Anchorage

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Introduction

Many factors can make a treatment difficult. An incorrect treatment plan, poor patient motivation, and markedly malaligned teeth can all cause difficulties and these topics are all discussed in relevant chapters of this book. A frequent difficulty is that of obtaining sufficient anchorage - particularly if a “six keys” occlusion is our goal. Andrews’ textbook documents the causes of failure to achieve a six keys’ occlusion and many of the cases would require additional posterior anchorage to be finished to his suggested goals. The anchorage available within one arch is related to space in that arch and that space is frequently obtained by extractions. Anchorage other than from this source has, with most biomechanics, involved enlisting the co-operation of the patient. This chapter chiefly addresses the means by which the need for this co-operation can be minimised and how the patients’ efforts can be put to best use. Reinforcing anterior anchorage - as in Class 3 or hypodontia cases - is discussed in the chapter on Managing Class 3 Malocclusions.

Sources of anchorage

Anchorage can be obtained from intra-oral and extra-oral sources and we should not forget the possibility of favourable growth and the question of our ability to enhance it. This latter aspect is discussed in the chapter on Functional Appliances. It is sensible to firstly summarise the possibilities for maximising intra-oral anchorage.

Sources of intra-oral anchorage

- **root surface area**
  As discussed below, this is a fundamental source of anchorage

- ? bony cortex
  In spite of previously widespread hope that this may prove source of anchorage, there seems little evidence that this is indeed the case. It is clearly not difficult to move teeth labially right through the cortex. Rebellato et al (1997) found that lingual arches did not prevent mesial migration of molars even when no intra-arch traction was applied. A study by Ellen, Schneider and Sellke (1998) found no enhancement of vertical or horizontal anchorage when using utility arches to set up cortical anchorage. These papers would also suggest that palatal arches would not be expected to add to posterior anchorage. A paper by Radkowski (2007) in fact reported slightly more anchorage loss when trans-palatal arches were used. Zablocki (2008) in a study of matched cases again found no vertical or mesio-distal anchorage effects from a palatal arch.

  **Key fact:** There is no evidence that palatal arches reinforce mesio-distal anchorage.

- **mucosa and underlying bone**
  This is the source of anchorage which is sought with Nance buttons, removable appliances and lingual flanges on functional appliances. It is hard to measure, but appliances which cover a larger area of mucosa would be expected to provide additional anchorage. These appliances can cause trauma to the palate as anchorage is lost. We do not use Nance buttons.

- **occlusal interferences**
  Some extraction patterns e.g. upper first and lower second premolars can create useful interlocking of the dentition and increase the root surface area resisting a loss of upper arch posterior anchorage. Conversely upper canines stuck mesial to lower canines can lose upper arch anchorage as can attempted reduction of an overjet in the presence of a complete overbite. A recent paper by Dudic (2013) measured the rate of premolar movement using a contralateral premolar as the control. As usual, a wide range of movement was found. Several potential factors influencing the rate – such as age and sex -were examined. Youth was indeed found to favour increased tooth movement, but the presence of an occlusal interference from the opposite arch was also a substantial influence.
This is convincing evidence that we must ensure the minimum of occlusal contact with teeth which we intend to move and that conversely, occlusal interlocking can be anticipated as a source of anchorage – wanted or counterproductive.

Clinical Tip: Occlusal interferences are often overlooked as a source of anchorage loss and we should disclude teeth we wish to move wherever practicable.

- implants and temporary anchorage devices (TADs)
  These are a powerful source of intra-oral anchorage and are discussed in the chapter on Temporary Anchorage Devices in Orthodontics.

The differential force theory
This theory states that within limits, the rate of tooth movement is related to the applied force per unit root surface area. i.e. within a certain range of force, a given force will result in less tooth movement if spread over a larger number of teeth. This concept is fundamental to orthodontic anchorage and is at the heart of all orthodontic treatment and treatment planning. It does however remain a theory which is far from fully proven, although there seems strong indirect evidence that the differential force theory has substance.

Maximising root surface area
For example, the study by Saelens and De Smit (1998) showed a greater mesial movement of molars and a lesser amount of anterior crowding resolved when second premolars rather than first premolars were extracted. Maximising root area in the anchorage unit is therefore sensible when anchorage is at a premium. In addition to choosing more anterior extractions, root surface area in the anchorage unit can be increased relative to the root area of the teeth we wish to move by:

- including second molars
- separate retraction of canines
- correcting centrelines one tooth at a time
- semi-transverse forces eg: pushing rather than pulling canines distally

Practical considerations may lessen the applicability and effectiveness of any of these in a given situation, but they are all potentially useful sources of anchorage.

Evidence for the differential force theory
A further complication is that the data on the relationship between force applied and tooth movement achieved has yet to confirm a clear picture of the relationship between the two. A study by Pilon et al (1996) in beagle dogs showed that the rate of tooth movement and the amount of anchorage loss were not significantly different for forces ranging from 50 g to 200 g. Some dogs had teeth that moved quickly and others moved slowly regardless of the force level. The rate of movement was highly correlated between the left and right sides for any dog and this suggests that inherent metabolic factors may be much more important than force level in determining the rate of movement of teeth - including those in an anchorage unit. Anecdotal clinical observation certainly suggests that human patients show similar variation in orthodontic response to applied force.

It might be concluded from a casual reading of this important paper that the differential force theory was in serious doubt in its entirety. However, tooth movement was still related to the root surface area - anchorage units moved less than the individual premolar teeth. The ratio of movement was not the same as the ratio between the root surface areas. The anchorage unit averaged ten times the root surface area of the premolar and yet moved an average of 25% of the premolar movement, not 10%. Root surface area definitely seems to matter i.e. there is some scientific support for the differential force theory, but we don’t yet know the exact extent of its influence and there are clearly other factors which are important.

A more recent paper by DeForest et al (2014) in a further study on tooth movement by that group, explored the effect of different force levels on the rate and type of canine movement using a sectional archwire. Applied forces
were either 306 cN or 16 cN for 3 months. The average canine movement was 5.3 and 2.4 mm respectively. Increasing the force nineteenfold approximately doubled the rate of movement with once again a large variation in movement for the same force. Movement was linear with no lag phases. The higher force also caused significantly greater flaring and distopalatal rotation on the 0.016” x 0.022” stainless steel wire.

A meta review by Ren et al (2003) referred to over 400 studies of relevance and it is clear that the details of the relationship between force applied and tooth movement remain insufficiently understood or documented.

Later work by this same team Von Bohl et al (2004), confirmed the poor correlation between force level and tooth movement or the degree of histological hyalinisation. This paper used an implant to cleverly compare different force level per unit root surface area with no complicating anchorage loss. The paper also has an excellent summary bibliography of force and pressure levels in previous studies. Numbers are necessarily small in studies using beagle dogs, but figure 4 in that paper does show data which suggest that for that dog, lower force favoured premolar movement whereas higher force favoured molar movement. This finding is supported by a more recent study by Yee et al (2009) who measured canine retraction and anchorage loss with a light (50 gm) and heavy (300 gm) forces over a 12 week period. The 300 gm force produced significantly more movement of both the canine and the anchorage unit and the percentage of anchorage loss was significantly higher (62%) with the heavy force than with the light force (55%). The size of that difference is certainly not dramatic but does support the differential force theory.

Root surface area – summary
- force level is only part of the explanation of rate of tooth movement
- spreading the force over larger root area does reduce the rate of movement (and thus preserve anchorage)

Retracting six teeth at once

In extraction cases where anchorage is not at a premium, clinicians traditionally retract the canines until there is sufficient space to align the incisors and then the complete labial segment of six teeth is retracted as a unit as opposed to fully retracting the canines to a class 1 relationship and then retracting the incisors. On theoretical grounds, retracting all six teeth simultaneously would be expected to increase anchorage demands and although this increase is not necessarily apparent clinically, there must be good reasons for choosing this theoretically more anchorage demanding plan. These reasons fall into two categories, namely, simplicity and control of canine rotation.

Simplicity and control: Sliding all six teeth as a unit along a stiff wire involves very simple archwire fabrication and activation when compared with three sectional archwires and closing loops. Also, the chances of trauma to the lips, cheeks and gingivae are very small and the obstacles to oral hygiene are minimised. This method also makes it easy to keep all teeth under control and at the end of space closure there is no need to align the teeth for a second time before finishing. These advantages must be weighed against the possible increase in anchorage required.

Self-ligating brackets and anchorage

The chapter Self-ligating brackets – theory and practice discusses in detail the potential benefits of using self-ligating brackets such as SPEED, In-Ovation or Damon Q. One such benefit is the ability to slide a tooth along a wire with very low friction and with no loss of control. This previously unavailable combination reduces the potential disadvantages of separate retraction of canines. We would therefore expect anchorage preservation to be enhanced if these mechanics are used with self-ligating brackets. It has certainly been reported in a very interesting study by Rajcich and Sadowsky (1997), that retraction of canines with sliding mechanics when the molar is prevented from tipping or sliding mesially incurs impressively low anchorage loss. There are simpler ways of controlling molar tip and slide than the one they suggest which uses an auxiliary arch. A crimped stop or hook is one of them. This combination of a self-ligating bracket, a stopped archwire and separate canine retraction is
worth close consideration for anchorage enhancement and is considered more fully in the chapter on Self-Ligating Brackets.

Tipping and uprighting teeth versus bodily movement

Appliances such as Begg and Tip-Edge deliberately allow extensive distal tipping of anterior teeth followed by a later phase in which the mesially tipped roots are moved distally. The differential force theory is frequently quoted in this context in support of the idea that this two-stage movement will consume less anchorage overall. This is another inadequately researched area. There is no doubt that tipping a tooth requires less anchorage than bodily movement, because a given force is concentrated on only a small part of the root area whereas in the anchorage unit where the teeth are held upright, the same force is spread over the whole mesially-facing area of the roots and is thus much lower per unit area of root surface. What has not been adequately explored is whether tipping and subsequently uprighting a tooth consumes less anchorage than achieving the same result with more bodily movement. In that second phase, the force is still resisted by the same root area in the anchorage unit, but is now also spread over the majority of the root surface of teeth in which the apex is more mesially placed than at the start of treatment and must therefore move distally through a large arc.

A study by Lotzof et al (1996) missed a potential opportunity to shed some light on this. Upper canine retraction was compared within the same patient with a Tip-Edge bracket on one canine and a Straight-Wire bracket on the other. The differences were not even close to being statistically significant, but suggested that with much larger sample size, the Tip-Edge bracket might have shown that using the flawed protocol chosen, 0.6 mm less anchorage loss over the approximately 11 week time required to retract the canines. Apart from the small sample size (12 cases) the major reservation about the study is that the tooth with the Tip-Edge bracket was, of course, allowed to tip distally but was not then uprighted. This negates any sensible comparison of rate of retraction or anchorage loss. It is easy to be critical and this study does reveal some of the practical difficulties in assessing the relative anchorage consumption of differing mechanics. More recently, a good study by Shpack et al (2008), found that bodily retraction of a canine consumes the same anchorage as tipping followed by uprighting and incidentally, bodily retraction was more rapid by an average of 38 days.

Measuring anchorage

In all the discussion about anchorage and anchorage loss, the relative merits of the various means of assessing anchorage are rarely discussed. Assessment means comparison over time of tooth position relative to a non-tooth structure. The data is either cephalometric or from study models.

Cephalometric measures of anchorage

- **lower incisor anteroposterior position**
  This is probably the most common method in clinical practice. A more labial position of the lower incisors at the end of tooth movement is conventionally considered to represent an overall loss of posterior anchorage, although of course such a change can be an entirely deliberate treatment aim. Similarly, except in the treatment of bimaxillary proclination or in some class 3 cases, a more posterior position of lower incisors following treatment is considered to be unused intraoral posterior anchorage. Cephalometric measures such as Lower incisor to Nasion-Pogonion, or Lower incisor inclination to mandibular plane are used to assess this aspect of anchorage consumption/loss. The reference structures being used are the Nasion-Pogonion plane or the mandibular plane or - in the Steiner analysis - the line Nasion-B point. This is a simple and very useful tool, but does have its limitations. In particular, it gives no information about the quantity and sources of anchorage provided to move teeth distally, only about the anchorage consumed.

- **pitchfork analysis**
  This is a very well known form of superimposition on bony structures, described and popularised by Lysle Johnston (1985, 1996). This reference structure is essentially the maxilla and zygoma. Johnston developed a comprehensive set of measures relative to a mean functional occlusal plane, which provide a measure of anteroposterior movement of upper and lower incisors and molars and the contributions of mandibular and maxillary growth. Whilst still not providing full quantification of the anchorage work done (no measurement of changes in incisor inclination or canine
angulation), it provides an extremely useful summary of the contributors to anteroposterior achievements.

- **superimposition on other cranial structures**
  There are other well-known reference structures, for example, De Coster’s line in the cranial base and Bjork’s ‘stable’ structures in the maxilla and mandible. Each structure has its merits. A paper by Mannchen (2001) has pointed out some disadvantages in the pitchfork analysis. The criticisms are essentially twofold: Firstly, that the maxilla is not the best structure on which to superimpose, because rotational changes of the maxilla during treatment will effect the resolved anteroposterior components. Secondly, that the mean functional occlusal plane can also change and effect the measurements relative to it. Mannchen compared the results when the same cases were assessed using the pitchfork analysis and Bjork’s structures. He found a tendency for the pitchfork to estimate more skeletal and less dental change (approximately 1 mm) compared to using Bjork’s structures. All reference structures have disadvantages – both in principle and in terms of the practicalities of reliable identification and measurement of structures. In an individual case the veracity of cephalometric superimpositions on the best fit of various structures should be viewed with significant scepticism.

**Study model measurement**
Over many years, there have been investigations of the suitability of the palatal rugae for superimposition of changes in maxillary teeth. There has been a recent resurgence of interest in this method, prompted by the developments in digital imaging which assist the recording, enhancing and measuring of the upper study models. Hoggan and Sadowsky (2001) reviewed some of the previous papers and carried out a study which concluded that palatal rugae landmarks are as reliable as cephalometric structures for superimposition. However, it should be noted that the standard deviation of repeated measurements was 0.8 mm or more for several of the measures. This would mean that a real difference of 1.6 mm is unlikely to be shown to be statistically significant. Indeed in the study, a difference of 1 mm between the cephalometric and study model measurements of the same parameter was not statistically significant. Of course, this also reflects on the relative unreliability of cephalometric measures of molar position. Ashmore et al (2002) have utilised different digitising techniques to measure molar movement in the vertical and anteroposterior directions and concluded that superimposition on the palatal rugae was sufficiently reliable to pursue as a method.

There is no ideal method of measuring anchorage loss and anchorage achieved, but cephalometrics provides information of great value for both scientific and clinical purposes. The use of palatal rugae needs further investigation, but with newer digital techniques and the advantage of good identification of tooth landmarks, it may prove to have a useful place.

**'Fixed' class 2 traction**
Intermaxillary traction - Class 2 in the context of this chapter - is a traditional way of transferring anchorage from one arch to another. Such traction is frequently required in extraction cases where retroclination of the lower incisors is not required and methods which reduce or eliminate the need for patient co-operation in relation to Class 2 elastics are surely worth considering. Many appliances have been produced to try to meet this aim. Most have not proved popular for a variety of reasons. Most commonly the problems are:

- excessive breakage rates of the class 2 device
- excessive breakage of the archwires or loss of adjacent bonded attachments
- difficult to place
  - quickly
  - with the correct activation
  - in a position where occlusal forces do not lead to breakage or distortion and where trauma to the cheeks is unlikely
- special attachments are required (e.g. oval upper molar tubes with the Klapper spring)
Devices, which are rapidly placed, comfortable, robust and effective, are clearly a big technical challenge, but a form of class 2 traction which is effective and requires no active patient participation remains a very worthwhile objective.

Types of fixed class 2 traction

- Saif spring
- Alpern interarch coil spring
- Jasper Jumpers
- Eureka piston spring
- Bite fixer
- Klapper superspring
- Forsus flat spring
- Forsus FRD spring
- TwinForce bite corrector
- Sabbagh spring
- (Fixed functionals- e.g. Fliplock Herbst)

This list is not comprehensive, new designs emerging with regularity. Nickel-titanium springs which can withstand being tied in as class 2 ‘elastics’ for several months were disappointing as a product because of breakage problems. Such springs were available under the name ‘Saif springs’ The Alpern spring is a sheathed coil spring. All other fixed forms of intermaxillary traction employ compression of an elastic device rather than extension.

Curving pusher springs
Several of the fixed class 2 traction devices can be grouped together under this heading. When the patient closes in a retruded mandibular position, the spring is compressed and curves buccally into the sulcus. We tried Jasper Jumpers in the past on a significant number of cases and found their effectiveness severely compromised by a very high breakage rate. A more recent version involves a snapaway capability which is claimed to preserve the ‘Jumper’ for reassembly, but this perhaps just saves on ‘Jumpers’ rather than enhances treatment efficacy. A study by Stucki and Ingervall (1998) reports a 9% breakage rate. Clinicians do report success however and this concept may prove its worth with more robust springs. Weiland et al (1997) have reported cephalometric changes with the Jasper Jumper which are typical of a tooth-borne functional-type appliance and overjet reduction in an average of six months, but no mention of breakages or other technical problems. A more recent development of this idea is the ‘Bite Fixer’. This has a coil spring which surrounds a flexible core rather than a central spring surrounded by a flexible cover (the Jasper Jumper design). We have tried these and met with success but they, or the archwires to which they are attached, are not immune from breakage. One challenge with this type of device is the need to build in a good range of action as the mouth opens by providing travelling space along a wire. Forsus flat springs are leaf-like nickel-titanium springs. Other companies sell the same spring under different names. A prospective study by Karacy (2006) found good and equal success with Forsus flat springs and Jasper jumpers with low breakage rates.

Tips when using Bite Fixers or other ‘curving pushers’

- if you have lower molar bands with double tubes, use them to place an auxiliary mandibular wire from the lower molar to the main archwire just distal to the lower canine. This increases the range of possible mandibular movement and prevents the need to remove a lower premolar bracket. The auxiliary wires are easy to fabricate. The additional investment in time, complexity and double tubes is reported to greatly increase patient comfort and certainly reduces breakage, but is likely to remain an unpopular additional complexity.
- if you have a self-ligating upper molar attachment such as the Ormco Snaplink, this eases the placement of such an auxiliary distal to the upper first molar.
- do not overactivate, especially at the first visit. This increases patient comfort. If the overjet is large, the device will be passive when the mandible is postured forward as far as the patient can achieve
Piston-type pusher springs

Eureka springs are compressed nickel-titanium springs in a piston arrangement. They are designed by John De Vincenzo and manufactured in San Luis Obispo, California. An excellent study by Stromeyer, Caruso and De Vincenzo (2002), measured the cephalometric effects in 50 consecutive cases which had failed to cooperate with conventional elastic class 2 traction. The appliance was successful in achieving class 1 canine and molar relationships in all cases in an average of 6 months (range 2 to 14 months). This compares with an average of 27 months of treatment prior to starting the Eureka springs because of non-compliance. The cephalometric changes were almost entirely dentoalveolar and of equal extent in upper and lower arches. The average age at the start of the Eureka spring stage was 16.0 years, reflecting the long previous treatment with no compliance. They are fairly technique-sensitive in terms of placement with correct activation and positioning, requiring a tieback ligature to be accurately placed.

Another version of this concept is the Sabbagh spring which can be used as a fixed functional or as a fixed class 2 traction device. The Forsus FRD is similar. The Twinforce bite corrector is also a linear piston device. As the name suggests, the TwinForce has two pistons containing two springs which give a longer range of action and therefore, it is hoped, a lower breakage rate.

Clinical Tip: All these appliances attach on the buccal surfaces and therefore tend to place buccal crown torque on the teeth. Palatal crown torque plus some contraction of the archwires may be needed to counteract this buccal flaring.

Clinical Tip: Piston-type fixed class 2 traction devices tend to be more comfortable and have a longer range of action.

One factor shared by all the curving pusher springs and many but not all of the piston-type springs is the need for a headgear tube for the distal (maxillary) attachment. This has several disadvantages:

- one suspects that this would severely tax the bond strength of a molar bond and placing molar bands is an additional chore.
- adjusting the attachment to ensure that the curving pusher-type (in particular) easily bypasses the archwire tube can be tricky – especially if the headgear tube is gingival to the archwire tube.

Clinical Tip: Piston-type fixed class 2 traction devices tend to be more comfortable and have a longer range of action.

Fixed functional appliances

These differ from fixed forms of class 2 traction only in that the force is stored in the muscles and ligaments rather than in the elasticity of a metal spring.

Types of fixed functional appliance:

- Herbst appliance
- MARA appliance
- Sabbagh appliance with spring element locked
- (Fixed twin-block)
- AdvanSync 2 molar-to-molar appliance

The MARA (Mandibular Anterior Repositioning Appliance), popularised by James Eckhart, consists of two buccally placed wire ‘wedges’ attached to molar bands which interlock in a postured bite as do twin-blocks or the Dynamax. We have no personal experience of these. More recently we have employed fliplock Herbst appliances (made by TP Orthodontics) direct to rectangular tubing slid over the archwires. This approach is very similar in its practicalities to the piston-type class 2 traction devices, but attachment is significantly easier - see the chapter on Functional Appliances. Terry Dischinger’s molar-to-molar appliance – AdvanSync – has a short telescopic piston attached just to the upper and lower molars and is described in the chapter on Functional Appliances.
It is probable that one or two designs of fixed class 2 traction will emerge as robust, easy to attach, comfortable and effective and these will steadily grow in popularity. Our impression is that the linear piston-type devices or a non-elastic Herbst-type attachment will prove more robust and more comfortable than the devices which compress into a curve towards the cheek. A large factor in the robustness of this linear piston-type of device may come from the inherent extendibility and the lack of need for the end of the device to travel along an archwire or auxiliary wire.

**Headgear**

**Decline in our personal use of headgear**

We have steadily used less headgear over many years until we now never use it. Several reasons contribute to this trend. Some relate to a slight shift in average treatment goals and others to availability of better technology for class 2 correction and anchorage control.

- functional appliances which have better compliance
- fixed functionals
- more class 2 elastics being employed
- self-ligating brackets seem to reduce anchorage demands (not proven) and favour earlier use of lighter class 2 traction
- more lower incisor proclination accepted
- more arch expansion -or at least buccal uprighting -accepted
- TADs have revolutionised intra-oral anchorage possibilities

**Direction of headgear pull**

We favoured a direction of pull that is significantly above the occlusal plane in order to avoid a backwards rotation of the mandible and the need to chase the retreating target of the lower incisors to obtain overjet reduction.

The excellent review by Bowden (1978) of the effects of altering headgear geometry has more recently been supported and amplified by Yoshida et al (1995) who investigated the initial direction of movement within the periodontal membrane of upper first molars with headgear using magnetic sensors. These authors support the view that a short outer bow ending opposite the centre of resistance of the molar offers the best options. They highlight the disadvantages of too flexible an outer bow in inadvertently altering the intended direction of force and they again point out the drawbacks of a cervical pull. It is however worth noting that the comparative vertical effects of occipital and cervical headgear may not be entirely clear-cut in clinical practice. For example, the paper by Burke and Jakobson (1992) revealed, as expected, substantial differences in upper molar extrusion, but no clear short or long term differences in measures of face height. O'Reilly et al (1993) show definite mandibular rotation from cervical headgear when compared to occipital pull. It would still seem sensible to avoid upper molar extrusion since this is only desirable in a class 3 case where autorotation of the mandible is being deliberately sought. Of course, the skeletal effects of headgear (see chapter on Functional Appliances) are not desirable in a class 3 case.

**Clinical tip:** Always pull from above the occlusal plane

**Force level**

No single study of which we are aware has thoroughly investigated in a controlled manner the effects of differing force levels. Many different papers have however shown very similar effects from widely varying force levels. One irritation is that many papers do not make clear whether the forces quoted are total or per side. It seems probable that force level is less important than force duration in a situation where force application is inherently intermittent. (It has incidentally been shown that high forces if required are tolerated much better if delivered by occipital rather than by cervical traction – O'Reilly 1993).
Hours of wear
If headgear is prescribed, we would favour using it only in bed at nights. Most, but not all, patients will co-operate sufficiently with headgear if asked only to wear it at night and several manoeuvres can be employed to lessen the problem of non-compliance. One of the simpler measures has emerged from a study by Cureton et al (1993a) who used concealed timers in the headgear of two groups of patients to show that the use of headgear calendars increased the wear by an average of 2.6 hours per day and also greatly increased the accuracy of the patients’ estimates of their hours of wear.

Clinical tip: If we use headgear, we should consider using headgear charts routinely

A further study by Cureton (1993b) using the same covert timers revealed that even experienced clinicians are very inaccurate at assessing the actual hours of wear that their patients are achieving, although with greater experience, orthodontists become more sanguine about the hours achieved (rightly) and lower their estimates. These covert timers were not sufficiently cheap or robust for routine use, but a much more modern inexpensive electronic device - the Affirm headgear traction module - became commercially available in the 1990s. A similar paper by Cole (2002), in a small number of patients (16) over a short period (8 weeks) also showed some marked lack of reliability in the recorded hours in a significant percentage of patients. Whist 69% wore headgear for >84% of the time recorded on their chart, 31% were at 58% or less. However, the RCT comparing palatal implants and headgear (Sandler et al 2008), reported very good levels of headgear compliance and success which rather surprised the authors.

Safety and headgear
Although reports of injuries from headgear continue to be rare in the literature (eg: Booth-Mason and Birnie 1988, Chaushu, Chaushu and Weinberger 1997), this is a topic which demands our continued close interest if we use headgear. Samuels (1996) and Samuels et al (1996b) have published surveys of the reported injuries in many countries and have classified the reported incidents as follows:

- accidental disengagement when the child was playing whilst wearing the headgear
- incorrect handling by the child during the fitting or removal of the headgear
- deliberate disengagement of the headgear caused by another child
- unintentional disengagement or detachment of the headgear whilst the child was asleep

Efforts to reduce the chance of injury from the facebow continue to follow one of three strategies.

- prevention of release of the facebow from the molar tube
- limiting the force required to release the traction force from the facebow and thus preventing elastic recoil injuries – catapult or slingshot injuries
- limiting the potential for damage by blunting or shielding all the ends of an inadvertently released facebow.

Examples of the first strategy are the plastic safety straps (e.g. Masel type) and the customised facebow locks developed by Samuels et al (2000). Safety straps have to try to square the circle of being tight enough to allow insufficient movement for the bow to leave the tube whilst still being capable of insertion and comfortable wear. In practice, this is usually achievable or at the worst, the facebow can be inadvertently removed from the tubes with the strap still attached, but the inner bow will remain in the mouth where the scope for serious, irreversible damage is extremely small and the range of possible labial movement of the bow in response to traction is too small to permit a ‘slingshot/catapult’ type of injury. Such safety straps are inexpensive, quick and easy to fix and to wear.

The customised facebow locks recommended by Samuels et al (2000) have become commercially available as Nitom headgears or they can be made ‘in-house’ by a laboratory adding to a chosen facebow. They are usually fairly easy to adjust and insert although with significantly rotated molars they can be awkward to place. Adjustments to the length of the inner bow also require adjustments to the safety lock wire. In many ways these
represent the most logical and potentially effective method to date. A paper describes the successful experience of a group of clinicians with these facebows (Samuels et al 2000). One comment is that even the short outer bows are inconveniently long unless used with a snapaway traction module.

Examples of the second strategy are the many snap-release headgears available of which some have better mechanical performance than others (Postlethwaite 1989, Stafford et al 1998), but all possibly suffer from the limits of their ambition which is solely to prevent one type of potential injury - the slingshot/catapult type.

Examples of the third approach are the previous Guardian facebow from Lancer, which is still available from GAC and the partially plastic bows made by Odontec. These are a sensible idea but significantly more demanding to insert than an orthodox bow or a Nitom bow (especially if the molars are rotated or instanding). We do not recommend this approach.

There is of course, no reason why more than one of these categories of safety measure cannot be simultaneously adopted. In addition, it is essential that suitable verbal and written instruction is always given about placing and removing the headgear and behaving appropriately when wearing headgear. The British Orthodontic Society has published guidelines on headgear safety and Samuels and Brezniak (2002), have published a review of this topic.

Distalising molars/assisting headgear

Several devices have been described as means of assisting or replacing headgear in the distalising of molars. Most of these are described as non-compliance devices

- repelling magnets
- compressed coilspring distaliser of various types, both buccal and lingual.
- Hilger’s Pendulum/Pendex appliance
- ‘nudgers’

Repelling magnets

- Several authors e.g. Gianelly (1989), Bondemark et al (1994) and Bondemark (2000) have described this use of magnets for distalising molars. We have not tried them for several reasons: other strategies work well, the force is inherently high initially with an exponential (which is the opposite of the required pattern (obeying Coulomb’s Law)) and attaching headgear simultaneously is not easy which leaves the problems of reciprocal forces and anchorage loss.

- Bondemark et al (1994) elegantly showed that superelastic coils are more effective than magnets in distalising molars and that this may well be associated with the much more constant forces applied by the superelastic coils. The appliances were reactivated every four weeks and the anchorage loss (no headgear was worn) was 50% of the 3 mm average distal movement in 6 months. This anchorage loss is a serious drawback to these methods of distalising molars without anchorage reinforcement and it must be assumed that in many such cases, the upper incisors will finish further forward than at the start of treatment or - if extractions are used - that the scope for upper incisor retraction is substantially reduced.

- Everdi et al (1997) also reported on a comparison between nickel-titanium coilsprings and repelling magnets. Again, the coilsprings produced greater distalisation, in spite of the magnets being reactivated at weekly intervals (!) to overcome the exponential decay of magnetic force. The molar distalisation was accompanied by significant tipping (approximately 9 degrees) in both methods. Anchorage loss was not even measured, but the photographs in the article show that the first premolar has moved mesially as much as the molar has moved distally from the second premolar. This suggests that the anchorage loss was large.

**Clinical tip:** In the light of these papers, we remain firmly disinclined to try magnets or to recommend them as a means of distalising teeth.
Distalising coil springs
Gianelly (1998) and Gulati et al (1998) have separately reported on the use of compressed coilsprings to distalise molars with either fixed or removable Nance appliances to reinforce anchorage. Gianelly did not measure anchorage loss. Gulati found approximately 1 mm of mesial movement of all ten anterior teeth for every 2.8 mm of distal molar movement. The Wilson coiling system also undoubtedly produces effective molar movement but the reciprocal forces have to be opposed by class 2 traction and the remarks above therefore apply.

The paper by Muse et al (1993) clearly shows that the class 2 traction to this appliance causes almost as much mesial lower molar movement as distalisation of the upper molar and the upper incisors are extruded by the class 2. If the co-operation with wearing the class 2 is not good then the upper incisors move labially instead. It is interesting to compare the changes obtained by Muse in four months with those described by Firouz et al (1992) using unassisted high-pull headgear instructed to be worn for 12 hours per day for six months. The rate of distalisation with headgear was 0.1 mm less per month than with the distalizing coils, but there was, of course, no anchorage loss with headgear alone and there was no distal tipping of the upper molars as with the coils.

Clinical conclusion:

Coil springs used in this way do not therefore seem to confer benefit unless the labial movement of the lower incisors is part of the plan and class 2 elastics are worn to enable harnessing of the anchorage in the lower arch. As with all anchorage considerations, very gentle forces with little obstruction can be surprisingly effective. e.g. opening of space with coil springs and low friction self-ligating brackets.

Pendulum appliance
This was described by Hilgers in 1992 and is analogous to a fixed 'nudger'. The TMA distalising finger springs are inserted into palatal sheaths on the molar bands. A relatively high force of 230 g per side is reported by Ghosh and Nanda (1996). As with the majority of these appliances, the anchorage loss was resisted by a Nance button.

### Table 13.1: Anchorage loss with molar distalising appliances

<table>
<thead>
<tr>
<th>Author</th>
<th>Method</th>
<th>Anchorage loss in mm. (usually the premolar) per mm. gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulati</td>
<td>Coilsprings</td>
<td>0.4</td>
</tr>
<tr>
<td>Muse</td>
<td>Wilson coilsprings</td>
<td>0.8</td>
</tr>
<tr>
<td>Ghosh</td>
<td>Pendulum</td>
<td>0.75</td>
</tr>
<tr>
<td>Byloff</td>
<td>Pendex (tipping)</td>
<td>0.48</td>
</tr>
<tr>
<td>Bussick</td>
<td>Pendulum</td>
<td>0.32</td>
</tr>
<tr>
<td>Byloff</td>
<td>Pendex (bodily)</td>
<td>0.53</td>
</tr>
<tr>
<td>Gianelli</td>
<td>Pendulum</td>
<td>0.69 / 0.48 / 0.41</td>
</tr>
<tr>
<td>Itoh</td>
<td>Magnets</td>
<td>0.25</td>
</tr>
<tr>
<td>Everdi</td>
<td>Magnets and coils</td>
<td>Not measured</td>
</tr>
<tr>
<td>Bondemark</td>
<td>Magnets and coils</td>
<td>0.35</td>
</tr>
<tr>
<td>Bondemark (2000)</td>
<td>Magnets and lingual coils</td>
<td>0.6</td>
</tr>
<tr>
<td>Keles</td>
<td>Coils</td>
<td>0.53</td>
</tr>
<tr>
<td>Ngantung et al</td>
<td>Distal jet</td>
<td>1.2 (!)</td>
</tr>
<tr>
<td>Gianelli</td>
<td>Coils and compressed loops</td>
<td>Not measured</td>
</tr>
<tr>
<td>Runge</td>
<td>Jones jig</td>
<td>1.00 (!)</td>
</tr>
<tr>
<td>Haydar and Uner</td>
<td>Jones jig</td>
<td>1.2 (!!)</td>
</tr>
<tr>
<td>Hoggan and Sadowsky</td>
<td>Jones jig</td>
<td>0.8</td>
</tr>
<tr>
<td>Papadopoulos et al</td>
<td>Jones jig</td>
<td>1.85 (!)</td>
</tr>
<tr>
<td>Mavropoulos et al</td>
<td>Jones jig</td>
<td>1.17 (!)</td>
</tr>
<tr>
<td>Fortini et al</td>
<td>Screws</td>
<td>0.4</td>
</tr>
<tr>
<td>Ferro et al</td>
<td>Nudger + headgear</td>
<td>0.19</td>
</tr>
<tr>
<td>Itoh</td>
<td>Magnets</td>
<td>0.25</td>
</tr>
</tbody>
</table>

**Firouz et al (1992)** using unassisted high-pull headgear instructed to be worn for 12 hours per day for six months. The rate of distalisation with headgear was 0.1 mm less per month than with the distalizing coils, but there was, of course, no anchorage loss with headgear alone and there was no distal tipping of the upper molars as with the coils.

**Jones jig and distal jet**
There are several named versions of compressed coil spring devices including the distal jet (placed on the palatal), Keles slider (also on the palatal) Keles and Sayinsu (2000), Keles (2002) and Jones jig (buccally placed). They vary slightly in their ease of use and in the usual force levels. Jones jigs use an average of 75 gm. force (Brickman et al 2000) and distal jets 240 gm (Ngantung et al 2001). However, the results are similar. Data on anchorage loss for most of these appliances is shown in Table 13.1. A further paper by Papadopoulos et al (2004) measured anchorage loss with a modified Jones jig. They too found it to be very expensive for anchorage. The overjet increased by 64% and the premolars moved mesially by 185% of the molar distal movement! The paper by Chiu et al (2005), comparing the distal jet and pendulum appliances (see below) found more distal movement and less anchorage loss in the distalisation phase with the pendulum.

Clinical conclusion:

Coil springs used in this way do not therefore seem to confer benefit unless the labial movement of the lower incisors is part of the plan and class 2 elastics are worn to enable harnessing of the anchorage in the lower arch. As with all anchorage considerations, very gentle forces with little obstruction can be surprisingly effective. e.g. opening of space with coil springs and low friction self-ligating brackets.
bonded to the first premolars. The advantage of the design is that patient compliance with wearing the removable appliance is not required. In six months, an average of 3.4 mm distal movement was achieved, with substantial variability and distal molar tipping of 8 degrees. The anchorage loss was an average of 2.6 mm or 0.75 mm for every 1 mm of distal movement of the molars. This is greater than the 0.25 mm and 0.35 mm anchorage loss per mm distal movement reported by Giannelly and by Bondemark using magnets. A pendulum appliance is clearly a technique which loses a great deal of anchorage and this may be related to the relatively high forces which are opposed by a relatively small anchorage unit. The oral hygiene consequences of a Nance button in place for six months should also be considered. The paper by Kinzinger et al (2005) showed that less anchorage was provided by deciduous molars than by premolars.

The Pendex appliance
This is a pendulum appliance with a midline expansion screw. Two papers by Byloff and Darendeliler (1997) and Byloff et al (1997) have further quantified the effects with smaller activations producing a reported initial force of 200-250 g. Anchorage loss of the premolars was 0.5 mm for every 1 mm distal movement with a high average distal tipping of 14.5 degrees for the first molar. The second paper describes a pendulum appliance with uprighting bends in the springs which were used to upright the distally tipped molars in a second phase of activation. The overall rate of distal molar movement was slower, but the distal tipping was reduced to an average of 6 degrees. The penalty was a slightly higher percentage of anchorage loss - 0.54 mm for every 1 mm distal movement - and more transmission of this anchorage loss through from the premolars to the incisors. A paper by Bussick and McNamara (2000) with a large sample of 101 patients found an average mesial movement of the premolars which was 32% of the distal molar movement. A variation on this theme is the distaliser described by Fortini et al (2004), which uses bilateral screws with a Nance button as the anchorage. This requires the compliance of the patient to turn the screws, but is cemented to molar and premolar bands. The average anchorage loss per mm of distal molar movement is shown in Table 13.1.

Anchorage loss with ‘non-compliance’ molar distalisers
This review of these appliances has focused on the high level of anchorage loss. It should also be remembered that they only distalise two teeth (or four if the second molars are counted) whereas at least eight of the anterior teeth will have moved mesially by approximately the amounts indicated in the table above. Enthusiasts for these appliances refer to the benefit of palatal arches or Nance buttons in preventing subsequent mesial movement of the molars when intra-traction is subsequently applied to distalise the anterior teeth. This overlooks the fact that Nance buttons (or similar) failed to prevent anchorage loss in the initial molar distalisation phase. The paper by Chiu et al (2005), comparing the distal jet and pendulum appliances is unusual in looking at the outcomes, including anchorage loss, through the entire treatment and not just the initial distalisation phase. Jasper jumpers, Nance buttons and in some cases, headgear, were used to support anchorage during the postdistalisation phase. In spite of this, the upper molars ended the treatment more mesially positioned than at the start and there was “significant flaring” of the incisors. It seems reasonable to contend that anchorage must be sought from outside the upper arch at some stage if a significant overall net gain in distal tooth movement is to be achieved. The long-standing theories of anchorage and the results from all the papers in Table 13.1 are still sufficient for us not to have included these devices in our practice to any significant extent. More recently, specific molar distalising devices to use have been described (eg: Karaman et al 2002 with palatal implants and Kinzinger (2009) with miniscrews, to support a distal jet). This is a very different scenario, is likely to be successful from the aspect of anchorage loss and is discussed in the chapter on Temporary Anchorage Devices in Orthodontics.

A recent meta-analysis by Grec et al (2013) is recommended for a formal review of the evidence on all these devices. In order to robustly compare data across studies, they confined their review to those papers which measured anchorage loss in terms of mesial movement of the premolars. The conclusion was that the average anchorage loss was approximately 66% of the distal movement of the molar, but with skeletal anchorage methods there was greater distal movement of the molars and almost equal distal movement of the premolar ie: positive anchorage gain and no anchorage loss. TADs have indeed revolutionised distal movement.
‘Nudgers’

These are removable appliances with finger springs to aid distalisation of molars and we used to employ them frequently. They are intended to assist headgear by holding on during the day to the progress obtained at night. Used without headgear, the remarks above on non-compliance molar distaliser apply equally to nudgers. Several well-known clinicians such as Ten Hoeve and Cetlin (1983) advocated such appliances. This appliance can lessen the required hours of headgear wear and it is also a very useful way to get differential movement in one quadrant when required. When we used more headgear, we found these appliances very valuable. As always, there are potential pitfalls. These are:

Potential problems with nudgers

- excessive molar tipping which then needs uprighting
- excessive anchorage loss with an increase in overjet
- a false sense of security which is dispelled when the nudger is discarded and the headgear is insufficient on its own

Avoiding problems with nudgers

These problems can be very largely avoided if the following points are noted:

- only activate the spring by 2 mm and make them out of wire no thicker than 0.7 mm and preferably 0.6 mm. If the headgear is not worn, then there should be virtually no detectable distal movement. Headgear is the motive force and the springs should very largely only hold on to what the headgear achieves. This is a significantly different situation from the use of coils, finger springs or magnets described above.
- overcorrect the molar relationship
- if the molars look undesirably tipped, leave the nudger passive and raise the outer bow to upright the molars before discarding the nudger
- use gentle initial aligning wires so that the headgear does not have to combat a sudden heavy uprighting force if any tipping has occurred
- if concerned at the time of stopping the nudger, increase the headgear hours for one visit

These are all applications of the usual principals behind anchorage conservation. Ferro et al (2000) published a study of 110 patients treated with a nudger and cervical headgear. They advocated gentle activation (2-3 mm.) of the finger springs and found an average of 3.6 mm. distal movement of the molars compared to untreated controls with an average of 0.7 mm increase in overjet. The anchorage loss was therefore 19% of the distal movement. This anchorage loss is not negligible but is lower than any of the figures in the table above for non-compliance appliances and, of course, the headgear offers a plausible means of maintaining the distal position of the molars once retraction of the anterior teeth starts.

Indications for using a nudger with headgear added at nights

- class 1 cases with class 2 molars
- class 2 division ii cases where distal molar movement is required
- adults needing distal movement
- asymmetrical molar relationships

These are all situations where the more powerful anchorage enhancing effects of functional appliances are less suitable, but the advent of TADS, particularly miniscrews, has rendered headgear essentially obsolete.

**Clinical tip:** If you are using headgear to correct a class 2 molar relationship, a nudger is a very worthwhile addition. The separation of the occlusion is an additional benefit and nudgers are a useful means of achieving a differential left/right effect.
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