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INVITATION TO SUBMIT

Northcroft Memorial Lecture Self-ligation: past, present and future

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Self-ligating brackets have an archwire slot with an inbuilt labial face – usually referred to as a clip or slide, which can be opened and closed to enable placement and removal of the archwire. These brackets which incorporate their own ligation system have existed for a surprisingly long time in orthodontics (the Russell Lock edgewise attachment being described by Stolzenberg in 1935), but they have made a major impact in orthodontics only in the last decade. With the rapid proliferation of brackets (Figure 1) has come a growing body of literature expounding and examining the claims made on behalf of these brackets.[1–4] This Northcroft memorial lecture aims to throw light on the subject of self-ligating brackets by looking first at the origins and context of their development, then to summarize the current hypotheses and evidence in relation to their performance and finally to give hostages to fortune by predicting some aspects of the future research into and use of self-ligation.

The past – historical context

Many designs for self-ligating brackets were described and patented from the 1930s, but it was not until the 1970s and 1980s that such brackets became widely available. This long gestation period was largely the result of two factors – the technical difficulty of manufacturing such brackets and the introduction in the 1960s of elastomeric ligation. The chief motivation for the development of self-ligation was the desire to speed the process of placing and removing archwires. Just removing and placing wire ligatures took an average of 16 min for a pair of archwires[5] and elastomeric ligation cut this to an average of 4 min, thus substantially reducing the need for a faster method of ligation. The concomitant disadvantages of increased friction and reduced security of archwire engagement with elastomeric ligation were not widely appreciated at the time. Edgelok (Figure 2, Ormco Corporation, 1717 W. Collins Ave. Orange, CA 92867) and Mobil-lock (Figure 3, Forestadent Bernhard Foerster GmbH, Westliche 151 75173 Pforzheim, Germany) were two brackets from that era. Both of these brackets had their good features, but also their deficiencies. A good example is the poor rotational control resulting from the very narrow labial surface on the upper right lateral incisor (Figure 3) and the corresponding need to increase the complexity of the bracket by having two labial elements on the wider central incisor. Another problem with Mobil-Lock was the difficulty of access to open and close premolar brackets with the straight 'screwdriver'.

A major step at that time was the introduction in 1980 of the SPEED bracket (Figure 4, Strite Industries Ltd, 298 Shepherd Avenue, Cambridge, Ontario, N3C 1V1 Canada). The principal engineering innovation was the use of a spring clip that was easy to manufacture with contemporary technology and was easy to open and close. Of perhaps greater long-term importance was the growing realization by Dr Hanson, the originator of the bracket, that self-ligation delivered low friction in combination with good archwire control and that this meant that teeth could be effectively and rapidly aligned with the application of much lighter forces. The effectiveness of the ligation also meant that much narrower brackets could be used with no loss of rotational control. The narrower brackets in turn brought the benefits of larger inter-bracket span which comprise lighter forces for any given wire and a longer range of action. Cases were presented and published which demonstrated the very good and perhaps surprising effectiveness of tooth alignment with these brackets, so it is natural to ask why they were only adopted by a minority of orthodontists at that time and for many years. The reasons are, I would suggest, pertinent to many new technologies introduced into dentistry and medicine.

Reasons for the slow adoption of self-ligation

Firstly, there were imperfections of design. This is always a probability with new and innovative products,

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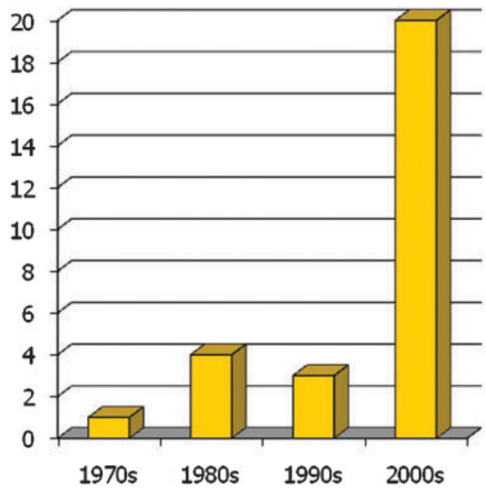


Figure 1 The number of new types of self-ligating bracket by decade

however carefully they have been tested by clinicians involved in their development. Taking the original SPEED bracket as an example, the original spring clips were prone to permanent distortion and there was no feature designed to limit the labial deflection of the clip. These shortcomings resulted in loss of archwire engagement and therefore undermined a central potential advantage of self-ligation. Also, there were no tiewings which, although no longer required for ligation, remain very convenient for the placement of elastic chain or ligatures to lace teeth together. Another factor was the concurrent introduction of the pre-adjusted edgewise appliance, an innovation which had an immediate and much stronger appeal to clinicians. The original SPEED bracket was a plain edgewise bracket. All of these disadvantageous design features have long since been addressed. Figure 5 shows a modern SPEED bracket with a fully pre-programmed slot, a retaining groove for the nickel–titanium spring clip and an additional labial hole which provides an alternative means of opening the clip. One distinctive original feature which remains is the absence of tiewings.

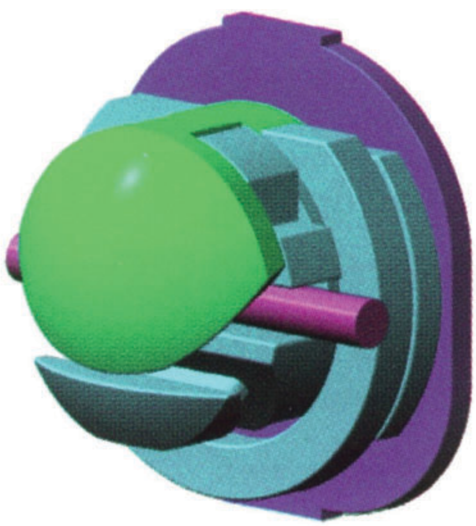


Figure 2 Edgelok bracket

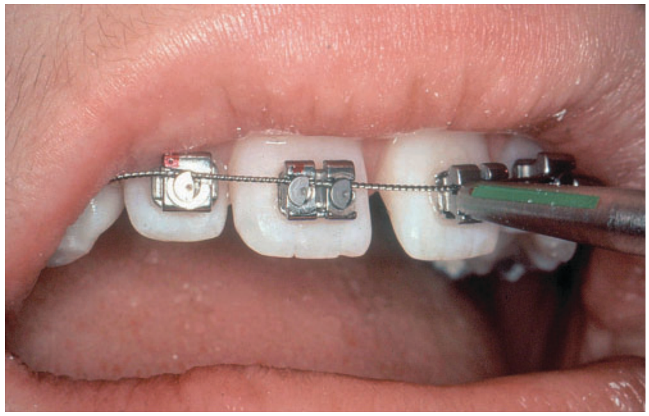


Figure 3 Mobil-Lock brackets, showing the rotating labial cams and the opening and closing tool

Activa (Figure 6, 'A' company, San Diego, CA, USA) was introduced in 1986. It had a pre-adjusted edgewise slot, but was another self-ligating bracket with several design imperfections. The clip was rather fragile, the bracket was too wide (a consequence of the choice of clip design), the curved inner surface of the clip effectively increased the slot depth with thinner wires, there were again no tiewings and as a result of the narrow and unorthodox junction between the bracket and its bonding pad, the effective bond strength was low.

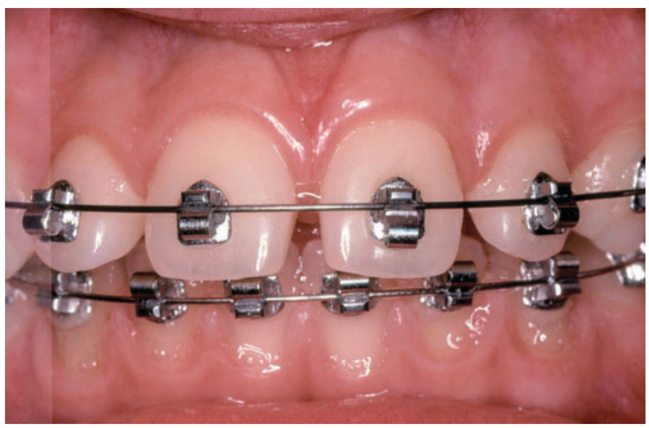


Figure 4 Early SPEED brackets in 1982 with no straight-wire pre-adjustment and no slot to restrain clip deflection

Figure 5 A modern SPEED bracket

These deficiencies were a significant factor in preventing the wide adoption of these brackets, but did not prevent good and rapid results in many cases. Figure 7 shows a case treated in 1992 by the author with Activa brackets in 13 months.

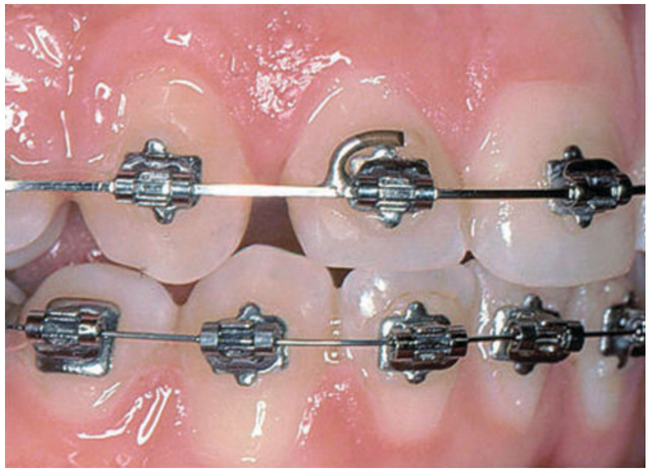


Figure 6 Activa brackets in 1989

Psychological factors

Psychological factors are possibly of equal importance in their influence on the adoption of new technology or

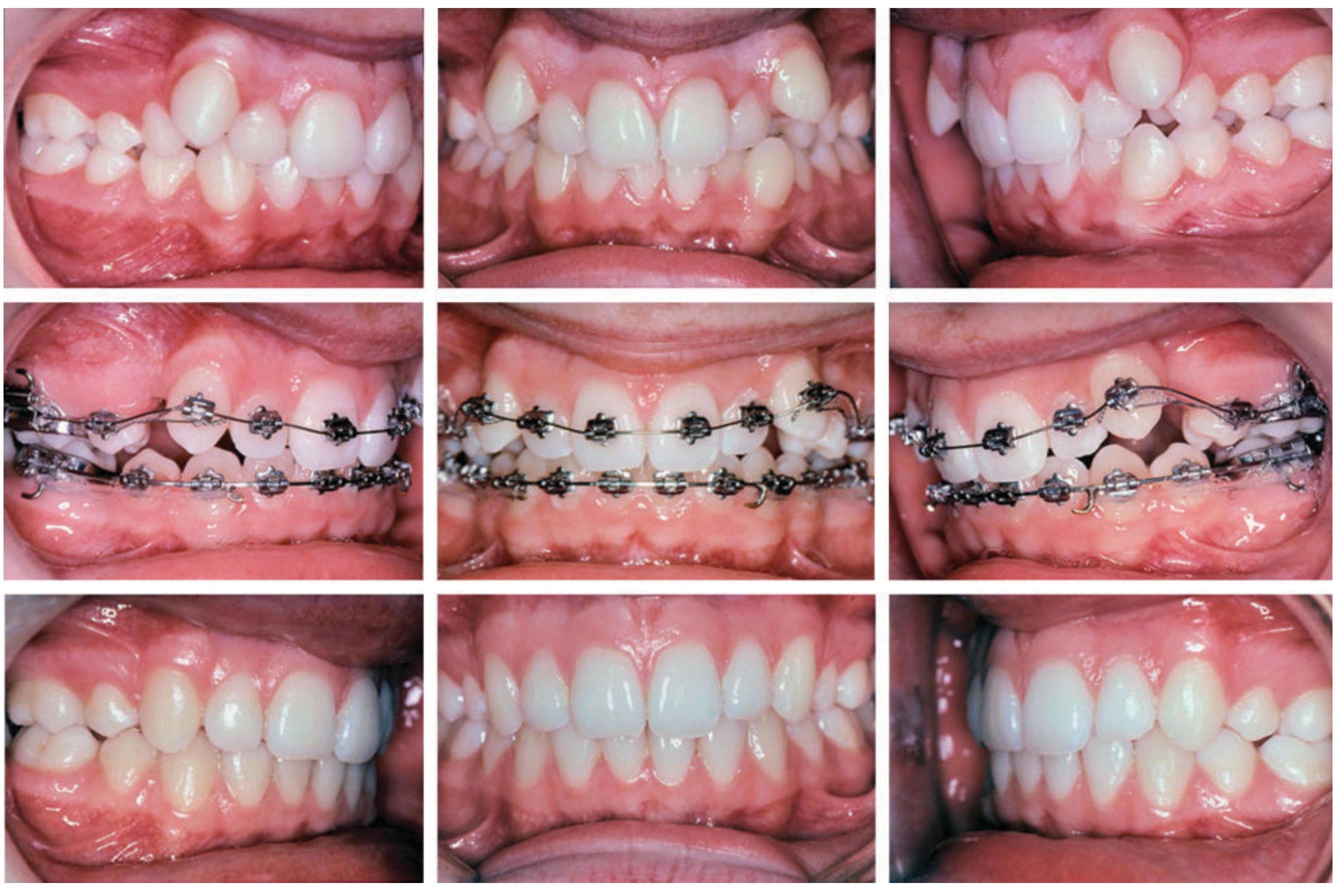


Figure 7 A case treated with Activa brackets in thirteen months finished in 1992

new ideas. Most of us have an element of innate conservatism and a desire to stay mentally and technically within our comfort zone. We learn a skill which minimizes the deficiencies of our equipment and then we stick with it because we are comfortable. The more skilled we become in a technique (such as bending complex archwires), the more unimpressed by and resistant to a new development (such as the pre-adjusted edgewise appliance) which reduces the need for this skill. We also make treatment plans which consciously or otherwise reflect the strengths and weaknesses of our current armamentarium. It is understandable that we may have a reluctance to discard or downgrade the importance of some skills and equally we may fail to realize that some aspects of our treatment plans are chiefly there to counter deficiencies in our equipment.

The situation in the early 1990s can perhaps be summarized by saying that self-ligation had demonstrated definite and sometimes striking benefits through its potential combination of archwire control, low friction and rapid archwire changes, but substantial further development was needed to make brackets which consistently provided all the benefits with no associated weaknesses or inconvenience.

The Begg appliance

It is relevant to mention the Begg appliance and its relation to self-ligation. Begg was a low-friction appliance and it had clearly demonstrated that this enabled low forces to be highly effective in producing rapid alignment. However, its popularity waned because this freedom of tooth movement was not matched by good archwire control within the slot. The consequent heavy dependence on auxiliary attachments made the appliance complex and potentially heavy on chairside time and made precision of tooth position harder to achieve with consistency. The orthodontic world preferred the simplicity, robustness and relatively good archwire control of the pre-adjusted edgewise appliance, but in doing so, it lost the advantages of low friction and light forces. It is worth noting the illustration (Figure 8) from Matasa's paper[6] in which his measurements confirm that with conventional elastomeric ligation, we can trade increased control of the archwire against low friction and ease of tooth movement, but cannot simultaneously have both.

The present – the current position of self-ligation

The references at the start of this article contain extensive information about current brackets, clinical

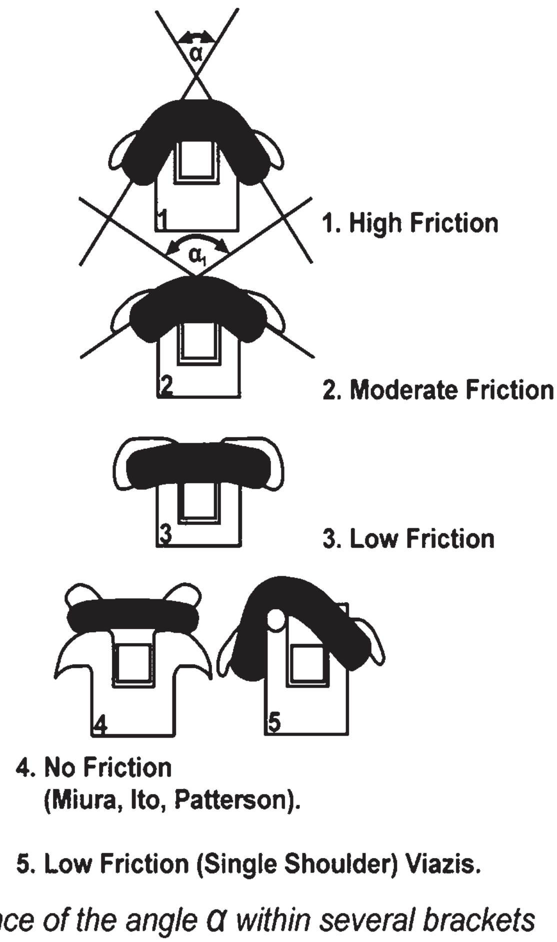


Figure 8 A figure from Matasa (2001) illustrating the inability of elastomeric ligation to simultaneously provide full, secure ligation and also low friction. Brackets with 'shoulders' such as the Viasis bracket reduce friction, but also reduce control (reproduced with the kind permission of the author)

applications and claimed advantages, so I will be succinct on many of these aspects.

Current brackets

Figure 1 shows that there has been an explosion of self-ligating bracket types in the last decade. The author has personal experience of fifteen different types of self-ligating brackets. This surge of activity has several causes. Firstly, manufacturing technology has advanced enormously. Metal injection moulding (MIM) and CAD-CAM technology are the two most powerful new tools enabling precise and cost-effective manufacture of small, complex bracket components. Equally important has been the momentum provided by a relatively small number of perceptive and persuasive clinicians who have enabled clinicians and manufacturers to have a much better understanding of the opportunities offered by self-ligation. Self-ligating brackets should be robust and provide consistently secure ligation with archwires of all sizes and materials. They must be easy for the clinician and comfortable for the patient to open and close with all archwires. They must be of a good size, but narrower mesio-distally than conventionally ligated brackets. It should be easy to place and remove elastomeric chain, wire underties and auxiliary hooks without impeding the operation of the clip or slide. Not all brackets meet these requirements to a sufficient degree. There are still brackets brought to the market that have significant weaknesses of design or construction, but equally there are now a number of good brackets available and therefore no practical reasons to avoid self-ligation.

Current evidence

The four core claimed advantages for self-ligation are

- secure, full archwire engagement;
- low friction;
- rapid archwire placement and removal;
- less need for chairside assistance.

These core features are now sufficiently proven. Many brackets now provide reliably secure ligation, although the thoughtful study by Pandis *et al.*[7] reveals that it cannot be taken for granted that the designed mechanical properties of the self-ligation mechanism will be sustained throughout treatment with all the current bracket designs.

Low friction has been thoroughly demonstrated in laboratory studies with designs of greatly increased clinical relevance. Investigations by Kusy and co-workers[8–11] are particularly recommended reading for their exploration of the effectiveness of self-ligating brackets in reducing friction when archwires are active in the slots, causing binding in addition to classical friction. A representative result from this work is that a passive self-ligating bracket when compared to a conventionally ligated bracket, reduced the resistance to sliding by 60 grams per tooth even in the presence of binding from mesio-distal tipping. Such work strongly supports the view that even though ligation is only one source of resistance to sliding, self-ligation can reduce this resistance to a clinically significant extent.

The increased speed of archwire changes may not seem immediately compelling, but with brackets being ever-easier to open and close, it is probably clinically significant. A paper by Turnbull and Birnie[12] is representative in showing an average time saving of two minutes per pair of archwires with Damon 2 brackets, which were not the easiest of brackets to open and close. In looking at such studies, it should be remembered that archwire changes with self-ligating brackets were being done by a single-handed operator and compared with four-handed changing of elastomeric ligatures.

Self-ligation and treatment efficiency

Several studies have investigated whether these established features of self-ligation result in treatment which is shorter or requires less chairside time. The hypothesis is that lower friction enables more effective relative movement between archwire and bracket and hence more rapid tooth movement whilst the reliable tooth control prevents the need to waste time regaining tooth control. Retrospective case control studies[13–15] have indeed found greater treatment efficiency. In contrast, the more recent random controlled trials (RCTs)[16–21] have almost all failed to show any such effect.

Possible reasons for differences between findings in treatment efficiency studies

In the retrospective studies:

- The groups may not be adequately matched for type and complexity.
- Some other factor may have been confounding the results, e.g. a different policy on extractions, archwire sequence or appointment interval with the different brackets.
- The case mix may have been unusual, e.g. more complex cases than average.

In the random controlled studies:

- None has yet reported on completed cases. Potential differences in treatment efficiency may be partially related to archwire control in the later stages of treatment. In the examples in Figure 9, it is highly likely that additional time and archwire changes were required to regain the rotational tooth control which has been lost with conventional elastomeric ligation.
- Factors such as case mix, appointment interval and archwire sequence may not have been optimized for self-ligating brackets, but have been chosen to be identical regardless of bracket type.

The 'nickel-titanium' dilemma: this name refers to the fact that it is almost universally accepted that nickel-titanium archwires are superior for tooth alignment when compared to their stainless steel predecessors; however, none of the studies which investigated that hypothesis ever demonstrated its truth. Similarly, no study ever demonstrated that pre-adjusted edgewise

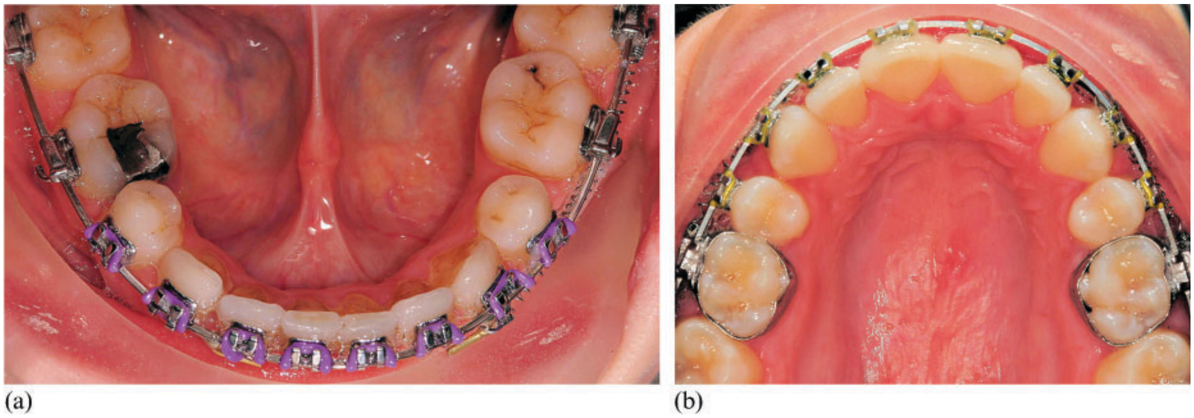


Figure 9 Two examples of loss of rotational tooth control with conventional elastomeric ligation. Three of the four canine teeth will need a backtrack in archwire size to regain control

appliances were superior to plain edgewise, but the former are overwhelmingly preferred for reasons that are regarded by clinicians as being self-evident and in no need of the highest order of scientific proof.

Is self-ligation less painful?

There have been a number of studies investigating this hypothesis.[15,16,22,23] Tagawa[15] found a substantial reduction in reported pain with Damon SL brackets and Pringle *et al.*[24] found significantly less pain with Damon 3 brackets; however other authors[16,22] have found no difference in the first week or month of treatment and one study[23] found that archwire changes with SmartClip brackets were reported as significantly more uncomfortable. The hypothesis that self-ligation may be less painful is based on the assumption that forces on the teeth will be lower. This is not necessarily the case and force levels will be discussed later in this article.

Is self-ligation less effective at delivering torque?

This hypothesis has been advanced and is probably based on the belief that the labio-lingual forces between the base of the bracket and a ligature system are a significant additional source of force couple, adding to the couple between the upper and lower bracket walls. This situation is not straightforward and is probably influenced by several factors.

- Conventional ligation can apply a high labio-lingual force, but can also permit incomplete archwire engagement. If this is the case, then the effective ‘play’ or ‘slop’ between archwire and bracket walls is significantly increased and torque effectiveness correspondingly reduced.
- An active self-ligation clip invades the bracket slot and might be expected to place an effective torque force at a smaller level ‘slop’ angle than a passive bracket. This has been investigated by Badawi *et al.*[25] who found that with an In-Ovation active bracket, the active clip which reduces the labio-lingual slot dimension provides sufficient force to reduce the effective ‘slop’ by 7 degrees with a $0.019'' \times 0.025''$ wire. This difference would be expected to sometimes result in detectable differences in achieved torque control.
- In routine clinical practice, the appropriate choice of bracket prescriptions and archwires might reduce this potential factor to an insignificant level. This view would be supported by the study by Pandis *et al*.[26] who in a study of 105 patients found no difference in incisor torque effectiveness when comparing Damon 2 and conventionally ligated brackets. The more recent increased availability of choices of torque prescriptions in self-ligating brackets would be expected to strengthen this conclusion.
- This author has experienced no difficulty obtaining torque control with either active or passive self-ligating brackets. The only disadvantage of lower friction is the need to prevent unwanted mesiodistal movement of the wire through the brackets, which leads to wire pokes or movement of teeth along the wire which leads to unwanted spaces.

The present – further current hypotheses about self-ligation

Many clinicians who use self-ligating brackets are of the opinion that when combined with light round wires, they facilitate the alignment of crowded teeth. Some –

Figure 10 A Class II division 2 case treated non-extraction using Damon 2 passive self-ligating brackets (reproduced with the kind permission of Dr Dwight Damon)

notably Dr Dwight Damon – have also proposed that the teeth align in a qualitatively different manner, producing less incisor proclination and more lateral expansion than conventional ligation. A well known case example (Figures 10 and 11) is reproduced by kind permission of Dr Damon. In this class II division 2 malocclusion, the very crowded arches have been aligned without extractions. The expectation would be that this would result in very pronounced incisor proclination. In fact the incisors moved labially less than 3 mm, but the posterior arch expansion was much greater than might have been anticipated (Figure 11).

This pattern of tooth movement has been attributed to a qualitatively different interaction of forces. In particular, it is suggested that the applied forces are so low that the lips can compete with and restrain incisor proclination. Additionally it has been proposed that the tongue position may alter in response to this expansion and possibly assist in the tooth movement. The force levels will be considered below, but first it is helpful to look at two consecutive visits in a case reproduced by kind permission of Dr David Birnie (Figure 12). It can be seen that the incisors have extravagantly (though temporarily) proclined. A major factor must surely be the high resistance to sliding produced by the figure of 8 elastomeric ligatures on the premolars which has prevented the excess wire sliding distally as the canines moved buccally. I suggest that self-ligation does not necessarily result in lower forces, but can generate a higher percentage of desirable force and a lower percentage of unwanted forces and it is this difference which can significantly alter the resulting tooth positions. In the case in Figure 12, the high and unwanted force on the incisors has arisen because of the friction from the elastomeric premolar ligatures.

The potential for measurement of these forces has been advanced to a very substantial degree by the work of Dr Badawi and co-workers at the University of Alberta into a force measurement system of impressive power, realism and versatility (Figure 13). This device can realistically simulate almost any arch alignment with any combination of brackets and archwires and measure

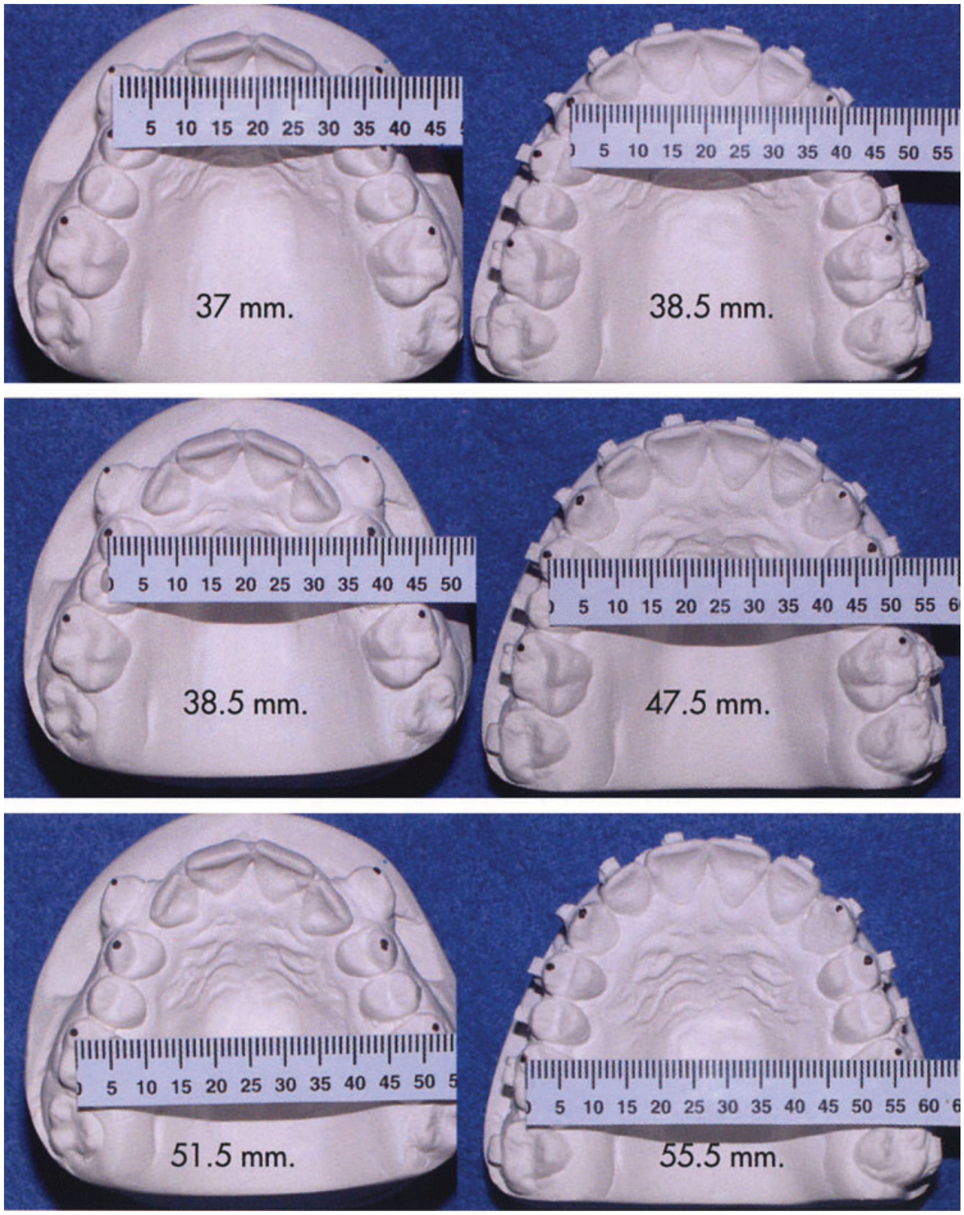


Figure 11 The changes with treatment in the lateral dimensions of the upper arch of the case in Figure 9 (reproduced with the kind permission of Dr Dwight Damon)

all the forces and moments simultaneously. Data from this equipment have been presented at several international meetings and results which are in press with the American Journal of Orthodontics and Dentofacial Orthopedics[27] demonstrate the much higher unwanted forces with conventional brackets and also significantly higher unwanted forces with active self-ligation when compared with a passive system.

The higher percentage of desirable force which can result from self-ligation is neatly and simply shown in the excellent study by Baccetti *et al.*[28] The simple but clever and illuminating aspect of this laboratory use of a strain gauge is that instead of measuring the force required to draw a wire through an irregular sequence of brackets (i.e. the unwanted resistance to movement), it measures the net desired force remaining on a displaced tooth. The study showed that a tooth displaced 3 mm vertically from the line of the arch with a 0.012′′ wire has only 50 g of net aligning force available with conventional ligation compared to over 90 g with most self-ligating brackets. With 4.5 mm of displacement, there is no remaining force available for alignment of

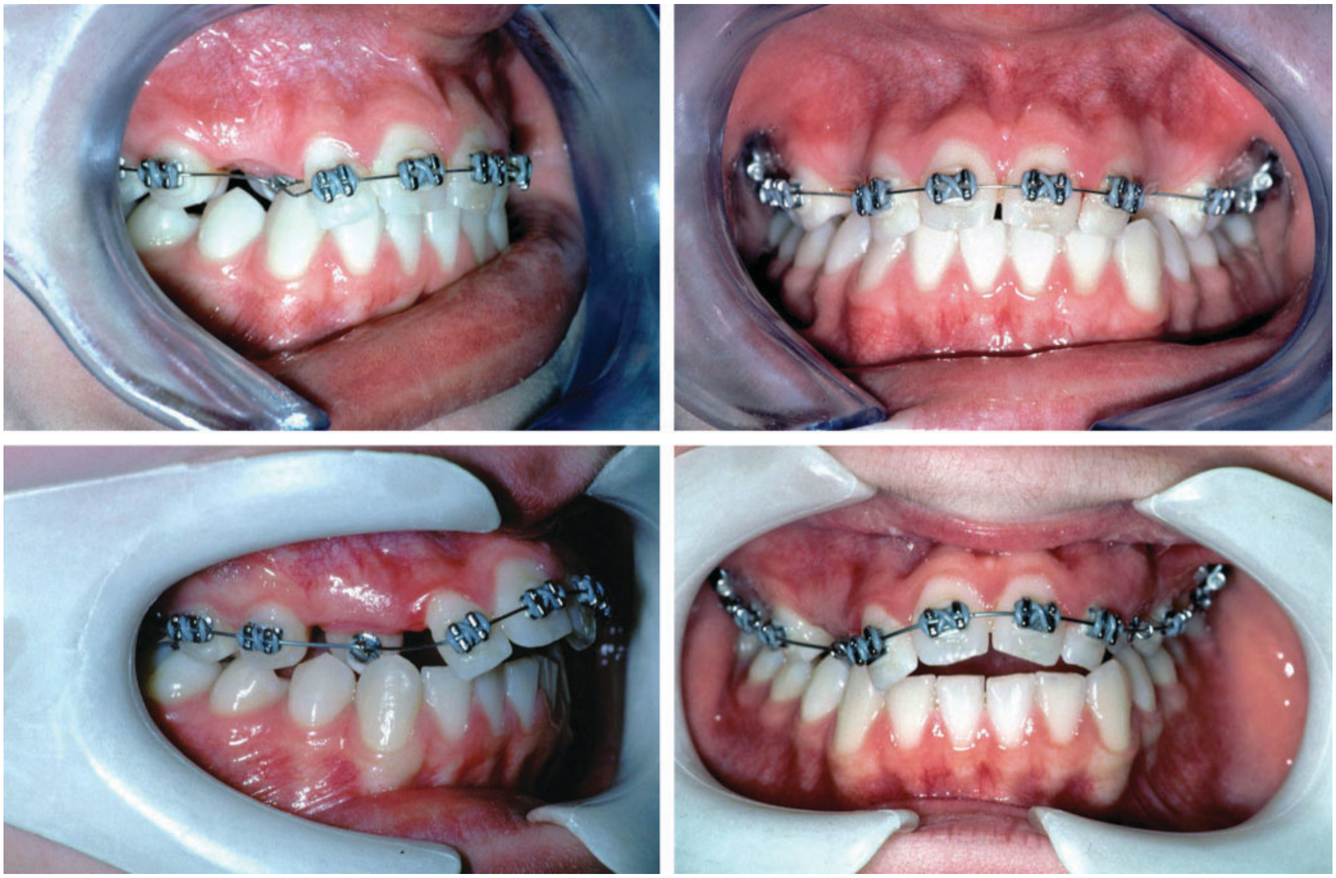


Figure 12 The changes in one visit showing substantial incisor proclination with figure of 8 elastomeric ligatures (reproduced with the kind permission of Dr David Birnie)

the displaced tooth with conventional brackets but over 80 g remains with self-ligating brackets in spite of the binding at each corner of the brackets.

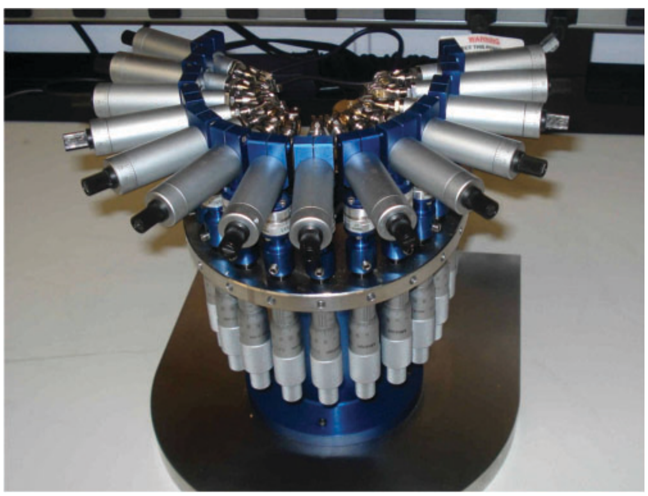
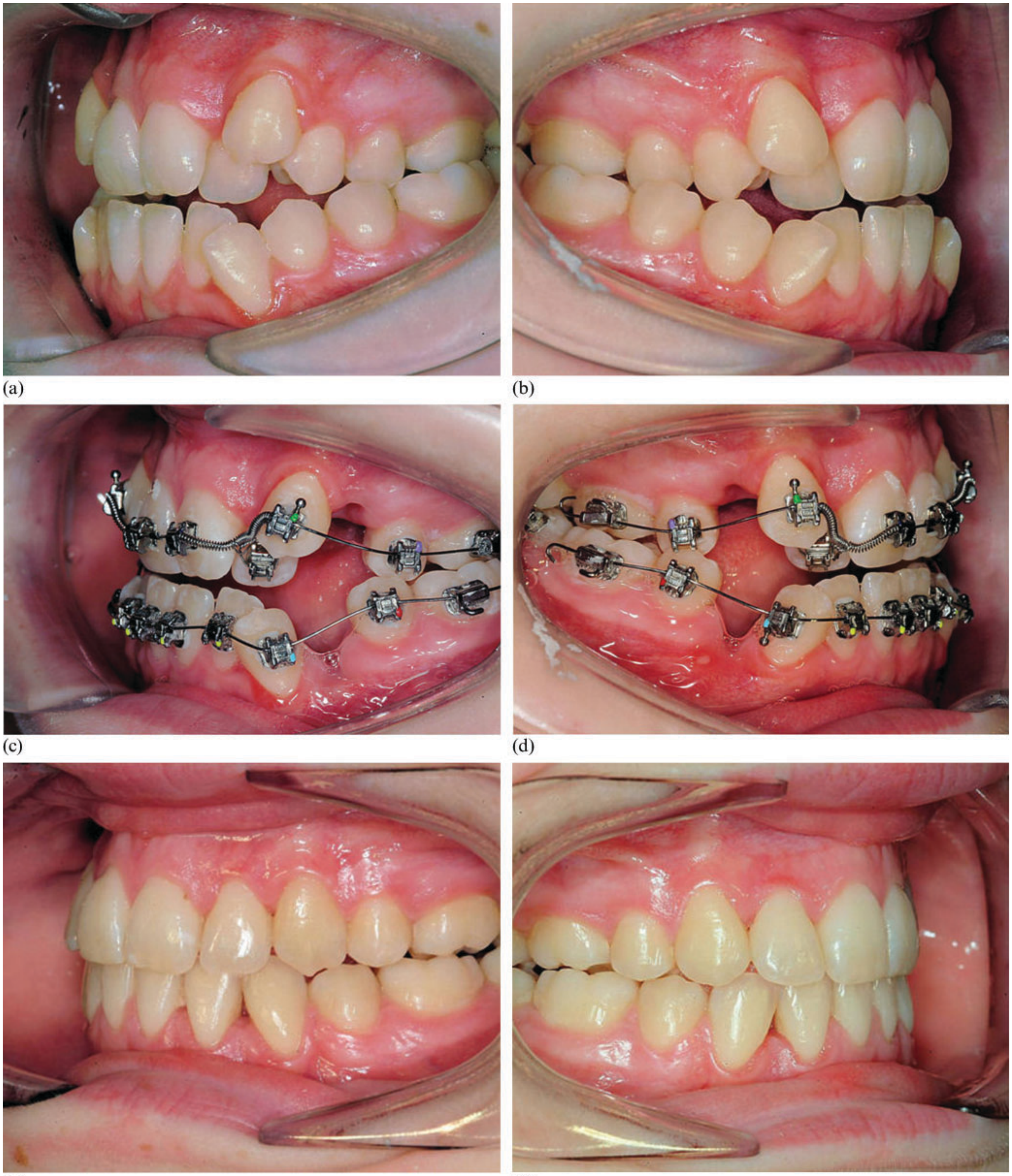


Figure 13 The Orthodontic Simulator (OSIM) developed by Hisham Badawi (reproduced with the kind permission of the author)

These recent studies support this author's view that self-ligation is not inherently and in all situations a low force system. Indeed with any given wire the lack of friction raises the net force on irregular teeth; however, the highly significant corollary is that with a suitably low-force wire in an irregular arch, self-ligation can still produce effective tooth moving forces[28] and these forces are combined with low unwanted forces on adjacent teeth. It is these unwanted forces which can resist or adversely change the direction of tooth movement. This difference in the combination of desirable and unwanted forces requires further experimental confirmation, but is probably a distinctive feature of self-ligation, which is less obvious than the combination of low friction and good control, but is equally significant. The role of forces arising from the soft tissues will remain less amenable to realistic measurement, but it may not be necessary to propose any significant change in soft tissue behaviour in order to explain tooth movements which at first encounter may prompt such suggestions. The exploration of this area of conjecture has some similarities to the long journey which led to our sound



(a) (b) (c) (d) (e) (f)

Figure 14 A case treated with passive self-ligation with extractions indicated by the need to create a positive incisor overbite rather than by the need to accommodate crowded teeth understanding and quantification of the mode of action of functional appliances.

Does self-ligation reduce the need for extractions?

A scrutiny of this claim benefits from some dissection of the indications for extraction (Table 1).

Crowding: the combination of low friction and good archwire control which self-ligation provides makes it practically easier to align crowded arches without extractions, if that is desired, than with conventional ligation. This reason for extraction is correspondingly reduced.

Profile: if research confirms that self-ligation can align teeth with less incisor proclination and relatively more lateral expansion, then this would reduce the need for extraction to prevent or correct a profile which is too full.

Interarch relationships: self-ligation in itself does not, in the opinion of this author, reduce the potential role for extractions to reduce an overjet. It may however help prevent the creation of an unwanted overjet as illustrated in Figure 12. With regard to establishing a positive overbite, it is equally possible that a reduction in incisor proclination for a given amount of tooth alignment may reduce the need for extractions to maintain a positive overbite, but there will always be cases where any such effect will be insufficient to eliminate the need for extractions. Such a case is illustrated in Figure 14 where self-ligation probably facilitated the alignment of very crowded teeth, but where extractions were still included in order to help achieve the incisor relationship.

This case has a very different initial incisor relationship to the case in Figure 10 and hence the indication for extraction although the degree of crowding is similar in the two cases.

These potential biomechanical differences with self-ligation compared with conventional ligation do, of course, leave as a separate, but related issue the choice for every clinician of the treatment goals in relation to arch expansion or antero-posterior incisor position.

Table 1 Reasons for extraction of teeth.

■ Space for alignment of crowded teeth
■ Improvement in profile
■ Inter-arch relationships
• Correction of overjet
• Increase of overbite

Self-ligation – the future

Lastly, this Northcroft lecture gives some hostages to fortune by including some predictions about self-ligation in the future. With regard to research, I predict that investigations with equipment such as Hisham Badawi's OSIM will show that the biomechanics is not always straightforward, but that self-ligation does indeed offer different and more desirable forces when compared to conventional ligation and that active self-ligating brackets are rather less advantageous than passive brackets in this regard. With regard to treatment efficiency, I predict that RCTs will continue to fail to show that there is a blanket advantage for self-ligation in this respect, but that if investigators and funding persist (and they did not with nickel–titanium archwires or the pre-adjusted appliance), it will eventually be shown that in some malocclusions treated with particular brackets and wires and treatment intervals, self-ligation is more efficient.

With regard to clinical practice, I predict that self-ligation will continue its advance to becoming the conventional form of ligation. At the lowest denominator this will be driven by the speed, convenience and neatness of the ligation mechanism, which was the original motivation for developing such brackets. The other currently established advantages will add to the clinician's appreciation of these brackets and the exploration of the wider hypotheses will be fascinating to observe and to take part in. George Northcroft was clearly keen on clinicians sharing their thoughts and experiences and he initiated and fostered collective learning. In the hundred years since he sparked what was to grow into the British Orthodontic Society, there have been many new ideas and innovations. We owe it to our patients to bring an enthusiastic, yet informed and critical scrutiny to all of these ideas and developments, but I am confident that at this stage, he would have come to the view that self-ligation is an idea whose time has come.

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