OVERVIEW

Self-Ligating Appliances: Evolution or Revolution?

PADHRAIG S. FLEMING, BDS, (Hons.), MS, MFD RCS, MFDS RCS, MOrth RCS
ANDREW T. DIBIASE, BDS (Hons.), MS, MOrth RCS, FDS RCS
ROBERT T. LEE, MDS, DOrth, MOrth, FDS RCS, FDS RCPS

(Editor's Note: In this quarterly column, JCO provides an overview of a clinical topic of interest to orthodontists. Contributions and suggestions for future subjects are welcome.)

Since the earliest orthodontic appliances,[1] clinicians have continually produced 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 preadjusted 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]

Preadjusted Edgewise Appliances

Numerous variations on Andrews's original prescription have been introduced over the past 30 years, but the basic principles are unchanged[8,9]; self-ligating brackets represent a further advancement. The designs of preadjusted edgewise brackets on the market include single, twin, and combination edgewise. The twin type has four tie wings for archwire ligation and a broader shape. Broader brackets may improve rotational control and reduce mesiodistal tipping, but the resulting reduction in the interbracket span of wire makes the archwire less flexible.[10]

Traditionally, stainless steel or elastomeric ligatures are used to secure the archwire in the bracket slot, although neither system is ideal. According to Harradine, the ideal bracket ligation system should be secure and robust, allow the archwire to be fully engaged in the bracket, pro-

Dr. Fleming is Senior Registrar in Orthodontics and Dr. Lee is a Professor, Department of Orthodontics, Royal London Hospital, London. Dr. Fleming is Senior Registrar and Dr. DiBiase is Consultant Orthodontist, Kent and Canterbury Hospital, Canterbury, England. Contact Dr. Fleming at Department of Orthodontics, Royal London Dental Institute, Whitechapel, London E1 1BB, England; e-mail: padhraigfleming@hotmail.com. This article is reprinted by permission from Austral. Orthod. J. 24:41-49, 2008.


Dr. Fleming


Dr. DiBiase


Dr. Lee

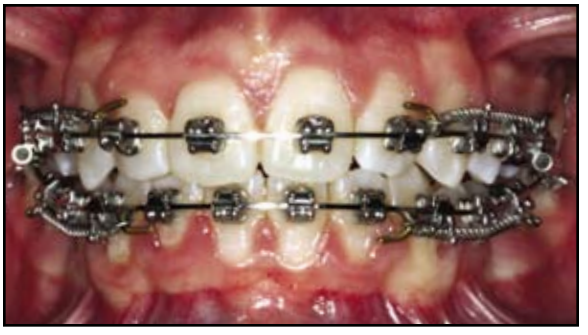

Fig. 1 In-Ovation R brackets.*

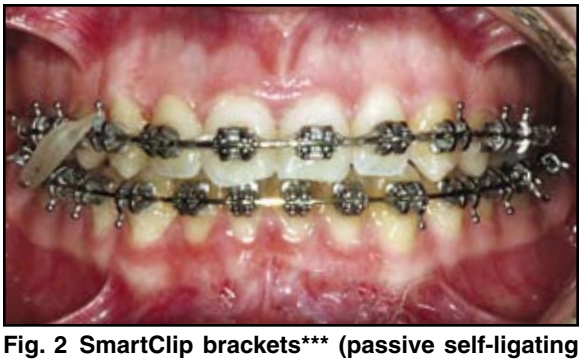

Fig. 2 SmartClip brackets* (passive self-ligating appliance).**

Fig. 3 Damon 3MX brackets† (semi-esthetic, passive self-ligating appliance).

duce low friction between bracket and archwire, be fast and easy to use, allow high friction if required, allow attachment of elastic chain, promote good oral hygiene, and be comfortable.[11]

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

Self-Ligating Brackets

A self-ligating bracket is a ligature-less system with a mechanical device built in to close off the edgewise slot.[12] Secure engagement may be produced by a built-in metal labial face or by a clip mechanism replacing the stainless steel or elastomeric ligature.

Both active and passive self-ligating brackets have been developed, referring to the bracket-archwire interaction. The active type has a spring clip that presses against the archwire (In-Ovation R,* Fig. 1; SPEED**). In the passive type, the clip or rigid door does not actively press against the archwire (SmartClip,*** Fig. 2; Damon 3MX,† Fig. 3). Active self-ligating appliances may allow better torque control with undersize archwires than can be achieved with passive appliances; storage of potential energy in a spring clip may also enhance the potential for labiolingual alignment.[11] The resistance to sliding is thought to be lower for passive appliances, however, which may improve the aligning capability of these systems (Fig. 4).

History of Self-Ligating Appliances

The concept of self-ligating brackets is not new, having been described initially in 1935 with the Russell Lock edgewise attachment[13] (Table 1). The purported advantages of the early systems included a 50% 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 having

*GAC International, Inc., 355 Knickerbocker Ave., Bohemia, NY 11716; www.gacintl.com. In-Ovation is a registered trademark.

**Trademark of Strite Industries Ltd., 298 Shepherd Ave., Cambridge, Ontario, Canada N3C 1V1; www.strite.com.

***Trademark of 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

†Registered trademark of Ormco/"A" Company, 1717 W. Collins Ave., Orange, CA 92867; www.ormco.com.

since been patented. Recent products include the SmartClip 2, In-Ovation C,* and Damon 3MX.

Properties of Conventional and Self-Ligating Preadjusted Edgewise Systems

A number of potential advantages of self-ligating appliances have been claimed,[11] including more secure and robust 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]

There are no published data on the last three purported benefits to date, but both in vivo and in vitro research relating to the other potential advantages is emerging. It is also important to mention

*GAC International, Inc., 355 Knickerbocker Ave., Bohemia, NY 11716; www.gacintl.com. In-Ovation is a registered trademark.

TABLE 1
HISTORY OF SELF-LIGATING BRACKET SYSTEMS

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

Adapted from Harradine.[11]
Product names are trademarks of their respective companies.

Fig. 4 Interaction of self-ligating brackets with .016" round archwire (A-C) and .019" × .025" rectangular archwire (D-F). Active appliance (In-Ovation R) is shown in A and D, passive appliances (SmartClip 2 and Damon 3MX) in B, C, E, F. Both passive and active brackets are interactive, with contact between wire and part of bracket slot.

that significant differences exist among the various self-ligating systems, and that the findings from individual trials may therefore not be applicable to all other appliances. In particular, the mechanism of wire engagement varies among self-ligating brackets, wire ligation may be active or passive, brackets may be single or twin in morphology, and bracket dimensions and profiles differ.

Of the nine reported advantages of self-ligating systems, the following have been investigated:

Secure, Robust Ligation and Full Bracket Engagement

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

Dowling and colleagues, in an in vitro investigation of elastomeric modules, showed a reduction in strength of 10-35% of the initial value after immersion in a simulated oral environment for a period of four weeks.[20]

Other studies on degradation of elastomerics have shown force reductions of 50-73% over similar periods.[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] A figure-8 configuration seems to make archwire ligation more secure, but this improvement comes at the expense of increased frictional resistance,[23] which may be on the order of 70-220%.[24]

Self-ligating systems allow secure ligation because full, robust engagement is assured unless the clip or slide mechanism fails or the bracket debonds.[11] In a retrospective analysis of Damon SL† brackets, however, 50% of patients had slide breakages, which almost always occurred 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. 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 and colleagues suggested that static friction is of greatest importance in tooth movement; 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.[26] Low friction is desirable within the bracket system to facilitate efficient arch leveling, alignment, and space closure while keeping anchorage requirements low. Occasionally, high friction is needed 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. Nevertheless, it is clear that the nature of ligation has a bearing on friction within the appliance system; in fact, Schumacher and colleagues suggested that it may be the primary determinant.[28]

Meling and colleagues examined the effects of friction in vitro and concluded that an elastomeric placed in an "O" configuration exerted a frictional force similar to the application of 50g of tensile force to the archwire.[29] Moreover, Bednar and colleagues showed that elastomerics introduced more friction into the appliance system than slackened stainless steel ligatures.[30] Shivapuja and Berger confirmed this finding, reporting that wire ligatures produced only 30-50% of the frictional forces attributed to elastomerics, but that these forces still reached undesirable levels.[18]

A plethora of in vitro studies have highlighted reduced friction in self-ligating systems in simulated oral environments (Table 2). The passive

†Registered trademark of Ormco/"A" Company, 1717 W. Collins Ave., Orange, CA 92867; www.ormco.com.

TABLE 2
IN VITRO STUDIES OF THE INFLUENCE OF BRACKET TYPE AND LIGATION MODE ON FRICTIONAL RESISTANCE

Study	No. Systems Tested	Highest Friction	Intermediate Friction	Lowest Friction
Shivapuja and Berger[18]	7	Ceramic conventional*	SPEED	Edgelok
Voudouris[31]	3	Sigma (American Orthodontics)	Interactwin (Ormco)	Damon SL
Thomas et al.[32]	4	Twin ("A" Company)	Time	Damon
Kapur et al.[33]	2	MiniTwin ("A" Company)	—	Damon
Pizzoni et al.[34]	4	Conventional ("A" Company)	SPEED	Damon SL
Hain et al.[23]	4	Victory with elastomerics (3M Unitek)	SPEED	Victory with loose steel ligatures
Khambay et al.[35]	4	Conventional* with elastomerics	Conventional* with wire ligatures	Damon 2
Griffiths et al.[36]	4	Inspire (Ormco) with SuperSlick module (TP Orthodontics)	Inspire brackets with elastomerics	Damon 2
Tecco et al.[37]	3	Victory	Damon 2	Time Plus (Adenta)
Henao and Kusy[38]	4	Mini Diamond (Ormco)	Damon 2	In-Ovation

*Unspecified conventional preadjusted edgewise appliance.
Product names are trademarks of their respective companies.

self-ligating appliances (Damon 2,† SmartClip) typically have lower friction than the active systems (In-Ovation R, SPEED), although the 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 clinical situations.[38,40]

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. It is difficult to determine how representative such simulations are of the clinical scenario, since tooth movement is a complex process resulting from a combination of periodontal tissue adaptation and bone remodeling induced by 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 debatable.[42] Although a reduced-friction appliance may be expected to produce more rapid, efficient alignment, rotational correction, and space closure, no published clinical evidence exists to confirm this hypothesis.[23]

Friction within the appliance system may be vastly increased in a crowded dentition. Read-Ward and colleagues reported that the reduction

†Registered trademark of Ormco/"A" Company, 1717 W. Collins Ave., Orange, CA 92867; www.ormco.com.

in friction achieved with self-ligating systems may be much lower when the wire is active.[26] SPEED brackets in particular produced low friction with round wires, but greatly increased friction with rectangular wires due to the engagement of the active spring clip. This study contrasts with an in vitro study finding almost identical levels of friction in active (In-Ovation*) and passive (Damon 2) appliance systems.[38]

In another in vitro study, using built-in tip and rotation of the brackets to mimic dental irregularity, little difference in friction was noted between Damon SL and conventionally ligated brackets.[43] Thorstenson and Kusy also examined the effects of varying bracket angulation on the resistance to sliding, simulating the influence of dental crowding on friction.[44,45] At all degrees of tip, the Damon brackets produced 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 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 with an Instron universal testing machine‡ (Table 3).[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 and colleagues, who investigated the influence of masticatory forces on friction within a conventional appliance system in a clinical trial.[47] Ten subjects chewed gum with the device in place to determine whether vibration would eliminate friction when compared to ex vivo measurements. The results suggested that vibration introduced by mastication reduced, but did not eliminate, the friction produced when sliding a bracket along an archwire.

TABLE 3
REDUCTION IN FRICTION WITH MASTICATORY FORCES

Archwire	Reduction in Friction
.021" × .025" stainless steel	85%
.019" × .025" stainless steel	80
.019" × .025" beta titanium	27
.016" stainless steel	19

After O'Reilly et al.[46]

On the basis of the available evidence, Harradine concluded that self-ligation provides a significant reduction in friction in all dimensions of tooth movement.[11] He stated 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, solid supporting clinical evidence has yet to be published.

Efficiency and Ease of Use

Self-ligation seems to result in a consistent, but modest, reduction in chairtime for fixed appliance adjustment compared to conventional appliances (Table 4). In particular, the use of self-ligating appliance systems results in a dramatic improvement in chairside efficiency when compared to the removal and insertion of archwires using stainless steel ligatures.[18] Authors have suggested that this time saving could be used to schedule more patients, increase efficiency, improve patient relations, or allow oral hygiene reinforcement.[16]

*GAC International, Inc., 355 Knickerbocker Ave., Bohemia, NY 11716; www.gacintl.com. In-Ovation is a registered trademark.

‡Instron Corporation, 825 University Ave., Norwood, MA 02062; www.instron.com.

TABLE 4
REPORTED REDUCTION IN CHAIRTIME REQUIRED FOR ARCHWIRE REMOVAL AND INSERTION WITH SELF-LIGATING APPLIANCES COMPARED TO CONVENTIONAL APPLIANCES

Study	Self-Ligating System(s)	Conventional Mode of Ligation	Time Savings
Maijer and Smith[16]	SPEED	Elastomerics	7 minutes
Shivapuja and Berger[18]	Activa, Edgelok, SPEED	Wire ligatures	12 minutes
Shivapuja and Berger[18]	Activa, Edgelok, SPEED	Elastomerics	1 minutes
Voudouris[31]	Interactwin	Elastomerics	2.5 minutes
Berger and Byloff[48]	SPEED	Elastomerics	2-3 minutes
Harradine[11]	Damon SL	Elastomerics	25 seconds
Turnbull and Birnie[49]	Damon 2	Elastomerics	1.5 minutes

Reduced Overall Treatment Time

Harradine 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.[6] The Damon SL cases required an average of four fewer months (19.4 vs. 23.5) and four fewer visits (12.7 vs. 16.5) to be treated to an equivalent standard, based on 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 vs. 25) and seven visits (28 vs. 21) for Damon SL cases, compared with conventional ligation.[17]

Retrospective studies of this nature are potentially biased by uncontrolled factors, including operator experience and preference, differing archwires and archwire sequences, and modified appointment intervals. Miles and colleagues noted that a reduction in treatment times may merely reflect a transition to more efficient treatment systems, rather than being related purely to use of self-ligating appliances.[50] They also suggested that with 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 overall length of treatment and number of visits between the two studies.

More Efficient Alignment

Miles compared the alignment efficiency of SmartClip brackets and conventional twin brackets in a prospective analysis of 48 patients.[7] 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 that .7mm 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° allowed by the passive self-ligating system with an .014" nickel titanium aligning wire. This study was limited by a small sample size, two-dimensional measurement, inclusion of both extraction and nonextraction cases, and measurement of the labial segment only.

***Trademark of 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

In a further clinical investigation of 58 patients, Miles and colleagues compared the efficiency of alignment and the degree of patient comfort with the Damon 2 and a conventional twin bracket in nonextraction cases, using a split-mouth study design.[50] At 10- and 20-week intervals, the twin bracket had achieved an irregularity index .2mm less than that of the Damon 2 brackets. The initial aligning wire was again .014" nickel titanium, with the potential for greater rotational play; this was followed by an .016" × .025" copper nickel titanium wire. Although early introduction of an .025" wire depth is advocated by users of the Damon appliance to facilitate initial rotational correction, in this study it failed to improve alignment efficiency. The split-mouth design eliminated the confounding effects of metabolic variation, but invalidated the measurements between the mandibular central incisors, since a bracket from each system was placed on the central incisors. Furthermore, the Damon 2 brackets have a higher profile and engage the wire with a gate mechanism, which may influence the nature and efficiency of dental alignment.

These findings suggest that any time savings arising from the use of self-ligating brackets do not occur in the initial alignment phase of treatment. 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, based on these prospective studies, unless time savings arise later in treatment, it seems unlikely that self-ligating systems can counterbalance their additional expense by providing more efficient treatment or a better treatment outcome in every case.

Improved Patient Comfort

Miles and colleagues also assessed subjective pain experiences related to Damon 2 and conventional preadjusted systems.[50] The Damon 2 brackets were initially less painful than the conventional brackets, but were associated with more pain when the second archwire was ligated. As a higher-profile bracket, the Damon 2 is also likely to cause more soft-tissue impingement, although no difference in lip irritation was reported between these two groups.

Arch-Dimensional Change and Stability

Although self-ligating appliances have been established for nearly 20 years, no detailed investigations of arch-dimensional changes related to treatment with these systems have been published. Consequently, the implications of treatment with self-ligating 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 reports have described increases in intermolar width exceeding 10mm, allowing nonextraction treatment; the longevity of such significant changes is likely to be reliant on permanent retention. Most advocates of self-ligating appliances do not aim for so much expansion, however, preferring to maintain pretreatment dimensions where possible.

A recent prospective study compared the effects of two preadjusted appliances on mandibular incisor angular and linear changes and on transverse mandibular arch-dimensional changes over a minimum period of 30 weeks.[53] Subjects were treated with a predetermined archwire sequence: .016", .017" × .025", .019" × .025" martensitic active nickel titanium (Nitinol XL***), and .019" × .025" 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. The self-ligating appliance produced significantly more expansion in the molar region, however (.91mm; p = .009). This finding was made despite the use of archwires of uniform dimensions and of similar bracket profiles in both groups. Potentially confounding factors, including pretreatment intermolar dimension and the degree of crowding resolved during treatment, were accounted for in the statistical model. The outcome indicates that

***3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

the mechanism of arch alignment produced by this passive self-ligating system may be different from that of conventional appliances. Importantly, the amount of crowding resolved during the study period was small (2.65mm). 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 intermolar region, leading to the development of spacing in the buccal segments during arch leveling and alignment, is a routine finding with the Damon passive self-ligating appliance.[51,52] An elastomeric tieback module has been developed to deal specifically with this problem, but 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 archforms.

Torque Expression

The influence of bracket type on torque expression in the upper labial segment has been assessed in a randomized controlled trial.[27] The Damon 2 appliance was found to be equally capable of torque delivery, relative to the SN and NA lines, compared to a conventional bracket system of Roth prescription. This finding may be surprising, since an in vitro study has emphasized that the Damon 2 slot may be as much as 17% oversize at the base and may also deviate from the expected rectangular cross-section and torque.[54] Of course, effective torque delivery involves the interaction of many factors.[55]

Little difference in mandibular incisor inclination change was reported in a prospective clinical trial of SmartClip and conventional brackets with MBT*** prescription. Incisor proclination of 4.41° and 4.32° occurred in the respective groups during arch leveling and alignment; incisor proclination was governed largely by the initial incisor inclination and the degree of crowding resolved during the study period.[53] An active self-ligating appliance that presses the wire into the base of the bracket may facilitate more effective torque expression with undersize archwires than can be achieved with a passive self-ligating system.[56]

***Trademark of 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

Conclusion

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 systems, but this effect is less marked in vivo.
- Disagreement exists concerning the importance of friction within orthodontic appliances, whether conventional or self-ligating, in vivo.
- There appears to be little difference in the alignment efficiency of conventional and self-ligating appliance systems.
- Clinical data documenting the efficiency of rotational correction and space closure with self-ligating systems remain limited.
- Use of self-ligating brackets results in a marginal reduction in chairtime required for appliance manipulation (Table 4).
- There is limited, retrospective evidence pointing to reduced overall treatment time with fewer scheduled appointments with the use of self-ligating systems.
- While many clinicians recommend selected self-ligating appliances to facilitate expansion in nonextraction treatment, there are no published long-term follow-up studies 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 on 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 the self-ligating 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 preadjusted 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 regarding the effects of self-ligating appliances on plaque accumulation and periodontal health, and on closure of extraction spaces. With continued refinement and the 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.

REFERENCES

1. Fauchard, P.: *Le Chirurgien Dentiste,* 2nd ed., Mariette, Paris, 1746.
2. Angle, E.H.: The latest and best in orthodontic mechanism, Dent. Cosmos 70:1143-1158, 1928.
3. Buonocore, M.G.: A simple method of increasing the adhesion of acrylic filling materials to enamel surfaces, J. Dent. Res. 34:849-853, 1955.
4. Newman, G.V.: Epoxy adhesives for orthodontic attachments: Progress report, Am. J. Orthod. 51:901-912, 1965.
5. Andrews, L.F.: The straight-wire appliance, origin, controversy, commentary, J. Clin. Orthod. 10:99-114, 1976.
6. Harradine, N.W.: Self-ligating brackets and treatment efficiency, Clin. Orthod. Res. 4:220-227, 2001.
7. Miles, P.G.: SmartClip versus conventional twin brackets for initial alignment: Is there a difference? Austral. Orthod. J. 21:123-127, 2005.
8. Roth, R.H.: The Straight-Wire Appliance 17 years later, J. Clin. Orthod. 21:632-642, 1987.
9. McLaughlin, R.P. and Bennett, J.C.: The transition from standard edgewise to preadjusted appliance systems, J. Clin. Orthod. 23:142-153, 1989.
10. Rinchuse, D.J.; Rinchuse, D.J.; and Kapur-Wadhwa, R.: Orthodontic appliance design, Am. J. Orthod. 131:76-82, 2007.
11. Harradine, N.W.: Self-ligating brackets: Where are we now? J. Orthod. 30:262-273, 2003.
12. Cacciafesta, V.; Sfondrini, M.F.; Scribante, A.; Klersy, C.; and Auricchio, F.: Evaluation of friction of conventional and metal-insert ceramic brackets in various bracket-archwire combinations, Am. J. Orthod. 124:403-409, 2003.
13. Stolzenberg, J.: The Russell attachment and its improved advantages, Int. J. Orthod. Dent. Child. 21:837-840, 1935.
14. Damon, D.H.: The Damon low-friction bracket: A biologically compatible straight-wire system, J. Clin. Orthod. 32:670-680, 1998.
15. Sims, A.P.; Waters, N.E.; and Birnie, D.J.: A comparison of the forces required to produce tooth movement ex vivo through three types of pre-adjusted brackets when subjected to determined tip or torque values, Br. J. Orthod. 21:367-373, 1994.
16. Maijer, R. and Smith, D.C.: Time savings with self-ligating brackets, J. Clin. Orthod. 24:29-31, 1990.
17. Eberting, J.J.; Straja, S.R.; and Tuncay, O.C.: Treatment time, outcome, and patient satisfaction comparisons of Damon and conventional brackets, Clin. Orthod. Res. 4:228-234, 2001.
18. Shivapuja, P.K. and Berger, J.: A comparative study of conventional ligation and self-ligation bracket systems, Am. J. Orthod. 106:472-480, 1994.
19. Taloumis, L.J.; Smith, T.M.; Hondrum, S.O.; and Lorton, L.: Force decay and deformation of orthodontic elastomeric ligatures, Am. J. Orthod. 111:1-11, 1997.
20. Dowling, P.A.; Jones, W.B.; Lagerstrom, L.; and Sandham, J.A.: An investigation into the behavioural characteristics of orthodontic elastomeric modules, Br. J. Orthod. 25:197-202, 1998.
21. Rock, W.P.; Wilson, H.J.; and Fisher, S.E.: Force reduction of orthodontic elastomeric chains after one month in the mouth, Br. J. Orthod. 13:147-150, 1986.
22. Wong, A.K.: Orthodontic elastic materials, Angle Orthod. 46:196-205, 1976.
23. Hain, M.; Dhopatkar, A.; and Rock, P.: The effect of ligation method on friction in sliding mechanics, Am. J. Orthod. 123:416-422, 2003.
24. Sims, A.P.; Waters, N.E.; Birnie, D.J.; and Pethybridge, R.J.: A comparison of the forces required to produce tooth movement in vitro using two self-ligating brackets and a pre-adjusted bracket employing two types of ligation, Eur. J. Orthod. 15:377-385, 1993.
25. Pandis, N.; Polychronopoulou, A.; and Eliades, T.: Failure rate of self-ligating and edgewise brackets bonded with conventional acid etching and a self-etching primer: A prospective in vivo study, Angle Orthod. 76:119-122, 2006.
26. Read-Ward, G.E.; Jones, S.P.; and Davies, E.H.: A comparison of self-ligating and conventional orthodontic bracket systems, Br. J. Orthod. 24:309-317, 1997.
27. Pandis, N.; Strigou, S.; and Eliades, T.: Maxillary incisor torque with conventional and self-ligating brackets: A prospective clinical trial, Orthod. Craniofac. Res. 9:193-198, 2006.
28. Schumacher, H.A.; Bourauel, C.; and Drescher, D.: The friction behavior of the ceramic bracket in arch wire-guided tooth movement, Fortschr. Kieferorthop. 51:259-265, 1990.
29. Meling, T.R.; Odegaard, J.; Holthe, K.; and Segner, D.: The effect of friction on the bending stiffness of orthodontic beams: A theoretical and in vitro study, Am. J. Orthod. 112:41-49, 1997.
30. Bednar, J.R.; Gruendeman, G.W.; and Sandrik, J.L.: A comparative study of frictional forces between orthodontic brackets and arch wires, Am. J. Orthod. 100:513-522, 1991.
31. Voudouris, J.C.: Interactive edgewise mechanisms: Form and function comparison with conventional edgewise brackets, Am. J. Orthod. 111:119-140, 1997.
32. Thomas, S.; Sherriff, M.; and Birnie, D.: A comparative in vitro study of the frictional characteristics of two types of self-ligating brackets and two types of pre-adjusted edgewise brackets tied with elastomeric ligatures, Eur. J. Orthod. 20:589-596, 1998.
33. Kapur, R.; Sinha, P.K.; and Nanda, R.S.: Frictional resistance of the Damon SL bracket, J. Clin. Orthod. 32:485-489, 1998.
34. Pizzoni, L.; Ravnholt, G.; and Melsen, B.: Frictional forces related to self-ligating brackets, Eur. J. Orthod. 20:283-291, 1998.
35. Khambay, B.; Millett, D.; and McHugh, S.: Evaluation of meth-

ods of archwire ligation on frictional resistance, Eur. J. Orthod. 26:327-332, 2004.
36. Griffiths, H.S.; Sherriff, M.; and Ireland, A.J.: Resistance to sliding with 3 types of elastomeric modules, Am. J. Orthod. 127:670-675, 2005.
37. Tecco, S.; Festa, F.; Caputi, S.; Traini, T.; Di Iorio, D.; and D'Attilio, M.: Friction of conventional and self-ligating brackets using a 10 bracket model, Angle Orthod. 75:1041-1045, 2005.
38. Henao, S.P. and Kusy, R.P.: Frictional evaluations of dental typodont models using four self-ligating designs and a conventional design, Angle Orthod. 75:75-85, 2005.
39. Matasa, C.G.: Self-engaging brackets: Passive vs. active, Orthod. Mat. Insider 9:5-11, 1996.
40. Henao, S.P. and Kusy, R.P.: Evaluation of the frictional resistance of conventional and self-ligating bracket designs using standardized archwires and dental typodonts, Angle Orthod. 74:202-211, 2004.
41. Meikle, M.C.: The tissue, cellular, and molecular regulation of orthodontic tooth movement: 100 years after Carl Sandstedt, Eur. J. Orthod. 28:221-240, 2006.
42. Braun, S.; Bluestein, M.; Moore, B.K.; and Benson, G.: Friction in perspective, Am. J. Orthod. 115:619-627, 1999.
43. Loftus, B.P.; Artun, J.; Nicholls, J.I.; Alonzo, T.A.; and Stoner, J.A.: Evaluation of friction during sliding tooth movement in various bracket-arch wire combinations, Am. J. Orthod. 116:336-345, 1999.
44. Thorstenson, G.A. and Kusy, R.P.: Comparison of resistance to sliding between different self-ligating brackets with second-order angulation in the dry and saliva states, Am. J. Orthod. 121:472-482, 2002.
45. Thorstenson, G.A. and Kusy, R.P.: Effect of archwire size and material on the resistance to sliding of self-ligating brackets with second-order angulation in the dry state, Am. J. Orthod. 122:295-305, 2002.
46. O'Reilly, D.; Dowling, P.A.; Lagerstrom, L.; and Swartz, M.L.: An ex-vivo investigation into the effect of bracket displacement on the resistance to sliding, Br. J. Orthod. 26:219-227, 1999.
47. Iwasaki, L.R.; Beatty, M.W.; and Nickel, J.C.: Friction and orthodontic mechanics: Clinical studies of moment and ligation effects, Semin. Orthod. 9:290-297, 2003.
48. Berger, J. and Byloff, F.K.: The clinical efficiency of self-ligated brackets, J. Clin. Orthod. 35:304-308, 2001.
49. Turnbull, N.R. and Birnie, D.J.: Treatment efficiency of conventional vs self-ligating brackets: Effects of archwire size and material, Am. J. Orthod. 131:395-399, 2007.
50. Miles, P.G.; Weyant, R.J.; and Rustveld, L.: A clinical trial of Damon 2 vs conventional twin brackets during initial alignment, Angle Orthod. 76:480-485, 2006.
51. Garino, F. and Favero, L.: Control of tooth movements with the SPEED System, Prog. Orthod. 4:23-30, 2003.
52. Damon, D.H.: The rationale, evolution and clinical application of the self-ligating bracket, Clin. Orthod. Res. 1:52-61, 1998.
53. Fleming, P.S.; DiBiase, A.T.; Sarri, G.; and Lee, R.T.: A comparison of mandibular arch changes during alignment and leveling with two preadjusted edgewise appliances, Am. J. Orthod. (in press).
54. Cash, A.C.; Good, S.A.; Curtis, R.V.; and McDonald, F.: An evaluation of slot size in orthodontic brackets: Are standards as expected? Angle Orthod. 74:450-453, 2004.
55. Gioka, C. and Eliades, T.: Materials-induced variation in the torque expression of preadjusted appliances, Am. J. Orthod. 125:323-328, 2004.
56. Rinchuse, D.J. and Miles, P.G.: Self-ligating brackets: Present and future, Am. J. Orthod. 132:216-222, 2007.
57. Kattner, P.F. and Schneider, B.J.: Comparison of Roth appliance and standard edgewise appliance treatment results, Am. J. Orthod. 103:24-32, 1993.