can be applied either preoperatively, extraorally during autotransplantation surgery, or within 2 weeks post-surgery [43]. However, some authors, including Andreasen et al. [37], Marques-Ferreira et al. [44], and Gaviño et al. [45], have suggested that revascularization can be achieved when the root is shorter than 8.07 mm and the diameter of the apical foramen is larger than 1 mm. These results are controversial, since studies by Iohara et al. [46], Laureys et al. [47], and Fang et al. [48] achieved a revascularization and regeneration in foramina of less than 1 mm. Prospective controlled clinical studies on extraoral apicoectomy are required to validate these findings, and this clinical procedure is yet to be recommended.

Autotransplantation performed with donor teeth of an ideal root developmental stage and using a procedure that avoids damaging the PDL and HERS enables continuing root growth [49]. Nonetheless, the extent of root elongation does not always occur and is difficult to predict [37]. The most common classifications of root stage development, according to the literature, are those described by Moorrees et al. [50] and Demirjian et al. [51]. Moorrees et al. [50] categorized development in stages 1 (beginning of root formation), stage 2 (one-fourth root formation), stage 3 (half root formation), stage 4 (three-fourths root formation), stage 5 (complete root formation with wide-open apex), stage 6 (complete root formation with half closed apex), and stage 7 (complete root formation with a substantially closed apex). Since no additional root development is possible, some clinicians have recommended that donor teeth should be transplanted between stage 3 and 5.

Van Westerveld et al. [52] evaluated the preoperative root development stage and the radiographic width of the apex as root-elongation predictors post autotransplantation. From a total of 58 transplanted premolars, 53 (91.4%) presented root elongation and the remaining 5 (8.6%) had no root elongation after autotransplantation. The mean length of root elongation at the end of follow-up measured 1.9 mm (range, 0.0–4.3 mm; SD, 1.2 mm). A wider open apex (≥2 mm) was statistically associated with root elongation post autotransplantation. These findings suggest that an ideal tooth autotransplantation should be performed when the root length of the donor tooth is approximately 50–75% of the total estimated, leaving the apical foramen with the potential for pulp regeneration (apex opening at least >1 mm radiographically).

9.3 Mechanisms of Root Resorption

During any of these three surgical procedures (autotransplantation, replantation, and surgical extrusion), the clinician may find three resorption situations: replacement resorption, inflammatory resorption, and surface resorption or cemental healing. Depending on whether pulp infection is present and on the state of the PDL, one of these three may occur, although sometimes combined resorption may occur. The main characteristics of each of them are explained below.

9.3.1 Replacement Resorption or Ankylosis (Fig. 9.1)

If the transplanted or replanted tooth has been exposed to air or stored in an inadequate medium for long periods or has been traumatically extracted, the PDL will become necrotic, thus making healing with a normal PDL impossible [53]. In such condition, the necrotic PDL will promote bone ingrowth, gradually substituting the tooth by bone [54]. The remodeling of the bone tissue is continuous as part of homeostasis [7]. When there is contact between the roots with necrotic or lost PDL and bone and its osteoclasts, cementum and dentin contribute to the bone remodeling process and root resorption and bone apposition occurs simultaneously on the root surface. This type of resorption is termed ankylosis, or replacement resorption. Ankylosis is nearly always progressive and will likely, over time, replace the tooth with bone, which may eventually result in tooth loss [55]. However, there is a very low risk of ankylosis occurring during any of these three surgical procedures because the clinician will have exhaustively planned the treatment in advance.

Fig. 9.1 Replacement resorption or ankylosis. Root dentin is replaced by bone, which results in a fusion of bone to tooth (ankylosis). This phenomenon occurs when there is an extensive loss of vital PDL

The rate of root resorption may progress depending on the rate of the patient's skeletal growth. Andersson et al. [55] found that root resorption progressed faster in younger (8–16 years) than in older patients (17–39 years). The mean resorption time for a replanted tooth ranges between 3 and 7 years in younger individuals, although in older patients such teeth may function for decades or for life.

The clinician detects the first sign of an ankylosed tooth through a metallic percussion, followed by reduced mobility, replacement resorption, and a gradual infra-position in growing individuals [56]. Infra-positioning is a condition that results from the local arrest of the surrounding alveolar bone growth simultaneously with the individual's continuous skeletal growth. This condition advances irreversibly and there is currently no means of arresting it. Consequently, infra-positioning leads to an unesthetic dento-gingival effect and aggravates future prosthetic rehabilitation.

However, in some instances a phenomenon known as partial ankylosis may occur. This is difficult to detect as some of these affected teeth present some mobility and respond normally to percussion test. For this reason, long-term radiographic evaluation is the only way to determine whether a partial ankylosis will evolve into a total replacement resorption or will heal by a new attachment.

9.3.2 External Inflammatory Resorption (Fig. 9.2)

In order for an inflammatory resorption to occur in a replanted or transplanted tooth, two conditions are required [57]:

1. The root canal system is, or has been, infected by bacteria.
2. There has been mechanical damage to the cementum during the extraction or the extra-oral manipulation, resulting in a loss of cementum, such that the dentinal tubules are exposed to the surrounding PDL and bone.

An inflammatory reaction in the host tissue takes place when bacteria and their by-products migrate through the tubules to the root surface [7]. This resorption is characterized by the radiographic appearance of loss of tooth substance (1–2 months after transplantation or replantation) as well as a radiolucency affecting the adjacent PDL and bone [11]. This is due to the presence of granulation tissue that contains capillary vessels in the resorption fossa, converting the area in radiolucency. Teeth with an inflammatory resorption will not respond to pulp sensibility testing and may be associated with other symptoms or clinical signs, according to general state of the tooth and surrounding tissues [19]. Most cases show no symptoms or signs, except when the infected root canal system is causing acute apical periodontitis or when an abscess develops. External inflammatory resorption may occur anywhere along the length of the root; characteristically it is observed laterally and apically post-trauma or autotransplantation surgery.

Fig. 9.2 External inflammatory resorption. The resorption of tooth structure is the result of adjacent inflammatory tissue, induced by infected pulp tissue. Resorption cavities can be observed in both the root and the adjacent bone, which are filled with granulation tissue. This is a reversible phenomenon, as if the infected pulp is removed, resorption will cease

When faced with an established resorptive process, the clinician can interrupt this resorption and encourage hard tissue repair through root canal treatment. A corticosteroid-antibiotic intracanal medicament is recommended to prevent and manage external inflammatory resorption [57]. Calcium hydroxide is not recommended as an immediate medicament owing to its irritant properties, but it is useful as a subsequent medicament to promote hard tissue repair where required [7]. After root canal treatment, in normal conditions, the clinician will observe a healing by new attachment due to the fact that the granulation tissue will be replaced with PDL tissue. Therefore, the clinician should always monitor the pulp state, especially that of donor teeth with open apex. As mentioned above, autotransplanted immature teeth are able to revascularize, allowing tooth root development. However, upon detection of an inflammatory resorption, root canal treatment should be commenced at the earliest opportunity since it will provide a new attachment.

9.3.3 External Surface Resorption (Fig. 9.3)

External surface resorption is a type of healing response to limited partial damage of the PDL. In this type of resorption, macrophages and osteoclasts reabsorb the cementum adjacent to the damaged PDL, causing a saucer-shaped cavity on the root surface [58]. When the closest cementoblast layer is integral and the underlying dentinal

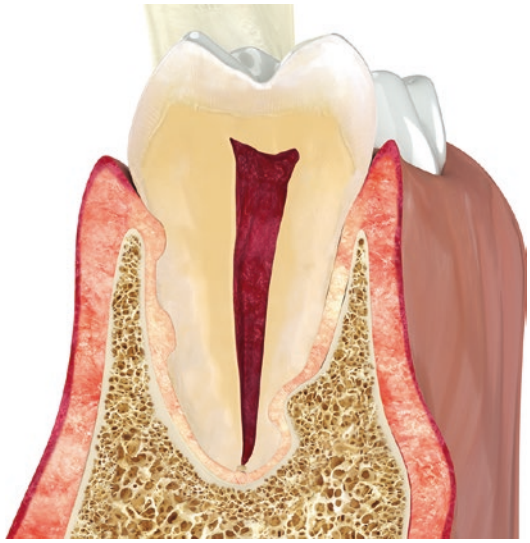

Fig. 9.3 External surface resorption. Surface resorption is the result of minor and partial damage to the PDL and is transient when repaired

tubules are uncovered, the cementoblasts will restore the damaged root surface and new cementum together with new Sharpey's fibers will repair the resorptive cavity. The surface resorption is self-limiting and repair-related, making it a non-progressive process. After the repair process, the clinician will observe a normal PDL width that follows the contours of the root defect. In both cases of minor trauma (concussion and subluxation) and replanted and transplanted teeth, surface root resorption is viewed as a favorable healing outcome [24].

9.4 Clinical Indications and Procedures

9.4.1 Classification

Knowing that surgical extrusion and intentional replantation follow an identical healing process to that of autotransplantation, these procedures fall within the same category. Autotransplantation can be classified into these three groups: (1) surgical extrusion, (2) intentional replantation, and (3) conventional autotransplantation. The main indications and step-by-step procedures are discussed below.

9.4.2 Surgical Extrusion: Indications and Technique

When restoring severely damaged teeth, an adequate biologic width and distance between the crown margin and alveolar crest should be ensured [59, 60]. In the case of insufficient tooth structure, the clinician may consider three options: surgical crown lengthening, orthodontic extrusion, or surgical extrusion [61]. Surgical extrusion, also referred to as intra-alveolar transplantation, entails the displacement of the remaining root to a more coronal position with a view to restorability based upon a sufficient ferrule [62]. The choice of one technique over another depends upon several patient-related factors: esthetics, clinical crown-to-root ratio, root proximity, root morphology, furcation location, individual tooth position, and strategic tooth position [63, 64].

The conditions of certain clinical situations are not conducive to surgical and restorative procedures. Extensive osseous surgery may produce increased pocket depth and mobility, furcation involvement, poor crown-to-root ratio, and loss of supporting periodontal tissues of the neighboring teeth or implants [65]. In the case of surgical crown lengthening in the anterior region, the loss of papillae, uneven gingival margins, and poor crown-to-root ratios might compromise the situation from the esthetic and functional point of view [66].

An alternative treatment approach would be an orthodontic forced extrusion [63]. This treatment is considered less invasive because it actually improves rather than compromises aesthetics, without interfering with the periodontal support of neighboring teeth [61]. Yet, these procedures have limitations, including patient acceptance, treatment duration, availability of appropriate orthodontic anchorage, and risk of relapse [66].

An alternative treatment is found in surgical extrusion, defined as a procedure in which the remaining tooth structure is repositioned more supra-gingivally in the same socket [67]. Tegsjö et al. [68] first developed the intra-alveolar transplantation or surgical extrusion of teeth fractured

Fig. 9.4 Surgical extrusion after dental trauma. (**a**) Preoperative clinical examination of fractured maxillary left central and lateral incisors. (**b**) Image of preoperative periapical radiograph showing intact PDL space with no evidence of root fracture. (**c**) Oblique complicated crown-root fracture in tooth 21 revealing subgingival fracture margin, and middle-third fracture of crown in tooth 22. (**d**) Emergency endodontic treatment in tooth 21. (**e**) Surgical extrusion procedure using forceps. (**f**) Tooth 21 fixed with a suture and a fiber-reinforced composite bonded to tooth 11. (**g**) Radiographic detail of surgical extrusion and teeth restored with fiber post and composite build-up. (**h**) Teeth before final impression. (**i**) Radiographic examination at 7 years post-surgery showing no evidence of root resorption, crestal bone resorption, or endodontic problems. (**j**) Clinical aspect of crowns at 7 years post-surgical extrusion. (Courtesy of Dr. Ramón Gómez-Meda)

by trauma in youngsters. This procedure, based on the biological behavior of dental replantation following avulsion, allows the clinician a direct observation of the root, thereby favoring the treatment planning. Khanberg [62] advocates bypassing both the osteotomy and bone graft in the root apical area and instead performing just a careful and gentle root luxation until the desired extrusion of the tooth is achieved. It is important to note that, apical root resorption and marginal bone loss occasionally occur; these phenomena are believed to be the result of surgical trauma [69].

This treatment is perfectly viable when the affected teeth have complete root formation and the remaining root in the socket is long enough to support a new restoration, such as a core-retained crown [70] (Fig. 9.4). It is widely agreed that the key to a successful surgical extrusion mainly hinges on an atraumatic extraction with minimal damage to the cementoblast layer on the root surface [71].

Traditional extraction techniques involve the use of elevators and periotomes, which unavoidably traumatize the alveolar bone and the root surface to some extent [72]. It is for this reason that techniques involving only forceps or specially designed extrusion instruments for vertical tooth extraction are recommended [71]. Minimally invasive vertical tooth extraction was introduced mainly to enable extraction of severely damaged teeth, without the need for flap-raising, thus reducing the degree of alveolar bone resorption [72–74].

9.4.2.1 Diagnosis and Treatment Planning

- It is essential to take the patient's medical history and ascertain whether they have any contraindications. Abnormal metabolic conditions or immunosuppressive risk factors can delay healing and reduce the prognosis of the technique. It is also important to have in mind the patient's age, as the procedure in older patients is more challenging due to their higher alveolar bone density.
- The ideal candidate teeth for this technique are monoradicular, particularly the conical shaped ones. The standard procedure for multirooted teeth is not recommended, especially in teeth with short root trunks, since they tend to develop periodontal furcation defects. The root minimum length needed for proper function should leave a minimum coronoradicular ratio of 1:1.
- In posterior teeth it is essential to take a bitewing radiograph to correctly measure the distance from the healthy margin of the tooth to the alveolar ridge.
- With this information, the clinician can plan the type of final restoration. The root length to extrude will vary in accordance with the tooth preparation selected. It should be taken into account that a preparation for an adhesive partial restoration preserves a larger amount of healthy tissue than one for a metal-free full-crown.

9.4.2.2 Surgical Procedure

- Whenever possible it is recommended to initially restore the tooth with a post or composite build-up to minimize the risk of fracture during surgical extrusion or uprighting. If this procedure is performed in conditions of absolute isolation, endodontic treatment or nonsurgical retreatment is also advised. If this is not possible, the root canal treatment should be immediately planned after replantation.
- After local anesthesia, a small scalpel blade or a micro-periosteal elevator can be used to carefully separate the gingival fibrous attachment, taking extreme care not to induce mechanical damage on the root surface. Subsequently, the clinician can luxate the tooth with the aid of forceps. However, in extremely difficult cases, such as teeth with very long roots and a completely missing coronal tooth structure, a vertical extraction device can be used [75]. It should be noted that in most cases there is no need to raise a flap when performing surgical extrusion.
- It is crucial to work under magnification to rule out cracks or fractures on the root surface. Depending on the site of the marginal defect, the tooth may even be rotated by 180° before replantation, facilitating the restoration and reducing the amount of extrusion needed.
- With the tooth placed in the optimum coronal position, the clinician can splint the tooth for 2 weeks using one of several flexible splinting methods, such as suture, stainless-steel wire and acid etch-composite resin or resin activated glass-ionomer cement [76].
- Surgical dressing can be used for 3–5 days to improve soft tissue healing and prevent contamination. The mismatch between the socket and the extruded root means that the splinting period may require up to 6 weeks in cases of high mobility of the extruded root [74]. Regardless of the type of restoration, the clinician must leave the tooth margin at least 3 mm from the bone crest (Figs. 9.5 and 9.6).
- If endodontic treatment has not been performed previously, it should be commenced within the first 2 weeks to avoid inflammatory root resorption [77]. If needed, an antibiotic-corticosteroid paste as an intracanal dressing may be recommended instead of calcium hydroxide, which may have a possible negative impact on periodontal healing [78].
- Extraoral root canal treatment is usually not recommended, since extra-alveolar conditions are not conducive to PDL survival. The longer the extra oral time, the greater the risk of root resorption [10]. However, it is advantageous if the clinician can perform this procedure with a maximum extraoral time of 12 min, because the most complex part at the endodontic level

Fig. 9.5 Surgical extrusion to save a mandibular premolar. (**a**) Clinical examination showing extensive secondary decay in the mandibular right first molar and partial destruction of crown structure in the mandibular right second premolar. (**b**) No signs of apical lesions were observed in either tooth. (**c**) Image after removal of decay and composite from both teeth. (**d**) Endodontic treatment of tooth 45 and nonsurgical retreatment of tooth 46. (**e**) Deep margin elevation or coronal margin relocation in tooth 46. (**f**) Step-by-step adhesive preparation of the workpiece. (**g**) Occlusal view of restored molar 1 week after luting. (**h**) Atraumatic surgical extrusion locating the tooth margin at least 3 mm from the bone crest. (**i**) Splinting the tooth with a stainless-steel wire and acid etch-composite resin. (**j**) Periapical radiograph showing space gained. (**k**) Tooth restored with fiber post and composite build-up. (**l**) Radiographic aspect at 4 weeks post-surgery. (**m**) Monolithic zirconia crown. (**n**) Placement of the zirconia crown on the surgically extruded tooth. Follow-up at 36 months: (**o**) periapical radiograph; (**p**) clinical aspect

Fig. 9.6 Management of a severely damaged maxillary premolar. (**a**) Deep decay affecting the maxillary left second premolar. (**b**) Periapical radiograph showing a previous endodontic treatment and an extensive subgingival decay compromising the biologic width. (**c**) Initial view of the tooth under rubber dam isolation before the nonsurgical retreatment. (**d**–**f**) A fiber post was placed to maintain material for a coronal restoration through radicular anchoring. (**g**) Radiographic aspect just after the nonsurgical retreatment and the composite build-up. (**h**) Surgical extrusion procedure. (**i**–**k**) Semi-rigid splint of the tooth by a wire-fixed composite. (**l**, **m**) Clinical aspect at 4 weeks post-surgery. (**n**) Tooth 26 isolation before the nonsurgical retreatment. (**o**) A limited volume cone beam computed tomography (CBCT) scan taken of the maxillary left quadrant to manage the tooth 26. (**p**) Location of the secondary mesiobuccal canal (MB2). (**q**) Nonsurgical retreatment completed. (**r**) Orthophosphoric acid etching. (**s**) Details of the preparation of both teeth. (**t**) Radiographic control at 8 weeks. (**u**, **v**) At 24 months, clinical and radiographic examination showed a healthy gingival condition associated with a normal periodontal contour

(apical area) is removed at once. Obviously, a key factor such as root length can limit its use. For example, this technique cannot always be applied in surgical extrusion, since the root reduction would be excessive and would compromise the coronoradicular ratio.

- Restorative treatment, whether direct or indirect, is usually carried out from 6 to 8 weeks post-surgical extrusion. Although systemic antibiotics have been prescribed for surgical extrusion, there is insufficient evidence to support or reject their indication [79].

9.4.3 Intentional Replantation: Indications and Technique

Intentional replantation is a useful endodontic procedure for correcting an evident endodontic failure in which a tooth is intentionally extracted, manipulated extraorally, and then replanted in its original site [4, 80] (Fig. 9.7). It differs from surgical extrusion in that this procedure entails positioning the tooth at the same bone level without having to position it more coronally than when it was surgically extruded. However, in some cases the clinician can combine the two techniques and thus improve both the restorability and the periapical condition of the tooth that needs to be treated.

Intentional tooth replantation, described as a treatment option for different selected and challenging situations, is all the rage among clinicians, yet this procedure is nothing new. According to Dryden and Arens [81], Pierre Fauchard first described its use in the eighteenth century. Over time, thanks to greater in-depth knowledge of wound healing processes, the indications for this procedure have evolved and increased. Intentional tooth replantation can be applied in a broad range of situations [4, 82, 83], including root canal treatment failure, anatomic limitation, accessibility problems, persistent chronic pain, external root resorption, vertical root fracture, accidental exarticulation, involuntary rapid orthodontic extrusion, patients with objections to apical microsurgery or trismus, and cases in which patients meet the expense of longer and/or costly expensive treatments. Given the almost 90% success rates shown in recent studies [84, 85], intentional replantation with more modern techniques are considered an accepted treatment modality [86].

Single-rooted and conical teeth are more favorable for extraction without producing major damage to the root surface while reducing the risk of fracture. Furthermore, it is important to take into account that extraoral time should be kept as short as possible [83]. The literature on avulsed teeth has contributed to our understanding of the implication of extraoral time, particularly dry time [87]. An extraoral time lasting more than 30 min increases the likelihood of replacement resorption [88].

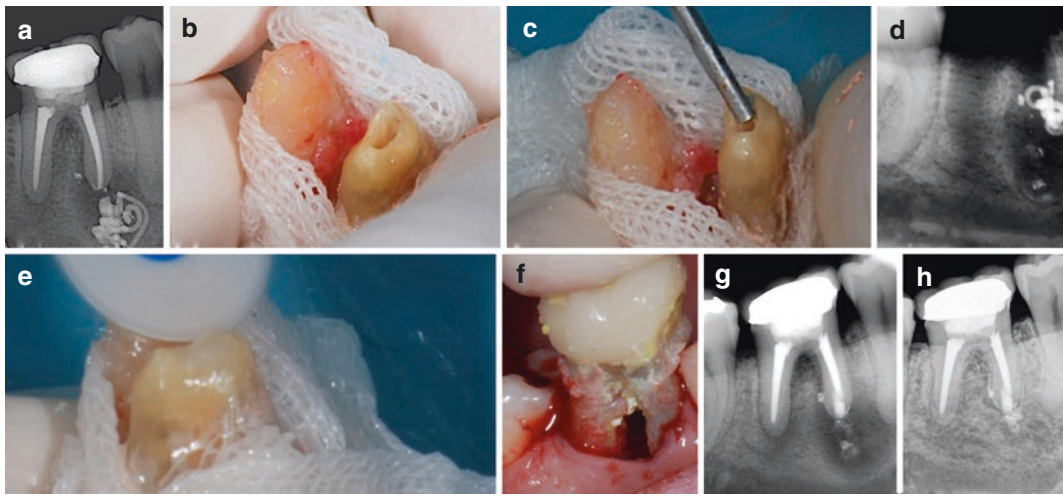

Fig. 9.7 Intentional replantation of a mandibular first molar. (**a**) Large amount of extruded material associated with a radiolucent lesion in the mesial root. (**b**) The coronal two-thirds of the root surface gently covered with gauze soaked with copious saline. Detail of the retrograde preparation. (**c**) Placement of a dual-cured resin-modified glass ionomer (Geristore; DenMat, Santa Maria, CA) as a retrograde filling. (**d**) Removal of the periapical granulation tissue and the extruded material while taking care to avoid damaging the socket wall. (**e**) Final polishing before tooth placement in the recipient site. (**f**) Digital pressure to place the tooth in its original position. (**g**) Immediate radiographic control after intentional replantation. (**h**) Periapical radiograph at 24 months post-replantation. (Courtesy of Dr. Miguel Roig and Dr. Fernando Durán-Sindreu)

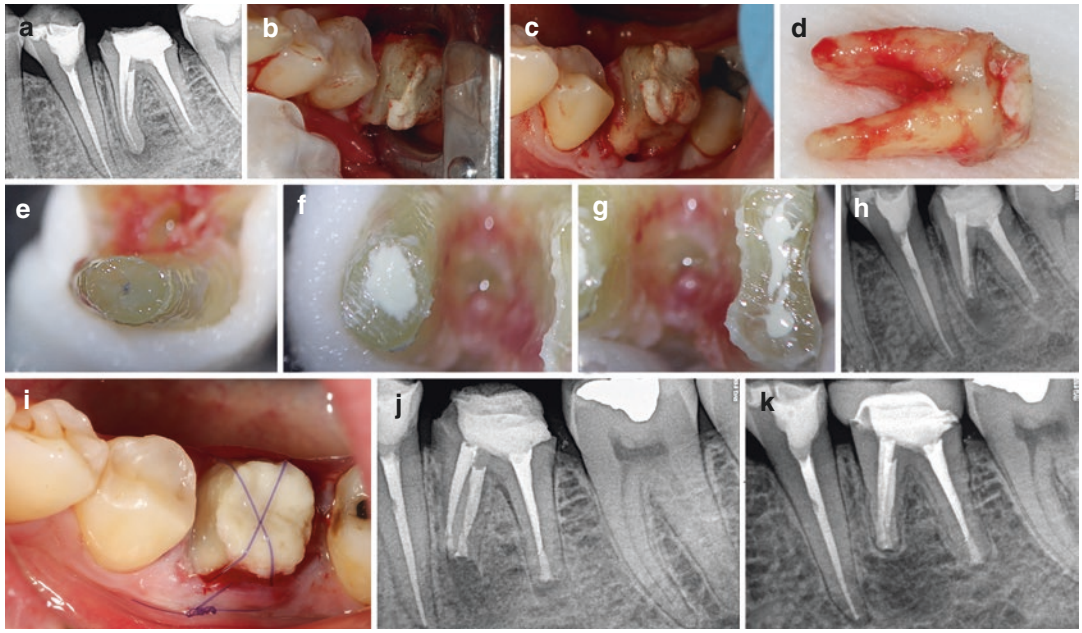

Fig. 9.8 Management of an endodontic failure. (**a**) Periapical radiolucency is visible in the area of the mandibular left first molar of a 34-year-old male. Fragments of broken instruments are observed in the apical part of both roots. Patient ruled out an apical microsurgery. (**b**, **c**) Extraction of the tooth using forceps. (**d**) The extracted tooth. Note that the tooth had an intact PDL covering the root. (**e**) Three millimeters of root resection were performed extraorally. Detail of one of the broken fragments under magnification. (**f**, **g**) Retrofilling with Biodentine (Septodont, Saint-Maur-des-fossés, France). (**h**) Postoperative periapical radiograph. (**i**) Fixation of the replanted tooth using sutures. (**j**) Three months after replantation. (**k**) Four years after replantation. Note an external surface resorption, a type of healing response to limited partial damage of the PDL

Recent advances in apical microsurgery have provided the clinician with solutions to some of the shortcomings for orthograde retreatment [89]. However, there are even cases that cannot be treated adequately with apical microsurgery, either due to anatomical factors (i.e., proximity to the mental nerve or maxillary sinus, buccal plate thickness or inoperable sites such as lingual surfaces of mandibular molars) or due to financial factors, which preclude conventional implant placement [90]. When both nonsurgical and surgical retreatments have a low prognosis or cannot be feasible, intentional replantation provides a solution resulting in fewer complications [82, 91]. In the event of a failed intentional replantation, we will have delayed time in placing an implant, as opposed to whether the implant was placed from the outset [85].

The principal advantage of intentional replantation is that tooth surfaces, including inaccessible areas, can be directly examined and repaired under magnification, reducing potential damage in the PDL (Fig. 9.8). This technique is potentially more cost-effective and less time consuming than the alternatives [90]. Originally, clinicians were recommended to carefully select each case and to inform the patient of a low probability of success. More recent studies have reported intentional replantation in previously insurmountable situations, such as teeth with vertical root fractures [92, 93], periodontally hopeless teeth [94, 95], or invasive cervical resorptions in which the clinician cannot access and seal the lesion conventionally [96].

Clearly, there are some contraindications that clinicians should know as: a more favorable prognosis with either conventional endodontic surgery or implant placement, an uncontrolled periodontal disease, a non-restorable tooth, an extraction requiring hemi-section or osseous

recontouring, a tooth that is part of a multiple-tooth prosthesis or when roots are divergent [97]. In the cases involving individual teeth with divergent roots, one clinician should perform a small osteotomy in the alveolar socket with the help of a 3D-printed tooth, while a second clinician performs the extra-alveolar apical surgery. This protocol significantly reduces extra oral time while avoiding the excessive friction over the tooth surface.

9.4.3.1 Diagnosis and Treatment Planning

- On the first visit, the patient must be informed of the different treatment options available and each one of their benefits and risks explained. Once the patient has understood what intentional replantation consists of, they must sign an informed consent. Needless to say, the patient's medical and dental history must be taken and any contraindications ascertained.
- Clinical and radiographic examination. Different tests should be performed such as periodontal probing, mobility, percussion, bite tests, acquisition of periapical radiographs, and limited CBCT images, if indicated. These tests will allow the clinician to assess both the endodontic status of the tooth (i.e., anatomical difficulty of the root canal system, presence of a separated instrument or a perforation, size and length of a post) and its anatomic relationship with neighboring structures, such as the mental nerve, inferior alveolar nerve, and maxillary sinus. It is also important to have in mind the patient's age, as the procedure in older patients is more challenging due to their higher alveolar bone density.
- Contraindications for intentional replantation include teeth that are candidates for apical microsurgery and teeth diagnosed with a vertical root fracture. In contrast, among the indications are teeth that could not be properly treated with apical microsurgery due to anatomic limitations and thick buccal bone and teeth with low accessibility to manage a radicular groove, endodontic perforation, or invasive cervical resorption.
- A small field of view CBCT scan allows the clinician not only a 3D assessment of the area of interest, but also the possibility of segmenting the tooth to be treated and manufacturing a 3D-printed tooth replica. This step substantially reduces extraoral time, particularly in multirooted teeth where replantation into the socket is challenging.
- A preoperative orthodontic movement for 2–3 weeks to mobilize the tooth is recommended in the intentional replantation of teeth with a complicated root structure and high risk of fracture during extraction [91].

9.4.3.2 Surgical Procedure

- One hour before the procedure, the patient should rinse with chlorhexidine gluconate 0.12% and take 600 mg of ibuprofen. A systematic antibiotic prophylaxis (i.e., amoxicillin/clavulanic acid) can lower the failure rate after intentional replantation [42]. The presence of two clinicians throughout the procedure can expedite management and reduce chair time.
- After local anesthesia, the clinician should extract the tooth as carefully as possible to avoid damaging the root surface, as described for the surgical extrusion. A #15 blade or similar can be inserted in parallel to the PDL space and gently tapped with a mallet. Then, using forceps, the clinician luxates the tooth slowly but steadily in the buccolingual direction until it is vertically displaced. Placement of a rubber band around the handles of the forceps may be useful in securing this step. An elevator must not be used during extraction to avoid any unnecessary damage to the root surface and alveolar bone crest. In some situations, a mucoperiosteal flap is an option to access the tooth apical to the crown margin, avoiding damage to the crown. Finally, the patient is instructed to bite on wet sterilized gauze while the tooth is being managed extraorally to maintain the recipient site contamination free.
- Once the tooth is extracted, it is submitted to treatment procedures in accordance with current standards of apical microsurgery [98]. Any granulation tissue attached to the root is

carefully removed and the tooth is placed under an operating microscope to examine for abnormalities such as fractures, cracks, and accessory canals. The coronal two-thirds of the root surface should be gently covered with gauze soaked with copious saline or HBSS.

- While one clinician is performing the extraoral apical microsurgery, a second clinician removes the periapical granulation tissue taking care to avoid damaging the socket wall. If there is 3D printed tooth replica available, it can be used to modify the socket until the fit of the replica fits smoothly and snugly in the recipient socket.
- Then the socket is rinsed with sterile saline solution and the tooth is replanted gently. If the tooth is stable, it is not strictly necessary to splint; the patient need only bite on gauze. However, an unstable tooth must be semi-rigidly splinted (i.e., resin wire splint or interrupted sutures) for 2 weeks. In addition, a surgical dressing can be applied to enhance healing and protect the area from infection and preserve the blood clot. Occlusal adjustment to minimize occlusal force for the first months may be indicated.
- In the event of an endodontic perforation or an invasive cervical resorption, the clinician should proceed in the same way, only by selecting one or another material according to each case.

9.4.4 Conventional Tooth Autotransplantation: Indications and Technique

Conventional autotransplantation is commonly indicated when a tooth is unrestorable and another tooth, such as a third molar or a malpositioned tooth, is not in function, or in cases of orthodontic problems [99]. However, the clinician should only propose this procedure when an appropriate donor tooth can be used without subsequent negative effects [7, 100] and when other treatment options (orthodontics, implants, fixed or removable partial dentures) are unfavorable in some aspects, such as function, time, cost, or long-term prognosis. There has been a renewed interest in this procedure, especially in growing patients, since it promotes functional adaptation and alveolar bone induction, thus re-establishing of a normal alveolar process [7].

Tooth autotransplantation is widely used to replace a single tooth, both in patients who have not completed craniofacial development and in adult patients. Therefore, as explained in the introduction, this therapeutic option is valid in many circumstances, including deep caries, trauma, periodontitis and endodontic problems, as well as in cases with tooth impact or agenesis. However, from all these situations, the clinician must clearly detect two highly different situations: one in which there is an early loss of a permanent tooth in a growing patient and the other in a patient who has already finished growing and has the option under normal conditions to have an implant placement.

Today, dental implants are a very common and predictable procedure for the rehabilitation of partially and completely edentulous arches, even in the area of esthetics, providing better outcomes compared to conventional fixed bridgework, resin-bonded restorations and removable partial dentures [101, 102]. Nonetheless, this treatment approach can frequently present technical complications and biological ones, including peri-implant diseases [103, 104]. These complications may have substantial economic implications [105] for patients and for their perception of the treatment [91]. In addition, implant dentistry is categorically contraindicated in growing patients because the implant cannot follow the maxillofacial development and it would remain in malocclusion during growth [106, 107].

The volume of the alveolar bone decreases significantly following extraction, creating a challenge for the prosthetic rehabilitation, particularly in growing patients [8]. The clinical consequences of these physiological hard and soft tissue changes may affect the outcome of ensuing therapies aimed at restoring lost teeth [108]. When considering implants, the clinician must often first carry out a bone augmentation technique. Therefore, it would be preferable to offer the patient autotransplantation, which main-

Fig. 9.9 Conventional autotransplantation of an immature tooth. (**a**, **b**) Preoperative radiographs of a severely damaged mandibular first molar in a 16-year-old female. (**c**) The first molar was non-restorable. The treatment plan was to transplant the patient's mandibular third molar. (**d**) Checking the suitability of the size and shape of the donor tooth through a limited CBCT. (**e**) The recipient site after the extraction of the first molar. The removal of alveolar septum was necessary. (**f**) The donor tooth (mandibular left third molar). Note that the tooth had an intact follicle. (**g**) After transplantation of the donor tooth. (**h**) Verification of donor tooth's position in the modified recipient site. (**i**) The transplanted tooth positioned 2 mm below the occlusal contact. (**j**) Radiographic aspect at 4 weeks post-surgery. (**k**) Follow-up at 3 months. (**l**) After healing (3 years after the procedure), root canal treatment was not necessary because the immature apex promoted revascularization, healing of the pulp, and continuation of root development. (Courtesy of Dr. Alejandro Núñez and Nacho Cañameras)

tains bone structure and adapts to both growth and developmental changes (Fig. 9.9). This treatment does entail potential complications, including pulp necrosis and infection, replacement resorption and stunted root development, among others. However, Rohof et al. [109] states that this type of complication has an incidence of <5%. It is important, therefore, to assess each patient to consider the immediate and short-term outcome, as well as the long-term outcome and alternative treatment options. A multidisciplinary approach is expected to enhance these outcomes for autotransplantation in children-adolescents and adults patients [110].

9.4.4.1 Diagnosis and Treatment Planning

- Before establishing candidates for a transplantation, a careful clinical (including photographs), radiographic, and periodontal examination should be performed. The clinician should take care to evaluate soft tissues and caries risk presented by the patient. As with any surgical procedure and the procedures mentioned above, medical and dental specialty consultations are required. To ensure a desirable antibiotic level in the patient's bloodstream, both during and after surgery, antibiotics should be prescribed a few hours prior to the procedure.
- Potential donor teeth for extraction must be analyzed to ascertain suitability of shape. At present, a limited CBCT scan of the area in question facilitates the evaluation and allows the clinician to select an ideal donor tooth. In addition, surgical planning software can be used to plan the tooth's ideal final position in the recipient site (Fig. 9.10). It is essential to measure the basic parameters, such as the mesiodistal and buccolingual widths of the alveolar ridge and the placement of the mandibular canal or maxillary sinus. The root development stage in growing patients should be 4 or 5.
- Oral hygiene phase. An oral hygiene, scaling, and root planing must be performed prior to,

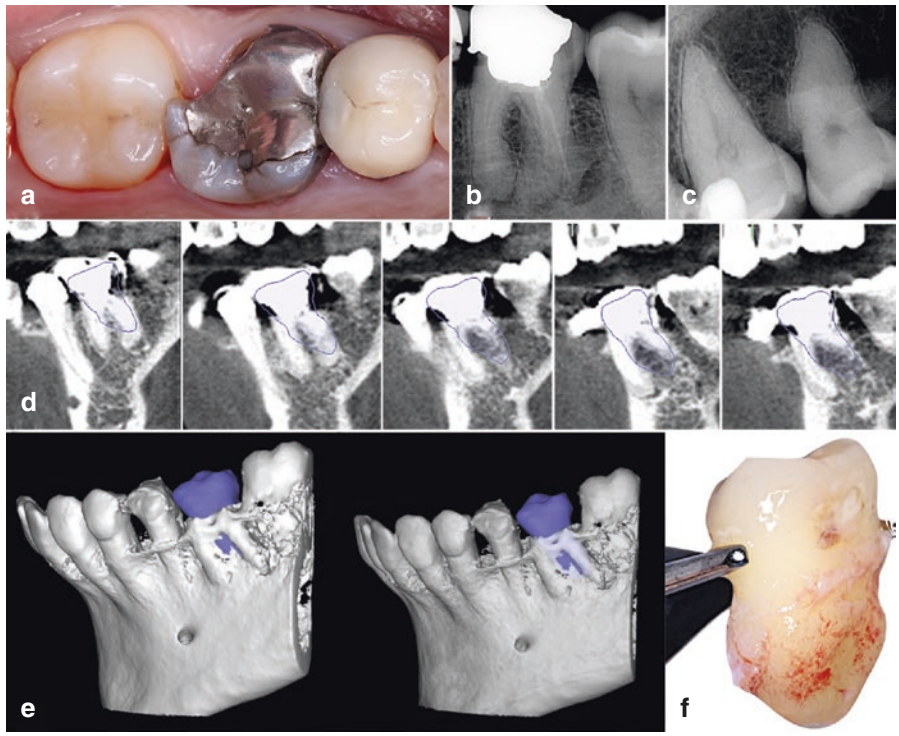

Fig. 9.10 Immediate autotransplantation in a fresh extraction socket. (**a**) Fracture of an amalgam restoration in the mandibular left first molar. (**b**) Preoperative periapical radiograph showing the presence of an accessory distolingual (DL) root (radix entomolaris). (**c**) Radiographic aspect of the donor tooth (maxillary left third molar). (**d**) Autotransplant digital planning. (**e**) Simulation of the 3D position of tooth 28 in the recipient site. (**f**) Tooth 28 after atraumatic extraction. (**g**) Post-extraction alveolar ridge. (**h**) Position of the donor tooth in the recipient site as digitally planned. (**i**, **j**) Semi-rigid splinting with adjacent teeth for 4 weeks. (**k**) Note the minimally invasive access cavity. (**l**, **m**) Follow-up at 1 month post-surgery. (**n**) Preparation completed and ready for adhesive cementation. (**o**) Lithium disilicate overlay. (**p**) Three years and 4 months after the procedure. A normal lamina dura and PDL space can be observed

Fig. 9.10 (continued)

or at the same time as, the surgical procedure. Before considering surgery, the clinician must be sure the patient has good oral hygiene habits. If they are not willing to change their habits, autotransplantation must be ruled out.

- Timing of extraction. Determining the right moment to extract the damaged donor tooth is not always easy, and factors such as pain or the root development of the donor tooth may hasten or delay the transplantation date. If tooth extraction and transplantation can be performed simultaneously, the PDL present in the extraction socket promotes healing while saving the patient undergoing a second surgery. However, in some situations the clinician may prefer or be forced to postpone the transplant: These cases may include acute or chronic infection or sinus tract at the extraction site, pregnant women, patients not available for an earlier surgery, congenitally missing teeth or early tooth loss, or an insufficient mesiodistal space in the recipient site and need for prior orthodontic treatment. Transplantations should be performed within 2 months post extraction, since extensive bone resorption may occur after that period.
- Timing of root canal treatment. In cases of fully developed teeth, it is necessary in most cases to perform an endodontic treatment. This can be done before, during, or 2 weeks post-transplantation, according to the position of the donor tooth and its anatomical complexity. The treatment aim is to prevent inflammatory root resorption.
- Fabrication of surgical models: 3D tooth replicas and guiding templates. 3D radiologic data

can be used to print tooth replicas that help clinicians prepare the recipient site, thus reducing possible injury to the donor tooth during the procedure and the extra oral time (Figs. 9.11 and 9.12).

9.4.4.2 Surgical Procedure (Fig. 9.13)

- Simultaneous anesthesia of the donor tooth and the recipient area. Anesthesia without vasoconstrictor is recommended if the donor tooth has an immature root, which is likely revascularize.
- Extraction of the damaged tooth. An atraumatic extraction should be performed as soon as possible, since both the bone surrounding the tooth and the PDL maintained in the recipient socket are key factors in the case of prognosis.
- Tooth replica try-in. The recipient site should be modified according to the dimensions of

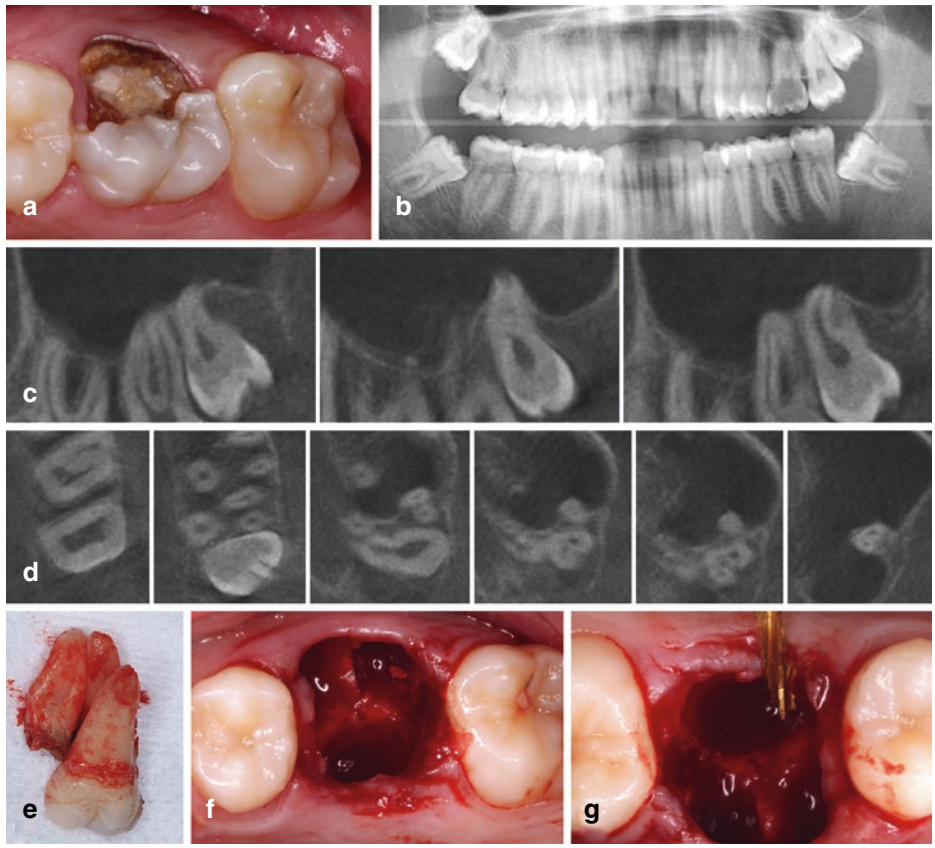

Fig. 9.11 Autotransplantation of a mature third molar. (**a**) An 18-year-old male with a chief complaint of pain around the maxillary left first molar. A deep caries was found and the tooth was planned to be replaced by the maxillary third molar. (**b**) The panoramic view at the first examination. (**c**, **d**) A limited CBCT showing the position of the maxillary left third molar. (**e**) The extracted maxillary first molar. (**f**) The recipient site post-extraction. (**g**) Preparation of the socket for the autotransplantation replacing the maxillary first molar. (**h**) 3D-printed tooth replica and the donor tooth. (**i**) Clinical view immediately after transplantation. Note that the position of the tooth was reversed, leaving the palatal root in the buccal area. (**j**) After autotransplantation of the donor tooth and suturing of the flap. No accessory fixation to the suture was needed since the primary stability was excellent. (**k**) Periapical radiograph after the procedure, and at 3 weeks post-endodontic treatment. (**l**) Occlusal view of the restored molar immediately after luting. (**m**) Radiograph 4 years later showing a normal PDL space

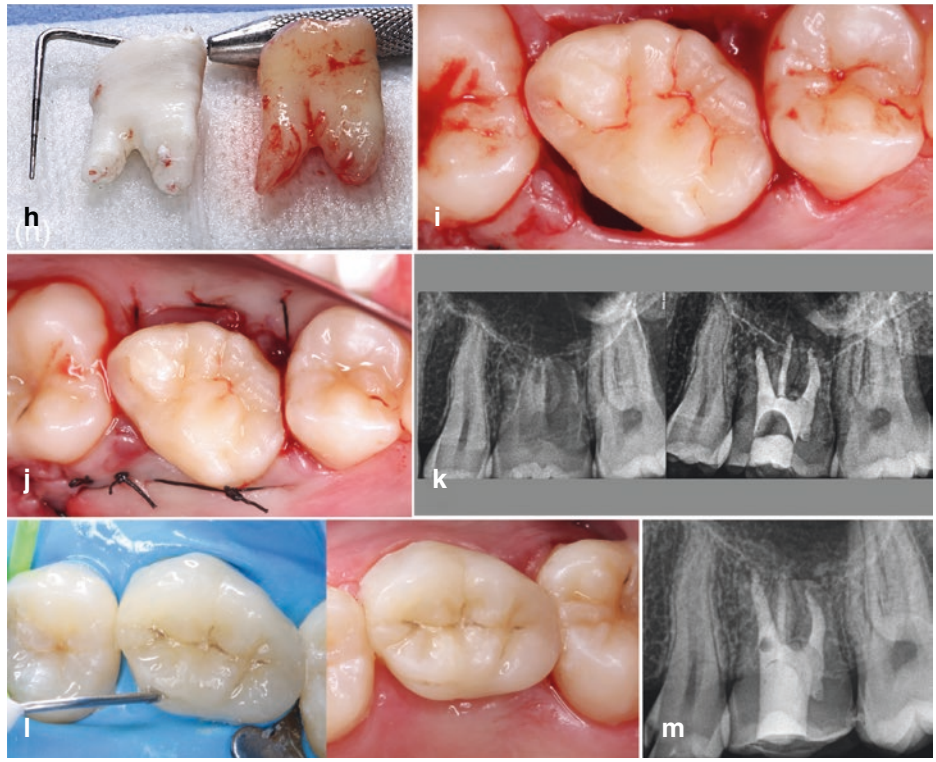

Fig. 9.11 (continued)

the tooth replica, with the aim of placing it in the same position previously digitally planned. Accordingly, the clinician can use 3D-printed guiding templates to ensure a faster and more accurate definitive placement of the tooth replica. Surgical round burs, at low speed but with water cooling, or piezoelectric inserts are recommended for this procedure. After removing any granulation tissue from the extraction socket, the alveolar septum should be removed in most cases of posterior teeth. Once the donor tooth replica fits passively and frictionlessly, the clinician may consider the modification of the alveolus finished.

- Extraction of the donor tooth. To perform this step, the clinician should use only forceps and avoid the use of luxators to preserve as much PDL as possible. Sometimes it is advisable to make a slight intra-crevicular incision before luxation. With a previous digital planning, the clinician will know whether it is necessary to reduce the length of the root or eliminate some of the root canal curvature to facilitate placement in the recipient socket or the future endodontic treatment. The donor tooth must be kept in appropriate storage conditions, such as commercial tooth storage media, Hank's balanced salt solution, or saline solution. The donor tooth is placed in the recipient site at the earliest opportunity, leaving it in a slight infraposition free from occlusal forces. In children, where the donor tooth is partially erupted with an immature root development, it should be placed at its original level of eruption to allow it to erupt, since the root formation continues after revascularization.
- Fresh extraction socket. In most cases of immediate autotransplant, it is not necessary to raise a flap. However, if tooth extraction at the recipient site has been performed within a

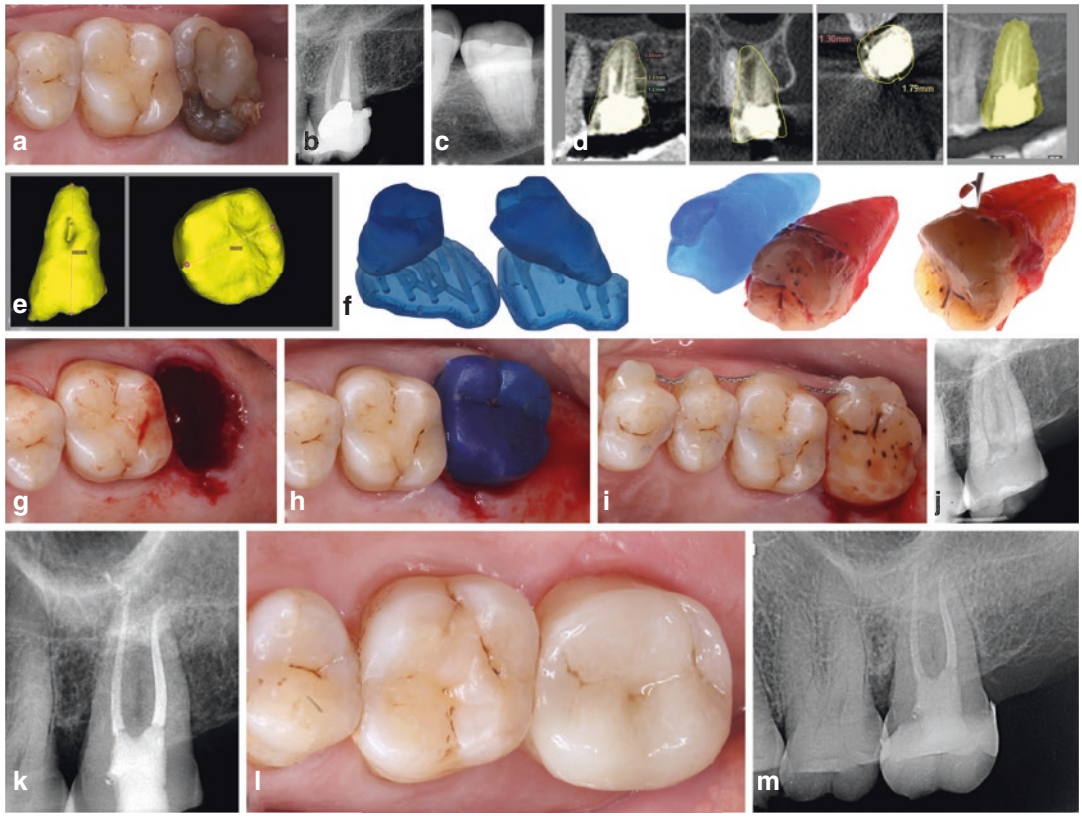

Fig. 9.12 Autotransplantation of a tooth with completed root formation. (**a**) A secondary decay of the maxillary left second molar in a 68-year-old male. The tooth could not be restored. (**b**) Radiograph of the affected tooth. (**c**) Radiograph of the donor tooth. The mandibular left third molar was considered to be the best candidate for transplantation. (**d**) Digital segmentation of the donor tooth. (**e**) Final segmentation of the tooth before printing the replica. (**f**) Comparison between the 3D-printed tooth replica and the donor tooth. (**g**) The recipient site post-extraction. (**h**) The replica tooth used to check the recipient socket. (**i**) The transplanted tooth with fixation in situ. (**j**) Radiograph immediately after transplantation. (**k**) Endodontic treatment performed 2 weeks post-surgery. (**l**) Occlusal view of the restored molar 1 month after luting. (**m**) Two-year radiographic follow-up

few weeks before the surgery, a full-thickness flap must be raised to expose the recipient site.

- Absence of recipient socket. When there is almost no extraction socket (i.e., temporary tooth) or none at all (i.e., teeth lost years ago or congenitally missing teeth), the recipient site must be surgically created or modified. This step can be taken more predictably if it is done using 3D technology. Otherwise, it is recommended to mark different reference points on the alveolar bone surface. Implant drills, surgical round burs, or even trephine burs, always irrigated with saline, can be used to perform the osteotomy in the recipient socket.
- Insufficient recipient socket. There are circumstances in which the clinician cannot ensure a sufficiently large recipient site [7, 8] for a predictable tooth autotransplantation. For buccal or lingual alveolar bone loss, the clinician should carry out guided tissue regeneration or an autogenous bone graft at the recipient site simultaneously with the transplant [29]. The mechanisms of action of these approaches are based primarily on separating the gingival connective tissue from the PDL, maintaining a space for the osteoblastic cells to proliferate.
- Primary stability and occlusal adjustment. The type of fixation and its duration depends on

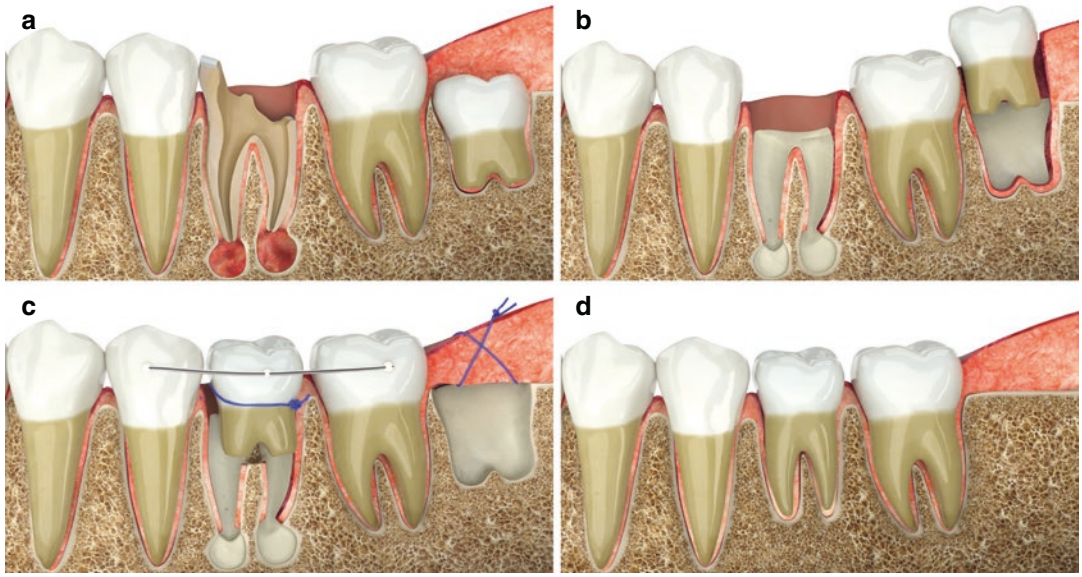

Fig. 9.13 Simulation of an immediate autotransplantation in a fresh extraction socket. (**a**) Situation before procedure. The mandibular first molar is non-restorable and the immature third molar is suitable in size and shape. (**b**) After the extraction of the unrestorable tooth, the recipient site is examined and the donor tooth is atraumatically extracted. (**c**) Transplantation of donor tooth with resin wire splint and interrupted sutures. (**d**) After healing, pulp vitality is maintained and root development is completed

several factors, the primary stability being one of the most important. In the event of a good initial primary stability, the postoperative fixation can be performed by suturing at the occlusal or buccal level. It is important to remember that the occlusal adjustment should be prior to fixation. The suture should be removed between 5 and 7 days. In the case of poor initial stability, a buccal/lingual acid-etch composite and flexible wire splint is indicated for a period of 4–8 weeks. In such case, the occlusal adjustment is advisable once the splint has been placed. During the first 2 or 3 days, a surgical dressing can be placed to protect the transplant against infection.

- Radiographic evaluation. The clinician should take a periapical radiograph before and after splinting to check the position of the donor tooth in the recipient socket. However, if the position of the donor tooth is the same as the tooth replica, this step can be omitted.
- Removal of the fixation. If the primary stability of the donor tooth has been adequate, the fixation can be removed at 4 weeks. However, if it has not been good, the fixation can be extended to 8 weeks. It is important to check that the transplanted tooth must stable before the splint is removed.
- Root canal treatment. Pulp healing is expected with transplanted immature teeth, making endodontic treatment unnecessary in most cases. Therefore, in normal conditions, root development will take place and the tooth will respond positive to electric pulp tests. If the roots do not continue developing and symptoms of pulp pathology (essentially, inflammatory root resorption) appear, the root canal treatment should be started immediately. If a mature donor tooth is accessible, the endodontic treatment can be completed before surgery. This approach can be highly advantageous, since in the hypothetical case of an intraoperative accident (i.e., separated instrument) during the endodontic treatment, the problem can be solved during autotransplant surgery. However, if the donor tooth is impacted or

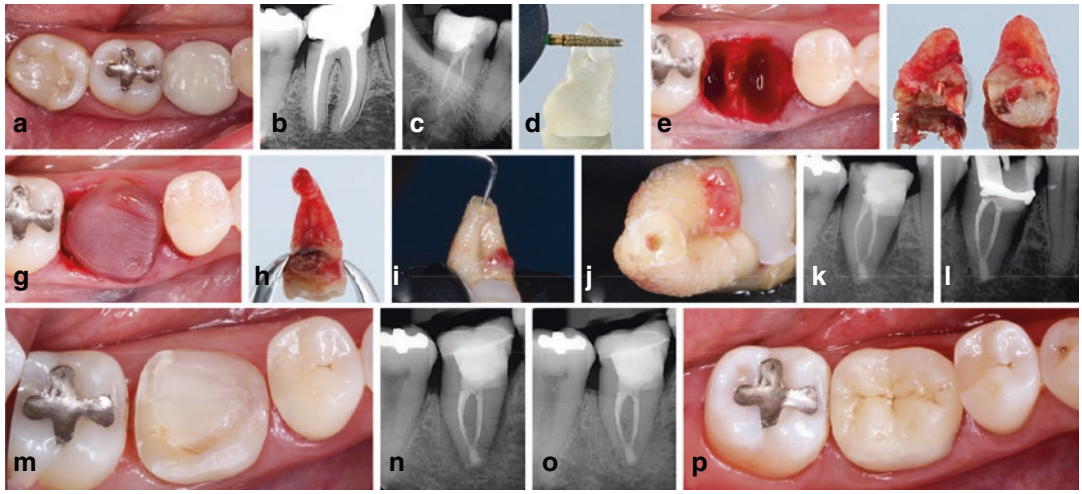

Fig. 9.14 Autotransplantation of a mature tooth combined with extraoral apicoectomy. (**a**) The patient was a 44-year-old female with a chief complaint of pain in teeth 46 and 48. Planning of the transplantation of the mandibular right third molar to the area of the non-restorable mandibular first molar. (**b**) Preoperative periapical radiograph. (**c**) Periapical radiograph of the donor tooth. (**d**) Simulation of the apical microsurgery in the printed replica. (**e**) The recipient site post-extraction. (**f**) Extraction of the non-restorable mandibular first molar. (**g**) Placement of the replica in the recipient site before extraction of the donor tooth. (**h–j**) The apicoectomy performed extraorally on the donor tooth, which was then replanted in the modified extraction socket. (**k**) Periapical radiograph immediately after transplantation. Note the apical retrofilling. (**l**) Nonsurgical retreatment performed 3 weeks post-surgery. (**m**) Cavity before impression. (**n**) Radiographic aspect of the restored molar 2 months after transplantation. (**o**) Three-year radiographic follow-up. (**p**) Three-year clinical follow-up showing excellent esthetic maintenance

erupted in a position that makes endodontic access difficult, root canal treatment should be started 2 weeks post surgery before removing the splint. The clinician may opt to complete the endodontic treatment in the same visit or place an interim dressing of calcium hydroxide in the root canal system. How long the intracanal medication is left inside the root canal depends on the clinician's criteria. Alternatively, root canal treatment can be performed extraorally during transplantation; however, this is not generally recommended, as there is a clear risk of damage to the PDL during the procedure (Fig. 9.14).

- Orthodontic and restorative treatment. After removal of the splint, the transplanted tooth normally sits naturally in its new position, especially when the donor tooth has an immature apex. It is vital to continuously check the position of the tooth to ensure there is no type of occlusal interference. In cases of autotransplantation to the anterior region, minor modifications of the morphology should be performed as soon as possible according to the esthetics and function of the tooth. One of the main advantages of the autotransplant technique is that it allows the clinician to work in a very conservative way and to finish the preparation on the enamel where the adhesion is superior to that of the dentin [111]. If necessary, an external bleaching can be performed when the tooth is still vital, or an internal bleaching in cases of an endodontically treated tooth. There are other scenarios where the clinician has no other choice than to perform an indirect restoration to place the tooth in an adequate occlusion and with the appropriate contact points with the neighboring teeth.
- A very frequent topic that clinicians ask themselves concerns the application of orthodontic forces to these transplanted teeth. In fact, there

are no papers on the effectiveness or success of orthodontic forces of autotransplanted teeth [109]. Despite the lack of randomized controlled trials (RCTs), the influence of orthodontic movements on transplanted teeth seems to have minimal or little relevance [112–114]. However, as any traumatized tooth with a PDL injury, it is generally accepted that orthodontic forces should not be applied to a transplanted tooth for at least 6 months postsurgery [115, 116]. In cases of autotransplantation of immature teeth, orthodontic treatment should ideally be started after complete PDL healing, but preferably before the bone alveolar has fully formed. Therefore, the onset time can vary from 8 weeks to 3–9 months posttransplantation [117, 118].

- Periodical follow-up. Once transplanted teeth have healed, they are prone to the same risks as any natural tooth regarding caries and periodontal disease. Thus, these teeth require a periodic follow-up, just as the other teeth in the mouth. The patient's proactiveness is crucial to ensure positive long-term results.

9.5 Concluding Remarks

In the last 30 years, a better understanding of wound healing processes following transplantation, replantation, and surgical extrusion has significantly increased the success of these procedures. However, there is no general consensus as to the criteria used, making success rates vary within studies. It is evident that regardless of the study assessed, the clinician can expect the same level of success from these procedures as can be expected from dental implants. Thus, in specific and properly selected cases, autotransplantation and replantation are highly effective procedures. In this aspect, the clinician must know the fundamental healing mechanisms of the PDL, the alveolar bone, and the gingival tissue and the pulp.

With careful case selection based on indications, autotransplantation can prove to be a sufficiently predictable treatment, with success rates of 70–95% over 5 years. Naturally, the individual clinician's skill and ability in the final results is also a determining factor. An autotransplantation can be made even more predictable by combining digital planning, experience, skill, and good judgment in case selection.

However, surgical extrusion, intentional replantation, and autotransplantation have low level of scientifically based evidence due to a lack of randomized controlled trials (RCTs). Adequately designed prospective studies with an agreed definition of success are indispensable for a more comprehensive insight into the success rates of these treatments. Detection of root resorption following replantation may take up to 3 years, implying that more investigation is necessary with a sufficient sample size that includes long-term follow-ups. Multicenter collaborative efforts to study this could yield the sample size required to draw meaningful conclusions.

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