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Self-ligating appliances: evolution or revolution?

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Aims: To review the literature relating to self-ligating orthodontic appliances.
Methods: Narrative review of the relevant historic and contemporary research.
Results: Proposed advantages of these appliance systems include reduced friction, more efficient mechanotherapy, improved operator efficiency, and more secure ligation. Randomised clinical trials investigating these potential advantages have largely been equivocal.
Conclusions: Self-ligating brackets are here to stay and continue to be refined and enhanced. Further prospective studies investigating their clinical application and performance would be welcome.
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Introduction

Since the advent of the earliest orthodontic appliances[1] clinicians have continually strived to produce modifications and enhancements to improve force delivery and operator efficiency. Major advances in the 20th century included the development of the edgewise appliance, hailed by its inventor as the 'latest and the best';[2] the discovery of enamel bonding techniques;[3] the subsequent application of bonding to orthodontics;[4] and the advent of the pre-adjusted edgewise appliance.[5] In the future will the renaissance of self-ligating appliances be viewed in a similar light? Certainly these systems have captured the imagination of many clinicians and are increasing in popularity.[6,7]

Pre-adjusted edgewise appliances

Numerous variations on Andrews' original prescription have been introduced into appliance systems over the past 30 years, although the basic principles are unchanged;[8,9] the advent of self-ligating brackets represents a further advancement. The designs of pre-adjusted edgewise brackets on the market include single, twin and combination edgewise. In the twin type there are four tie wings for archwire ligation, a broader shape and consequent reduction in the inter-bracket distance. Broad brackets may improve rotational control and reduce mesio-distal tipping, but the consequent reduction of the inter-bracket span of wire makes the archwire less flexible.[10]

Traditionally, steel or elastomeric ligatures are used to secure the archwire in the bracket slot, although neither system is ideal. According to Harradine,[11] the ideal bracket ligation system should be secure and robust; allow the archwire to be fully engaged in the bracket; have low friction between bracket and archwire; be quick and easy to use; allow high friction if required; allow attachment of elastic chain; assist good oral hygiene; and be comfortable.

Self-ligating brackets have been developed in an attempt to better approximate these ideal properties by overcoming the limitations of steel and elastomeric ligatures in terms of ergonomics, efficiency, plastic deformation, discoloration, plaque accumulation and friction.

Self-ligating brackets

Self-ligating brackets are ligature-less bracket systems having a mechanical device built into the bracket to close off the edgewise slot.[12] Secure engagement may be produced by an in-built metal labial face or by a clip mechanism replacing the steel or elastomeric ligature.

Both active and passive self-ligating brackets have been developed; these terms refer to the bracket-

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Figure 1. System R brackets (GAC International).



Figure 2. SmartClip (3M Unitek) brackets, a passive self-ligating appliance.



Figure 3. Damon MX brackets; this is a semi-aesthetic passive appliance.

Table I. Self-ligating bracket systems (Adapted from Harradine[11]).

System	Year
Russell Lock	1935
Ormco Edgelok*	1972
Forestadent Mobil-Lock*	1980
Strite Industries Speed*	1980
'A' Company Activa*	1986
Adenta Time*	1994
'A' Company Damon SL*	1996
Ormco TwinLock*	1998
'A' Company/Ormco Damon 2*	2000
GAC In-Ovation*	2000
GAC In-Ovation R*	2002
Forestadent Phillippe*	2002
3M Unitek SmartClip*	2004
Denrum SURE*	2005
Forestadent Quick*	2005
Ormco Damon 3MX*	2006
3M Unitek SmartClip 2*	2006
GAC InOvation C*	2006
3M Unitek Clarity SL*	2007

* Trade names

archwire interaction. The active type has a spring clip that presses against the archwire e.g. System R (GAC International, USA; Figure 1) and Speed (Strite Industries, Canada). In the passive type the clip or rigid door does not actively press against the archwire e.g. SmartClip (3M Unitek, USA; Figure 2) and Damon 3MX (Ormco 'A' Company, USA; Figure 3). Active self-ligating appliances may allow better torque control with undersized archwires than the passive appliances; storage of potential energy in a spring clip may also enhance the potential for labio-lingual alignment.[11] However, the resistance to sliding is thought to be lower for passive appliances; this may enhance the aligning capability of these systems (Figure 4).

History of self-ligating appliances

The concept of self-ligating brackets is not new, being described initially in 1935 with the Russell Lock edgewise attachment.[13] The purported advantages of the earlier systems included a 50 per cent improvement in operator efficiency.[13] A resurgence in popularity of self-ligation occurred in the 1990s reflecting further refinement,[14] with many self-ligating systems since patented (Table I). More recent developments include SmartClip 2, InOvation C and Damon 3MX.

Properties of conventional and self-ligating pre-adjusted edgewise systems

A number of potential advantages of self-ligating appliances have been claimed[11] including: more robust and secure ligation,[6] reduced friction,[15] enhanced efficiency and ease of use,[16] reduced overall treatment time,[6,17] efficient alignment of severely irregular teeth,[6] improved patient comfort,[18] better plaque control and anchorage conservation,[18] and reduced risk of operator injury including 'puncture wounds'.[16]

To date there is no published research concerning the latter three purported advantages, although both in vivo and in vitro research relating to the other potential advantages is emerging. It is also important to mention that significant differences exist between the various self-ligating systems and therefore the findings from individual trials are not applicable to all other such appliances. In particular, the mechanism of wire engagement varies among self-ligating brackets; wire



Figure 4a



Figure 4b



Figure 4c



Figure 4d



Figure 4e



Figure 4f

Figure 4. Interaction of self–ligating brackets with 0.016 inch round archwire (Figures 4a-c) and 0.019 x 0.025 inch rectangular archwire (Figures 4d-f). An active appliance (System R) is shown in Figures 4a and 4d and passive appliances (SmartClip 2 and Damon MX) in Figures 4b, 4c, 4e and 4f. Both passive and active brackets are interactive with contact between the wire and part of the bracket slot.

ligation may be active or passive, brackets may be single or twin in morphology, and bracket dimensions and profiles differ. Of the nine proposed advantages the following have been investigated:

Secure robust ligation/full bracket engagement

The shortcomings of elastomeric materials are well-known. Taloumis et al.[19] in an in vitro study highlighted high decay rates of elastomeric forces within 24 hours. The authors concluded that the tested ligatures appeared to be suitable for use during initial aligning and levelling, but that the rapid force loss and permanent deformation of these products could 'preclude their use for rotational and torque corrections'.

Dowling et al.[20] in an in vitro investigation into behavioural characteristics of elastomeric modules showed a reduction in strength of 10 to 35 per cent of the initial value after immersion in a simulated oral environment for a period of four weeks.

Other studies on force degradation of elastomerics have shown force reductions of 50 to 73 per cent over a similar period.[21,22] Degradation of elastic performance has been found to cause a significant loss of full bracket engagement as the elastomeric stretches, which is not mirrored by a concomitant reduction in frictional forces.[22] Elastomerics in a figure-of-eight configuration make archwire ligation more secure; however, this improvement comes at the expense of increased frictional resistance,[23] which may be of the order of 70 to 220 per cent.[24]

Self-ligating systems allow secure ligation as full, robust engagement is assured unless the clip or slide mechanism fails or the bracket debonds.[11] However, in a retrospective analysis of Damon SL brackets 50 per cent of patients had slide breakages, which occurred almost always during slide opening or closure.[6] The author reported that the introduction of newer systems had 'virtually eliminated' such problems; clinical impressions support this view.

Table II. In vitro studies on the influence of bracket type and ligation mode on frictional resistance, arranged in chronological order.

Study	Systems tested	Highest friction	Intermediate friction	Lowest friction
Shivapuja and Berger[18]	7	Ceramic conventional*	Speed	Edgelok
Voudouris[31]	3	Sigma	Interactwin	Damon SL
Thomas et al.[32]	4	'A' Company Twin	Time	Damon
Kapur et al.[33]	2	MiniTwin	–	Damon
Pizzoni et al.[34]	4	Conventional 'A' company	Speed	Damon SL
Hain et al.[23]	4	Victory with elastomerics	Speed	Victory with loose steel ligatures
Khambay et al.[35]	4	Conventional appliance with elastomerics*	Conventional appliance with steel ligatures*	Damon II
Griffiths et al.[36]	4	Inspire with SuperSlick module	Inspire brackets with elastomeric	Damon II
Tecco et al.[37]	3	Victory	Damon II	Time Plus
Henao and Kusy[38]	4	Mini Diamond	Damon II	In-Ovation

* Denotes unspecified conventional pre-adjusted edgewise appliance.

Furthermore, prospective clinical research has shown bond failure rates of self-ligating systems to be comparable to those associated with conventional appliances.[25]

Reduced friction

Read-Ward et al.[26] suggest that static friction is of greatest importance in tooth movement as, during sliding mechanics, tooth movement occurs in a series of short jumps as the archwire and biological resistance strive to upright the root through alveolar bone. Low friction is desirable within the bracket system to facilitate efficient arch levelling, alignment and space closure while keeping anchorage requirements low. Occasionally high friction is preferable to prevent unwanted movement of a tooth along the wire, and to facilitate torquing movements.[11,27]

Research on frictional resistance to orthodontic tooth movement in vivo is complex; therefore our knowledge is almost entirely derived from laboratory-based investigations using simulated oral environments. However, it is clear that the nature of ligation has a bearing on friction within the appliance system with Schumacher et al.[28] suggesting it be the primary determinant.

Meling et al.[29] examined the effects of friction in vitro and concluded that each elastomeric placed in an 'o' configuration exerts a frictional force similar to the application of 50 g tensile force to the archwire. Moreover, Bednar et al.[30] showed that elastomerics introduced more friction into the appliance system than slackened steel ligatures. Shivapuja and Berger[18] confirmed this finding, reporting that wire ligatures produce 30–50 per cent of the frictional forces attributed to elastomerics, but that these forces still reach undesirable levels.

A plethora of in vitro studies has highlighted reduced friction in self-ligating systems in simulated oral environments (Table II). Passive self-ligating appliances (Damon II, SmartClip) typically have lower friction than active systems (System R, Speed) although results have been variable,[39] reflecting inconsistencies in experimental design. Frictional resistance seems to increase dramatically in self-ligating systems in regions of greater bracket displacement, corresponding to crowded segments in the clinical situation.[38,40]

Friction in vivo

Laboratory investigations have attempted to replicate the impact of the oral environment on the appliance system by mimicking dentoalveolar tissues, using salivary substitutes and intermittent jiggling forces similar to masticatory forces. However, it is difficult to determine how representative such simulations are of the clinical scenario; tooth movement is a complex process resulting from a combination of periodontal tissue adaptation and bone remodelling induced by

Table III. Reduction in friction with masticatory forces (After O'Reilly et al.[46]).

Arch wire	% reduction in friction
0.021 x 0.025 inch stainless steel	85
0.019 x 0.025 inch stainless steel	80
0.019 x 0.025 inch beta-titanium	27
0.016 inch stainless steel	19

stress.[41] These factors coexist with growth in the clinical situation, making accurate replication in the laboratory impossible. Indeed the importance of friction within orthodontic appliances in vivo is debated.[42] Although a reduced friction appliance may be expected to produce more rapid, efficient alignment, rotational correction and space closure, no published clinical evidence to confirm this exists.[23]

In the crowded dentition friction within the appliance system may be vastly increased. Read-Ward et al.[26] reported that the reduction in friction with self-ligating systems may be much less when the wire is active. Speed brackets in particular produced low friction in round wires; however, friction increased greatly with rectangular wires due to the engagement of the active spring clip. The latter study contrasts with an in vitro study,[38] highlighting almost identical levels of friction with active (InOvation) and passive (Damon II) appliance systems.

In a further in vitro study[43] with inbuilt tip and rotation of the brackets to mimic dental irregularity in vivo, little difference in friction was noted between Damon SL and conventionally ligated brackets. Thorstenson and Kusy[44,45] also examined the effects of varying bracket angulation on the resistance to sliding, simulating the influence of dental crowding on friction. At all degrees of tip the Damon brackets resulted in slightly less friction, although friction increased in the presence of crowding for both appliance systems. These findings, allied to those of Henao and Kusy,[38] underscore the reduction in frictional resistance associated with self-ligating systems, while suggesting that differences may be less marked than those reported in many other in vitro investigations.

Masticatory activity may reduce the impact of frictional resistance within an orthodontic appliance system in vivo. In a further in vitro analysis, repeated bracket displacement simulating the masticatory cycle was produced, while the frictional resistance was measured using an Instron universal testing machine (Table III).[46] The authors concluded that the importance of friction in orthodontic appliances might be overstated, given the likelihood of bracket or archwire displacements under masticatory forces in vivo. Similar conclusions were reached by Iwasaki et al.[47] who investigated the influence of masticatory forces on friction within a conventional appliance system in a clinical trial. Ten subjects chewed gum with the device in place, to determine whether vibration eliminated friction when compared to ex vivo measurements. The results suggested that vibration introduced by mastication reduced, but did not eliminate, friction when sliding a bracket along an archwire.

On the basis of the available evidence, Harradine[11] concludes that self-ligation provides a very significant reduction in friction in all dimensions of tooth movement. He believes that self-ligating systems enable a tooth to 'slide along an archwire with lower and more predictable net forces, while maintaining complete control, with almost none of the undesirable rotation of the tooth resulting from a deformable mode of ligation, such as an elastomeric'. Although this may well be the case, at this stage robust clinical evidence supporting this observation has not been published.

Efficiency and ease of use

Self-ligation seems to result in a consistent, but modest, reduction in chairside time for fixed appliance adjustment over conventional appliances (Table IV). In particular the use of self-ligating appliance systems results in a dramatic improvement in chairside efficiency when compared to removal and insertion of archwires using steel ligatures.[18] Authors have suggested this saving could be used to schedule more patients, increase efficiency, improve patient relations, or allow oral hygiene reinforcement.[16]

Reduced overall treatment time

Harradine[6] retrospectively compared the overall treatment duration of 30 cases treated with Damon SL brackets to 30 matched cases treated by the same operator with conventional brackets. The Damon SL cases required an average of four fewer months (19.4 versus 23.5 months) and four fewer visits (12.7 versus 16.5) to be treated to an equivalent standard based on

Table IV. Reported reduction in appointment time required for archwire removal and insertion with self-ligating appliances compared with conventional orthodontic appliances, arranged in chronological order.

Study	Self- ligating system(s)	Conventional mode of ligation	Time saving
Maijer and Smith[16]	Speed	Elastomerics	7 mins
Shivapuja and Berger[18]	Activa, Edgelok, Speed	Wire ligatures	12 mins
Shivapuja and Berger[18]	Activa, Edgelok, Speed	Elastomerics	1 min
Voudouris[31]	Interactwin	Elastomerics	2.5 mins
Berger and Byloff[48]	Speed	Elastomerics	2-3 mins
Harradine[17]	Damon SL	Elastomerics	25 secs
Turnbull and Birnie[49]	Damon 2	Elastomerics	1.5 mins

the Peer Assessment Rating scores. This study was retrospective, with the author conceding that the selection of cases for inclusion may have reflected a 'tendency to include only the more successful and pleasing'. A further clinical study in three practices found an average reduction in treatment time of six months (31 versus 25 months) and seven visits (from 28 to 21) for Damon SL cases compared with conventional ligation.[17] However, retrospective studies of this nature are potentially biased due to uncontrolled factors including operator experience and preference, differing archwires and archwire sequences, and modified appointment intervals.

Miles et al.,[50] commenting on these retrospective studies, reported that the reduction in treatment times described may merely reflect a transition to more efficient treatment systems rather than being related purely to use of the self-ligating appliance. He also suggests that with the advent of more efficient treatment approaches, the use of self-ligating brackets is likely to be less influential. In addition, it is interesting to note the significant discrepancy in the length of treatment and the number of visits required between the two studies.

More efficient alignment

Miles[7] compared the alignment efficiency of SmartClip brackets and conventional twin brackets in a prospective analysis of 48 patients. The SmartClip bracket was no more effective at reducing irregularity during the initial stage of treatment than a conventional twin bracket ligated with elastomeric modules or stainless steel ligatures. The author noted 0.7 mm more irregularity remained after initial alignment in the group treated with SmartClip than in a group treated with Victory, which he attributed to the rotational play of 6.8 degrees allowed by the passive self-ligating system using a 0.014 inch aligning NiTi wire. This study was limited by a small sample size, two-dimensional measurement, inclusion of both extraction and nonextraction cases, and confinement of measurement to the labial segment only.

In a further clinical investigation of 58 patients, Miles et al.[50] compared efficiency of alignment and patient comfort related to Damon 2 and a conventional twin bracket in nonextraction cases, using a split-mouth study design. At 10 week and 20 week intervals the twin bracket had achieved an irregularity index of 0.2 mm lower than Damon 2 brackets. The initial aligning wire used in that trial was also 0.014 inch NiTi with the potential for greater rotational play; this was followed by a 0.016 × 0.025 inch CuNiTi wire. Early introduction of a 0.025 inch wire depth is advocated by users of the Damon appliance to facilitate early rotational correction; nevertheless, this failed to result in enhanced alignment efficiency. This study adopted a split-mouth design eliminating the confounding effects of metabolic variation; however, this invalidated measurement between the mandibular central incisors as a bracket from each system was placed on the central incisors. Furthermore, the Damon 2 brackets are a higher profile bracket and engage the wire via a gate mechanism; these factors may influence the nature and efficiency of dental alignment.

These findings suggest that any time saving arising from use of self-ligating brackets does not occur in the initial alignment phase of treatment. However, alleviation of dental irregularity is impossible to measure perfectly; most trials have failed to control for individual metabolic variation; and the results may have been unintentionally biased by inaccurate bracket placement. Nevertheless, unless time savings arise later in treatment, on the basis of these prospective studies, it seems unlikely that self-ligating systems counterbalance their additional expense by resulting in more efficient treatment or better treatment outcomes in each case.

Enhanced patient comfort

Miles et al.[50] also assessed subjective pain experience related to Damon 2 and a conventional pre-adjusted system. Damon 2 brackets initially were less painful than the conventional brackets, but were associated with more pain when ligating the second archwire. The Damon 2 bracket, a higher profile bracket, is also likely to result in greater soft tissue impingement; however, no difference in lip irritation was reported between the two groups.

Arch dimensional change and stability

Although self-ligating appliances have been established for almost 20 years, there are no published detailed investigations of arch dimensional changes related to treatment with self-ligating systems. Consequently, the implications of treatment with such appliances on long-term stability remain unclear. A number of isolated case reports documenting dimensional changes with the Damon appliance during treatment have been published.[14,51,52] These cases have described inter-molar width increases exceeding 10 mm allowing nonextraction treatment; the longevity of such significant changes is likely to be reliant on permanent retention. However, most advocates of self-ligating appliances do not aim for such expansion, preferring to maintain pretreatment dimensions where possible.

A recent prospective study[53] compared the effects of the two pre-adjusted appliances on angular and linear changes of the mandibular incisors, and transverse mandibular arch dimensional changes over a minimum period of 30 weeks. Subjects were treated with a predetermined archwire sequence: 0.016 inch; 0.017 × 0.025 inch; 0.019 × 0.025 inch martensitic active NiTi archwires (Nitinol XL, 3M Unitek, USA) and 0.019 x 0.025 inch stainless steel archwires of uniform archform. Bracket type had no effect on incisor inclination changes or the widths between the canines, first premolars and second premolars. However, the self-ligating appliance produced significantly more expansion in the molar region (0.91 mm; p = 0.009). This finding arose despite the use of archwires of uniform dimensions in both groups, and the profiles of the bracket types being similar. Additionally, potential confounding factors including pretreatment inter-molar dimension and the degree of crowding resolved during treatment were accounted for in the statistical model. This outcome indicates that the mechanism of arch alignment produced by this passive self-ligating system may be different from conventional appliances. Importantly, the amount of crowding resolved during the study period was small (2.65 mm). Consequently, it would be reasonable to expect the observed effect to be more marked in crowded arches, although further research to confirm this assumption would be welcome.

Transverse expansion in the inter-molar region is a routine finding leading to the development of spacing in the buccal segments during arch levelling and alignment with the Damon passive self-ligating appliance.[51,52] An elastomeric tie-back module has been developed to deal specifically with this problem; however, the Damon appliance also incorporates expanded archwires, which may contribute significantly to the degree of expansion produced. It remains unclear whether similar expansion will occur with standard archwire forms.

Torque expression

The influence of bracket type on torque expression in the upper labial segment has been assessed in a randomised controlled trial.[27] The Damon 2 appliance was found to be equally capable of torque delivery to a conventional bracket system of Roth prescription relative to the S-N and N-A point lines. This finding may be surprising as an in vitro study has highlighted that the Damon 2 slot may be oversized by up to 17 per cent at the base and may deviate from the expected rectangular cross-section and from the torque reported;[54] however, effective torque delivery involves the interaction of many factors.[55]

Little difference in incisor inclination change was also reported in the mandibular arch for SmartClip and conventional brackets with MBT prescription in a prospective clinical trial. Incisor proclination of 4.41 degrees and 4.32 degrees occurred in the respective groups during arch levelling and alignment; incisor proclination was governed largely by the initial incisor inclination and the degree of crowding resolved during the study period.[53] It is also believed that active self-ligating appliances pressing the wire into the base of the bracket may facilitate more effective torque expression with undersized archwires than passive self-ligating systems.[56]

Conclusions

On the basis of the reviewed literature the following conclusions may be drawn:

Self-ligating systems outperform appliances ligated in a conventional manner in the ex vivo situation, producing considerably less friction within the appliance system; however, this effect is less marked in vivo.

Disagreement exists in relation to the importance of friction within orthodontic appliances, both conventional and self-ligation, in vivo.

There appears to be little difference in the alignment efficiency related to conventional and self-ligating appliance systems.

Clinical data documenting efficiency of rotational correction and space closure for self-ligating systems remains limited.

Use of self-ligating brackets results in a marginal reduction in chairside time required for appliance manipulation (Table IV).

There is limited, retrospective evidence pointing to reduced overall treatment time with fewer scheduled appointments for self-ligating systems.

While many clinicians advocate the use of selected self-ligating appliances to facilitate expansion facilitating nonextraction treatment, there is no published long-term follow-up on the stability of this approach.

Self-ligating appliances are a welcome evolution commanding an ever-increasing market share and undoubtedly representing the pinnacle of bracket technology. To date published prospective trials into these systems have considered alignment efficiency during the initial stages of treatment; torque expression in the upper labial segment; pain experience; and the efficiency of appliance manipulation. By and large the clinical promise of these systems has not been reflected in the outcomes of these controlled clinical trials.

A lack of supporting evidence does not invalidate the appliances; indeed the pre-adjusted edgewise appliance also has little evidence to support its widespread adoption.[57] Nevertheless, in this era of evidence-based dentistry, further affirmative evidence would be reassuring, particularly the analysis of effects of self-ligating appliances on plaque accumulation and periodontal health, and on closure of extraction spaces. However, with continued refinement and resourceful application of active and passive properties, the proposed benefits of self-ligating systems may be harnessed, leading to unparalleled flexibility and versatility in treatment mechanics.

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