Introduction

Permanent tooth avulsion is seen in 0.5–3% of all dental traumatic injuries.1 Successful management of an avulsed permanent tooth is largely dependent upon minimising extra-oral root desiccation and the application of an appropriate splint.2 The sequelae3 of the replantation of avulsed teeth include: tooth loss, pulp necrosis, pulp canal obliteration, ankylosis,4 root resorption, bone loss and periodontal defects.5

Ankylosis is the result of a competitive healing and repair process of the damaged periodontal ligament and cementum in which there is progressive replacement by osseous tissue so that the root surface and alveolar bone fuse. Replacement resorption often follows ankylosis whereby the surrounding bone replaces the root dentine.6

When ankylosis of a maxillary incisor occurs in a pre-adolescent, the affected tooth fails to erupt and...

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Introduction: Clinical practice encounters the unfortunate consequences of dental trauma. The avulsion of permanent teeth is seen in 0.5–3% of all dental traumatic injuries, and when re-implanted, a tooth can undergo ankylosis in the form of replacement resorption. When ankylosis of a maxillary incisor occurs in a pre-adolescent, the affected tooth gradually becomes infra-occluded with time, which results in severe local dentoalveolar disturbances in normal growth and development, along with aesthetic concerns that challenge orthodontic management. To achieve an ideal dental outcome, an interdisciplinary approach is often required.

Aim: To detail a case report of an infra-occluded ankylosed central incisor successfully treated with a single tooth osteotomy and distraction osteogenesis in conjunction with mechanotherapy to correct the osseous and gingival margins.

Method: This combined orthodontic/surgical case report was completed in stages by (1) pre-surgical orthodontics to diverge the roots of the adjacent teeth from the surgical site, (2) a single tooth osteotomy followed by distraction osteogenesis, (3) post-surgery orthodontics, and (4) retention. Consent and complete records were obtained, including pre-treatment photographs, radiographs and cephalometric superimpositions over an eight-year period from initial presentation until retention.

Results: Distraction osteogenesis in combination with orthodontics successfully managed the dentoalveolar and soft tissue defect. If tooth replacement is eventually needed, donor site morbidity associated with conventional bone and soft tissue grafting procedures may be eliminated.

Conclusion: This combined interdisciplinary treatment is an effective alternative to bony and soft tissue augmentation procedures that may not be as predictable in restoring vertical and horizontal osseous and soft tissue defects resulting from severe infra-occlusion of anterior teeth.

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migrate with the remaining alveolar process as the dentoalveolar compensatory mechanism is disrupted during normal vertical growth of the maxilla. Vertical growth is the last dimension to slow during the post-pubertal period, therefore ankylosed teeth appear gradually more infra-occluded with time and can often become an aesthetic concern. Depending on the magnitude of the remaining vertical maxillary dentoalveolar growth, adjacent teeth can also be affected, leading to severe local dentoalveolar disturbances in normal growth and development. To achieve an ideal dental outcome, an interdisciplinary approach is required and many reconstructive procedures may be needed to correct these severe local disturbances. Alveolar distraction osteogenesis can be used in conjunction with orthodontics to correct both the osseous and gingival margins. If implant restoration is eventually needed, it may eliminate donor site morbidity after conventional bone and soft tissue grafting procedures.

**Diagnosis and aetiology**

A 12-year-8-month old pre-pubertal male (JCM) was referred to a private orthodontic practice in April 2008 after a history of multiple traumatic injuries to his anterior teeth. His trauma history included avulsion of the 11 at approximately age 10 years 7 months, and endodontic treatment of teeth 21 and 12. A periapical radiograph of the 11 showed signs of extensive external inflammatory root resorption (Figure 1).

The patient demonstrated a flat facial profile with a dolichofacial and mild Class III skeletal pattern due to a long lower facial third. The maxillary incisors were proclined, which increased the overjet (5 mm), but the overbite was minimal (1 mm), all of which supported a Class II division 1 incisor relationship. The 11 showed signs of infra-occlusion related to the ankylosis. The patient had a high lip line (Figure 2a) and a fraternal twin (sister had a severe skeletal Class III relationship that required orthognathic surgery). Given the strong family history of Class III growth and signs of ankylosis from previous trauma, the decision was made to monitor his developing skeletal and dental pattern for management at a later date. The patient was reviewed and returned three years later (age 15 years 10 months) with exacerbation of his Class III malocclusion to an anterior open bite (3 mm) but a stable overjet of 5 mm (Figure 3). The dentofacial change was noted to be a combination of ankylosis and continued vertical growth. The buccal segments were in a Class I relationship and mild crowding and dental rotations were present in both arches. A single tooth cross-bite involved the 17. A panoramic radiograph showed that all teeth were present and the 11 and 21 were in infra-occlusion. The patient was reviewed for the following three years until cephalometric superimpositions indicated that vertical growth was slowing (Figure 2b) and the maxillary anterior teeth had not altered position during growth, despite significant changes in the surrounding dentofacial region. There was concern that unpredictable Class III growth may have affected the treatment options but, on review, all anterior teeth progressively became more infra-occluded and the anterior open bite worsened (Figure 3). The gingival margin of the 11 was now about 6 mm apically positioned compared with the 21. The lateral cephalogram measurements are shown in Table I.

![Figure 1. Periapical radiographs of patient’s maxillary anterior teeth (a) 2006 initial avulsion; (b) 2006 after splint removed with the 11 showing signs of external replacement resorption in the apical 1/3; (c) 2006 Ca(OH)₂ dressings in place; (d) 2006 obturation of 12, 11 and 21.](image-url)
Figure 2a. Initial orthodontic consultation (2008) JCM 12 years old.

Figure 2b. Cephalometric superimpositions (2008 and 2014).
Table I. Cephalometric measurements.

| Facial type:          | Age 9 | SD   | F=15, M=19 | Date: 2008 | Date: 2016 |
|-----------------------|-------|------|------------|------------|------------|
| Facial axis           | BaN-CC,Gn | 90  | 3          | 89         | 90         |
| Mandibular plane      | PO-GoM | 26  | 5          | 23         | 29         |
| Mandibular plane      | GoGn-SN | 32  |            | 36         | 35         |
| Cranial base angle    | Ba-SN  | 131 | 5          | 133        | 131        |
| UAFH:LAFH             | N-ANS-M | 45.55 | 42.58     | 41.59      |
| Maxilla:              |       |     |            |            |            |
| Mx to cran base       | SNA   | 82  | 3          | 76         | 78         |
| Mx to cran base       | ANP     | 0mm | 3mm 1mm 1mm | -3mm -2mm  |
| Palatal plane         | SN-ANS,PNS | 10  | 4          | 7          | 7          |
| Mandible:             |       |     |            |            |            |
| Md to cran base       | SNB   | 80  | 3          | 75         | 78         |
| Md to cran base       | Po-NPerp | -6mm | 4mm F:0mm M:2mm | -2.5mm -2.5mm |
| Maxilla-mandible:     |       |     |            |            |            |
| SNA-SNB difference    | ANB   | 2   | 1.5        | 1          | 0          |
| Wits analysis         | AO-BO | 2   |            | F:0mm M:-1mm | -2mm 0mm  |
| Maxillary teeth:      |       |     |            |            |            |
| Inc position          | 11,21 (Lab)-NA | 4mm |           | 10mm 7mm  |
| Inc inclination       | 11,21-NA | 22  |            | 38 27     |
| Inc position          | 11,21 (edge)-APo | 3.5mm | 2mm  | 9mm 5mm  |
| Inc inclination       | 11,21-APo | 28  | 4          | 36 23     |
| Inc to pal plane      | 11,21-ANS,PNS | 109 | 5          | 122 112   |
| Mandibular teeth:     |       |     |            |            |            |
| Inc position          | 31,41 (Lab)-NB | 4mm |           | 3mm 4mm  |
| Inc inclination       | 31,41-NB | 25  |            | 17 15     |
| Inc position          | 31,41 (edge)-APo | 1mm | 2mm  | 3mm 0mm  |
| Inc inclination       | 31,41-APo | 22  | 4          | 18 19     |
| Inc extrusion         | 31,41-OccPlane | 1mm | 2mm  | 0mm 0mm  |
| Inc to Mn plane       | 31,41-MnPlane | 90  |            | 85 79     |
| Maxillary-mandibular teeth: |       |     |            |            |            |
| Interincisal angle    | 11,21-31,41 | 130 | 6          | 124 138   |
| Soft tissues:         |       |     |            |            |            |
| Lip to E plane        | -2mm  | 2mm | -4mm       | -1mm -4mm |

Treatment objectives
The following treatment objectives were considered for the patient: (1) to normalise and maintain the buccal occlusion, (2) to obtain a normal incisor relationship, (3) to improve smile aesthetics, and (4) to correct the osseous and gingival margins in the ankylosed region (maxillary right central incisor).

Treatment alternatives
The situation is one that is unfortunately and occasionally faced by dental practitioners. Despite management of the traumatised teeth at the time, the final outcome was less than ideal. The major complicating problem was how to best manage the ankylosed tooth and the lack of vertical development.
Figure 3. Pre-treatment records (2014).

Figure 4. Mid-treatment records (2015).
of the surrounding alveolar process. The ankylosed 11 had been undergoing replacement resorption and internal resorption for some time and therefore had a compromised long-term prognosis.

In deference to his age at the time of initial presentation and the expected continued vertical alveolar growth, the following corrective treatment options were considered:

1. Clinical experience dictates that extraction of an ankylosed 11 may result in the loss of supporting bone, particularly the thin buccal plate. Early surgical removal of the ankylosed tooth would result in less restriction of the vertical growth and eruption of adjacent teeth; however, this would likely leave a significant bony defect that would require management at the cessation of growth. The quality and quantity of bone would likely be unsuitable for eventual implant replacement and the patient would benefit from the eventual augmentation of the osseous and soft tissue defect. Prior to the cessation of growth, the patient would need to wear a prosthesis for the missing tooth during his formative years.

2. The ankylosed infrapositioned 11 could be decoronated, leaving the root to be replaced by bone. An existing root filling should be removed before the root is covered with a mucoperiosteal flap, as the endodontic filling would be an obstacle to complete bone healing. The coronal part of the root surface would be reduced to 2 mm below the marginal bone. The empty root canal should be allowed to fill with blood and ideally the procedure should be done before the adolescent growth spurt. When ankylosis is diagnosed in the early mixed dentition (age seven to 10 years) the tooth should be decoronated within two years, but unfortunately this ideal treatment window was missed. In this case, the patient had reached the onset of his pubertal growth spurt, and a rapid increase in infraposition was to be expected. This patient already had infra-occlusion and so further soft tissue and bony reconstruction would be later required to achieve an ideal result.

3. Leave the ankylosed tooth in situ until its eventual loss due to replacement resorption. Given the amount of growth remaining, this would result in unpredictable infra-occlusion and tipping of the adjacent teeth, restriction of dentoalveolar vertical growth and distortion of the alveolar ridge, and worsening of the anterior open bite. Considering the high lip line, a composite crown build-up of the infra-occluded 11 was considered but would have appeared unaesthetically long. The osseous deficiency would commit the patient to bone and soft tissue reconstructive procedures before replacement with a single tooth implant. A conventional bridge could be used; however, given the patient’s high lip line and display of the area, it would be difficult to prosthodontically reconstruct the bony and soft tissue deficit even with the aid of pink porcelain or acrylic.

4. Extraction of the 11 was a consideration and space closure through orthodontic tooth movement whereby the 12 could have been centralised with a crown or veneer, the 13 lateralised with some aesthetic recontouring, and the 14 cuspidised to provide canine guidance. However, the patient had a reasonable Class I dental relationship without crowding and an underlying skeletal Class III relationship, which is more difficult to camouflage with missing maxillary units. If the Class III relationship worsened as predicted, it may even commit the patient to a combined orthodontic and Class III orthognathic surgical correction.

5. Surgical luxation to attempt to break the fusion between the cementum and bone was not acceptable because of the severe root resorption. The potential for fracture through the cemento-enamel junction of the ankylosed tooth during luxation would have been a likely consequence, and the tooth might have well re-ankylosed during repair and the application of an orthodontic force.

6. A single tooth osteotomy and distraction osteogenesis to allow rapid movement of the tooth was considered. This was the preferred option to provide potential long-lasting benefits and avoid the need for significant augmentation procedures. There was a real risk that a distraction force applied through the crown of the ankylosed tooth during osteogenesis might have resulted in a fractured crown due to the severe resorption instead of increasing alveolar height. This option might reduce the need for bone and soft tissue reconstructive procedures.
before replacement with a single implant crown. In addition, a single tooth osteotomy would reduce the relative infra-occlusion and open bite, improve the dental aesthetics and gingival height symmetry in the medium term, and provide the patient with the option of keeping his natural tooth in the short to medium term.

Treatment progress

The treatment options were discussed at length with the patient and parents. It was decided to distract the ankylosed tooth, with its surrounding bone and soft tissues, and consent was obtained. Orthodontic treatment of the upper arch commenced with the aim of diverging the roots of 12 and 21 away from the 11 to gain inter-radicular space for the osteotomy (Figure 4). This was confirmed radiographically. Fixed appliances were removed and a custom-made bonded acrylic splint/distractor device (Figure 5a) (Archform Orthodontics, VIC, Australia), similar to that described by Kofod et al. (2005) with an expansion screw of 7.5 mm, inserted immediately prior to surgery (Figure 5b).

Surgery was performed at a local private hospital under laryngeal mask anaesthesia. The anterior maxilla was infiltrated with 10 mg of 0.5% marcaine with adrenaline. A full thickness vestibular incision was made and a mucoperiosteal flap was reflected anteriorly and posteriorly to expose the anterior nasal spine and also the coronal portion of the ankylosed 11 (Figure 5c). The outline of the osteotomy was performed with a 201 burr and completed with a spatula and curved osteotomes. The osteotomised segment was distracted with use of the intraoral distractor to ensure that there was no impingement of the tooth as it was moved coronally (Figure 5d). The distracted segment was then repositioned back to its starting point and the wound was closed in a routine fashion with 4.0 chromic gut sutures. The patient was discharged with pain relief and antibiotics. All third molars were removed at the time of the procedure, which passed without complications.

After a latency period of four days to allow callus formation, the distraction of the dentoalveolar block was started. Each turn of the distractor represented 0.2 mm and 32 turns were completed. The patient activated the mechanism four times daily for five days (20 turns at 0.8 mm per day, or 4 mm), then twice daily for five days (12 turns at 0.4 mm/day, or 2.4 mm). The distraction period extended over 11 days and the position of 11 was overcorrected by 1 mm. The distraction protocol was based on that proposed by Kofod et al. The distraction appliance was removed at four weeks and stabilisation of the segment was performed by the placement of orthodontic fixed appliances on the upper arch. The direction of the distraction and osteotomy cuts moved the segment...
in a slightly palatal direction and the tooth was in an edge to edge anterior relationship (Figure 6c). A subsequent minor surgical procedure was performed to manually move the segment labially (Figures 5e and 5f). Fixed appliances were placed in the lower arch and finishing orthodontics was performed. Inter-arch elastics were used to help maintain the vertical position of the 11. Fixed appliance treatment was completed approximately six months after the surgery. A fixed palatal retainer was placed in both arches to help maintain the positions of the anterior teeth. The patient has many further options available for prosthodontic work to improve aesthetics.

**Discussion**

Replantation after traumatic avulsion can result in local damage to the periodontal ligament, and ankylosis is a common sequela. Replacement resorption may follow due to injury to the innermost layer of the periodontal ligament and the cementum. Ankylosis forms from an area of healing adjacent to the alveolar bone. Clinical diagnosis of ankylosis is made by a change in the sound of percussive tone and a decrease in the normal physiological movement within the periodontal complex. Ankylosis can also be visible on a periapical radiograph as an interruption in the lamina...
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...dura/periodontal ligament; however, it is not always apparent as the area is often small, localised on the root and not visible on a two-dimensional radiograph. A lack of movement in response to orthodontic force or a failure of movement with normal skeletal growth and dentoalveolar compensatory eruption can confirm the clinical diagnosis of ankylosis. Ideally, a tooth should be decoronated at the first sign of ankylosis to allow bone to replace the ankylosed root. Unfortunately, in clinical practice it is not always possible to have an ideal set of circumstances and infra-occlusion, in the current case, had been progressing for some time.

This case report describes a method for correcting an ankylosed incisor and the surrounding alveolar ridge defect by distraction osteogenesis in combination with fixed appliances. Distraction osteogenesis provided an optimal treatment modality to correct a severe vertical alveolar defect because of its unique ability to simultaneously manage the adjacent soft tissue and bone volume in a horizontal and vertical direction. The patient was aware that the tooth in question had a poor prognosis and that, if the procedure was successful in moving the dental, osseous and soft tissues, it would allow for more prosthetic options upon the eventual failure of the tooth.

Distraction osteogenesis has long been a technique for correcting skeletal deformities, and was first described by Ilizarov in the field of orthopaedics in 1971 and introduced in the maxillofacial region by MacCarthy et al. (1992). The distraction process involves a controlled displacement of a surgical fracture, and a segment of mature bone can be moved vertically into the alveolar ridge defect without the need for bone grafting. New bone is regenerated in the distracted osteotomy site, and the gradual distraction allows reorganisation of associated soft tissues. Distraction osteogenesis consists of three sequential periods: latency, distraction, and consolidation. Latency is the period from bone division to the onset of traction and is the time allowed for callus formation. During the distraction period, gradual traction is applied and new bone is formed. The consolidation period allows maturation of the new bone after the traction force is discontinued. Favourable clinical results of distraction...
treatments have been reported for dentulous or edentulous alveolar processes.\textsuperscript{19,20} Vertical or combined vertical and horizontal alveolar defects often pose difficulties in achieving ideal aesthetic prosthetic replacement in a patient with a high lip line. Planned movements in distraction osteogenesis can be problematic as careful correction of tooth position in three dimensions is difficult, and the nature of the device used only allows osseous movement along the screw vector. The alveolar ridge defect requires a significant acute stretching of the soft tissue, which is often the limiting factor and a potential for relapse.\textsuperscript{21} The same problem exists when considering replacement of ankylosed teeth by dental implants when the vertical and horizontal alveolar defect necessitates bony reconstruction and augmentation before implant placement. The surgical technique to augment horizontal defects is a well-documented procedure with high predictability, whereas the augmentation of vertical alveolar ridge defects by guided bone regeneration is a technically demanding treatment option with unpredictable osseous and soft tissue outcomes. However, alveolar distraction osteogenesis has been shown to be efficient and reliable in reconstructing vertical alveolar defects.\textsuperscript{22-26}

Continuing and remaining alveolar growth is a major concern, because of the likelihood of infra-occlusion and a vertical deficiency. Vertical growth is the last to cease in the craniofacial region,\textsuperscript{10} and the patient was kept under review until the majority of vertical growth was complete. At that time, it was considered that any vertical growth would be clinically insignificant and would not negatively affect the treatment effects (Figure 2b). Once vertical growth had ceased, the risk of relapse is expected to be minimal, and the patient can be completely managed both orthodontically and surgically. A patient with remaining growth potential can be either overcorrected or subjected to the procedure again at a later date. This patient had a high lip line and the area in question would present a significant future aesthetic challenge for the restorative dentist. Overcorrection was performed to compensate for potential infra-occlusion if there was unpredictable future vertical growth of the dentoalveolus (Figure 9). The surgeon and the orthodontist are advised to provide growing patients the best possible information about timing of the distraction osteogenesis with respect to their remaining growth potential. Any minor aesthetic concerns could be corrected prosthetically by lengthening the incisal edge of the final restorative work, or through periodontal gingival grafting/recontouring of the final soft tissue levels (Figure 8).

When planning the procedure and the fabrication of the distraction device, several aspects require consideration. Firstly, the provision for adequate mesio-distal space for the osteotomies at the surgical site required orthodontic tooth movement of the adjacent teeth from the area to avoid periodontal ligament damage (Figure 4). Both the surgeon and the orthodontist must be aware of the special three-dimensional problems of moving a dento-osseous segment. Distraction osteogenesis only moves the dento-osseous segment in the direction allowed by the planned osteotomies (usually in a trapezoidal shape in both horizontal and labio-lingual dimensions) and the appliance (direction of the vector of the distractor thread). In this case, the dento-osseous segment needed to be rotated and torqued. The movement must be clinically and surgically realistic and the bony cuts planned to allow movement in the three dimensions. Unfortunately, the device used was only able to move the tooth in a single vertical direction, and did not allow torque or labial movement, which resulted in an edge to edge anterior relationship. This could not be corrected by prosthetic camouflage and therefore necessitated a second surgical procedure to position the tooth labially to a more acceptable position (Figure 5). The final position of the distracted osseous segment and tooth was with the dental midline off-centre to the right by approximately 1 mm. Orthodontic finishing and space closure occurred, resulting in a mild Class II buccal segment relationship on the left. A non-consonant smile line also resulted (Figure 8).

Cephalometric superimpositions indicated that the tooth had been distracted by 6 mm vertically and palatally by 3 mm (Figures 10 and 11). The lower incisors had extruded and retroclined by 1 mm, which was a side-effect of vertical inter-arch elastic use in the finishing stages to help camouflage the mild Class III dental relationships (Figure 11). Restorative treatment may now take place to improve the aesthetic concerns of the patient. When ultimate failure of 11 occurs, the patient has many restorative options including implant replacement, which may not require any osseous or soft tissue procedures. It might be argued that waiting a long time before growth to cease before
commencing treatment may unknowingly cause psychosocial effects associated with a negative dental appearance. Early extraction and temporary prosthetic replacement also carries its own problems in a young patient.

Conclusions
This case report illustrates the interdisciplinary management involving orthodontics and surgery in the treatment of a growing patient with an infra-occluded, ankylosed, anterior tooth. A satisfactory outcome was achieved using distraction osteogenesis to manage the dentoalveolar and soft tissue defect. This combined interdisciplinary treatment had the advantage of levelling the incisal edge and the gingival margin of the ankylosed tooth to the correct position, and subsequently avoided augmentation procedures that may not be as predictable in restoring vertical and horizontal osseous and soft tissue defects.

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