TRADITIONAL ELASTIC LIGATURES *VERSUS* SLIDE LIGATION SYSTEM. A MORPHOLOGICAL EVALUATION

R. CONDÒ, A. CASAGLIA, E. ARMELLIN, S.G. CONDÒ, L. CERRONI

Department of Clinical Sciences and Translational Medicine, University of Rome "Tor Vergata", Rome, Italy

SUMMARY

***Objective*. Elastomeric materials play an important role in the orthodontic practice, including the retraction force to move teeth into extraction sites, closing diastemas, selective shifting of the midline and generalized space closure. Frictional resistance and ligating strength of archwire-bracket-ligature complex occurs during utilization of elastomeric and metallic ligatures when orthodontic forces are applicated. The aim of this study was to analyze elastic deformation of three types of elastomeric ligatures, after clinical use.**

Material and Methods. Elastomeric ligatures: ring-shape, transparent, latex ligatures (Leone® S.p.A.), ring-shape, grey, polyurethane ligatures (Micerium® S.p.A.) and grey, polyurethane, Slide low-friction ligatures (Leone® S.p.A.). A total of 9 orthodontic patients undergoing fixed orthodontic therapy were selected. Three specimens were applied, one for each types of ligature, inside the oral cavity of each subject. Samples were kept in the oral cavity for 28 days, ligating 0.16 X 0.22 inches stainless steel archwires to stainless steel premolars brackets (Leone® S.p.A., Sesto Fiorentino, FI, Italy) for Bidimensional technique. After the pre-established time, the systems of ligature were removed and washed. Control group consisted of 9 unused specimens of each ligation type. Each elastomeric ligature was observed under the scanning electron microscope (SEM) to determine variations in size. The archwire-bracket-ligature complex was also analyzed.

Results. Transparent O-ring ligatures showed significant volumetric and structural changes. The external rounded shape was rather maintained, while the internal shape tended to appear square. Both external and internal diameter significantly increased ($p<0.005$ and $p<0.0001$ respectively) while the thickness decreased ($p<0,005$) when analyzed with t-test. Polyurethane ring-shape ligatures retained the initial ring design. Both external and internal diameter increased ($p<0.0001$), while the thickness remained almost unchanged. The internal border was more squared, and showed jagged edges with continuous and irregular extroversions. Grey, polyurethane Slide low-friction ligatures showed a reduced dimensional change. There was a slight increase in two dimensions, length and width, (14-16%) ($p<0.05$ and $p<0.001$) while there was a not significant decrease in thickness (10%).

Conclusion. From SEM analysis of ligature morphology it emerges that latex and polyurethane O-ring ligatures endure significant volumetric and structural changes, after clinical use, index of a greater degree of friction and early loss in functionality. Grey, polyurethane Slide low-friction ligatures presented limited variation in size after clinical use.

Key words: orthodontic ligature, deformation, SEM.

Introduction

Orthodontic sliding mechanics using pre-adjusted brackets is a common approach to the translation of a tooth or groups of teeth (1). Optimal orthodontic forces should be high enough to induce tooth movement without interrupting the vascular support to the periodontal ligament. Significant resistance to movement may arise due to the frictional force, generated at the edgewise bracket/archwire interface tending to impede the mechanical sliding and the force of ligation between the orthodontic arch, bracket and the ligation system used (2-4).

In general, the method of ligation represents an important element in determining the frictional force (5, 6). With regard to friction, stainless steel ligatures, even more so if not very tight, produce lower frictional force in the buccal segment (7, 8). Regarding the elastic modules, they are used mainly in the early stages of initial tooth align-

ment and levelling, when light and continuous forces are able to produce tooth translation and when archwire must be free to slide in the slot to affect a certain mesio-distal tipping (9).
Orthodontic ligatures have an important role during edgewise bracket sliding along a continuous archwire, the function of constituting the connection between the bracket and orthodontic archwire. There are two types of orthodontic ligatures: heat-treated stainless steel and elastomeric rings. The former are modelled from a steel wire of a diameter between 0.008 and 0.014 inches. They ensure a sufficiently rigid and stable ligation between orthodontic bracket and archwire, though favouring the development of significant friction levels during mechanical sliding (10).
Elastomeric ligatures are manufactured in different morphological modules (ellipsoid or circular), with different diameter and width, with rough or smooth surface (11). The elastic modules are produced as coloured, grey, and colourless but between these two there are significant differences in the strength of tension developed and the capacity for extension (12). Considerable advancement has occurred in the field of orthodontic materials and technology associated with archwire, bracket manufacturing and novel adhesive techniques (13).
Elastomeric materials are organic polymers whose dimensions can vastly change under load and then return to their original size, or nearly so, when load is removed. Generally, orthodontic elastomers are used for the production of elastics for intra-oral or extra-oral use and orthodontic ligatures (14).
In orthodontics the most widely used elastomers are polyurethanes, thermosetting polymers resulting from a step-reaction polymerisation of polyesters or glycopolyesters and bi- or polyisothiocyanates (15).
Despite the differences in chemical composition, the mechanical behaviour of this material is similar to natural rubber (16).
Polyurethanes are not considered ideal elastic materials because they are easily pigmented, they are susceptible to degradation during tensile load applied in oral cavity. Viscoelastic behaviour shows a marked structural relaxation; mechanical properties are subjected to changes depending on time and temperature (17). The time-dependent force decay may be attributed to variation in manufacturing techniques such as dying, cut stamping or injection moulding, effect due to additives, different morphological or dimensional characteristics of the chains (18).
The friction arising from a ligature depends upon its coefficient of friction and the forces it exerts on the bracket and archwire. From a mechanical standpoint, a direct proportional relationship exists between elastic module width and tensile strength while an inversely proportional relationship exists between the tensile strength and the inside diameter of the circular ligature.
Additionally, elastic ligatures have a considerable elastic deformation capacity, and rupture occurs at a very high level of deformation without plastic deformation, thus elastomeric are more fragile materials (19).
Although these materials are changed periodically (every 3-4 weeks) they are rapidly subjected to decay of force and to permanent deformation which worsens due to intraoral humidity and temperature present in the oral cavity (20, 21). Elastomeric ligatures have shown a force relaxation characterized by a rapid loss induced during the first 24 hours with a similar pattern of decay for all ring ligatures. This rapid loss of strength together with the permanent deformation precludes their clinical use in rotational and torque correction (19).
The more the surface of the elastic ligature is smooth, polished and free of irregularities, the more it reduces the development of friction during mechanical sliding, although many studies have shown that the elastomeric ligatures induce greater friction, during tooth movement, than that produced by stainless steel ligature (22).
In contact with biological oral fluids and colourants introduced with food intake, the elastomer quickly undergoes the phenomena of permanent pigmentation, acquiring stains that range from yellow-brown to greenish for those coloured, while the chroma of the grey module remains sufficiently unaltered (23).

The conventional elastomeric ring-shape ligatures, as well as stainless steel ones, develop high ligation forces and friction; to improve the mechanical slide and reduce the friction phenomena, mainly generated using traditional elastic modules, a new ligation system was produced: low-friction Slide elastomeric ligature (Leone® S.p.A., Sesto Fiorentino, FI, Italy). Its complex morphology guarantees excellent stability between bracket and archwire, leaving it perfectly free to slide in the slot, without generating unwanted frictional forces (24).
The purpose of this study was to observe and compare the morphology of the conventional ring-shape ligatures and that of the Slide ligatures, before and after clinical use, in order to analyze the degree of surface alteration, the elastic deformation and the relationship existing between the bracket ligature system and the orthodontic archwire.

Materials and methods

Experimental protocol

The morphology of three different types of ligatures was evaluated: transparent, latex, ring-shape ligatures (Leone® S.p.A., Sesto Fiorentino, FI, Italy), grey, polyurethane, ring-shape ligatures (Micerium S.p.A., Avegno, GE, Italy) and grey, polyurethane Slide low-friction ligatures (Leone® S.p.A., Sesto Fiorentino, FI, Italy).
The specimens consisted of 9 male and female subjects (aged 13-17 years). Informed consent was obtained from all the subjects. Patients were supplied with standardized toothpaste and asked to refrain from any other hygiene products for the duration of the trial.
The specimens tied a stainless steel 0.16 X 0.22 archwire to stainless steel twin premolars brackets (Leone® S.p.A., Sesto Fiorentino, FI, Italy). Ligatures were placed according to the following scheme: upper second premolars with Slide ligatures, upper first premolars with grey, ring-shape ligatures, lower second premolars with steinless steel ligatures, and lower first premolars with transparent, ring-shape ligatures.
After 28 days ligatures were removed by the same operator that tied them in, transferred on an orthodontic ligature instrument, and singularly introduced in Falcon test tubes containing a saline solution (NaCl 0.9% -4° C).
Nine specimens of each type of ligature were collected to determine size variation. Control group consisted in 9 unused specimens of each ligature type. The archwire-bracket-ligature complex for each ligature system was also analyzed.

Morphological analysis with SEM

Specimens were subject to a preparation phase consisting of fixing, dehydration, and sputtering: the specimens were washed twice with PBS (Phosphate Buffered Saline, Sigma-Aldrich, St.Louis, MO, USA), fixed in a 2.5% glutaraldehyde solution in PBS for 30 minutes and washed twice with PBS. Then specimens were dehydrated with ethanol solutions in PBS at increasing concentrations: twice in a 70% solution 15 minutes, twice in a 90% solution for 15 minutes, and twice in 100% ethanol for 15 minutes.
Finally specimens were treated for 5 minutes with HMDS (Hexamethyl disilazane, Sigma-Aldrich, St.Louis, MO, USA), dried and glued on stubs. Stubs were treated with acetone to eliminate possible impurities and, through a specific device (Quick Drying Silver Paint, Agar Scientific LTD, Stansted, Essex, England), specimens were glued on stubs prior to be subjected to the golden sputtering (SEM Coating System, Bio-Rad, Microscience Division, Hercules, CA, USA), for 4 minutes.
Once cooled down, the specimens were stored vacuum-sealed inside a glass container and analysed within 5 days. SEM at different magnification was used for morphological evaluation of 9 unused and 9 used ligatures of each type. The Student t-test for comparison of 2 means for independent samples was used for statistical analysis.

Results

The SEM analysis of the three system of ligation, before and after clinical use, permitted the extrapolation of three dimensions mean value as reported in Tables 1 and 2. The transparent, ring-shape, latex ligatures (TR), have the shape of a hollow cylinder, with regular sharp edges. The smooth surface is crossed by occasional imperfections, such as sparse granules and striation (Fig. 1).

The grey, ring-shape, polyurethane ligatures (GR), have the shape of a bevelled ring. Surface, characterised by small irregular grains, is interrupted on the external border by anoblong introflection due to separation of the peduncle from bracket to dispenser (Fig. 2).

The grey polyurethane Slide low-friction ligatures (GS), have a bevelled rectangular form, with internal figure-eight form. The two thin and trapezoidal inner cavities are arranged symmetrically at the two extremities of the rectangle, at the same distance from the externalborder and are separated by a thick square connection. At the centre of the deflection, the lower base shows a residue of material belonging to the peduncle adhesion bracket-support. The extremely homogeneous surface is crossed with fine striations and little grains; in the centre it is also present single irregularity of larger dimensions (Fig. 3).

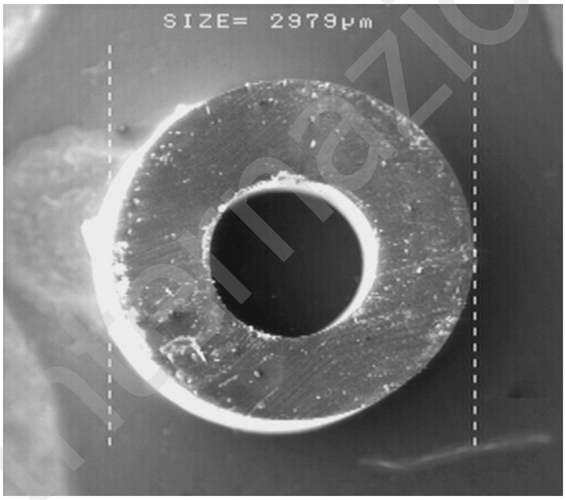

Figure 1
SEM micrograph of a not-used transparent elastomeric ligatures of ring type in latex (TR) at original magnification x20.

Table 1 - Mean value (MV) and standard deviation (SD) (mm) of external diameter (ED), internal diameter (ID) and thickness (T) of transparent elastomeric ligatures of ring type in latex (TR), and grey ligatures of ring type in polyurethane (GR), before (not used) and after 4 weeks of clinical use.

		E D		ID		T	
		MV	SD	MV	SD	MV	SD
TR	Not used	**2.98**	0.06	**1.34**	0.03	**0.78**	0.02
	4weeks	**3.85**	0.30	**2.03**	0.16	**0.50**	0.04
GR	Not used	**2.78**	0.05	**1.09**	0.02	**0.86**	0.02
	4weeks	**3.52**	0.25	**2.03**	0.16	**0.83**	0.06

Table 2 - Mean value (MV) and standard deviation (SD) (mm) of base (B), side (S) and thickness (T) of grey polyurethane Slide low-friction ligatures (GS). (not used) and after 4 weeks of clinical use.

		B		S		T	
		MV	SD	MV	SD	MV	SD
GS	Not used	**3.28**	0.06	**3.57**	0.07	**0.70**	0.01
	4weeks	**3.82**	0.19	**4.09**	0.20	**0.63**	0.03

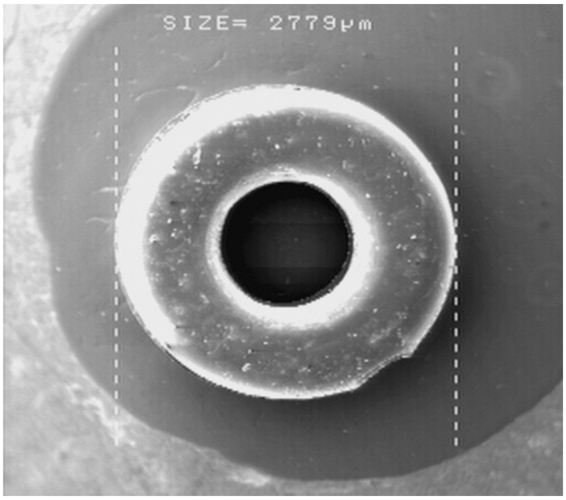

Figure 2
SEM micrograph of not used grey ligatures of ring type in polyurethane (GR) at original magnification x20.

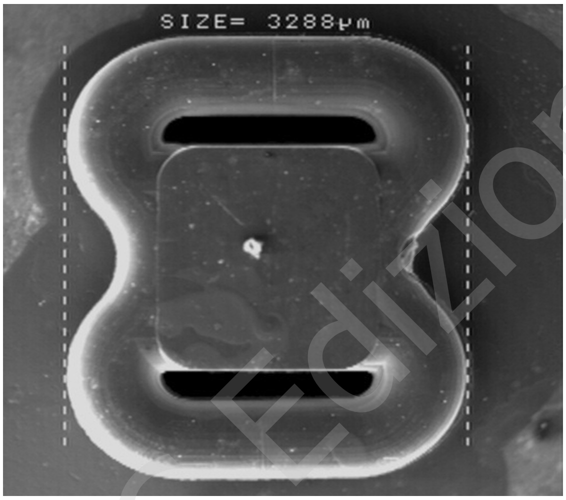

Figure 3
SEM micrograph of a not-used grey polyurethane Slide low-friction ligatures (GS) at original magnification x20.

Low magnification (x20) SEM images of transparent, ring-shape ligatures (TR) after 4 weeks of permanence in oral cavity is showed in Figure 4. The TR showed significant volumetric and structural changes. The external rounded shape is now bevelled, while the internal cavity tends to appear square. Both the external diameter (+29%) and the internal diameter (+51%) significantly increased ($p<0.005$ and $p<0.0001$ respectively) and the thickness decreased (+36%, $p<0.005$). At higher magnification the surface, excessively rough, is crossed by major longitudinal grooves and large granules of organic unknown compounds (Fig. 5A, B).

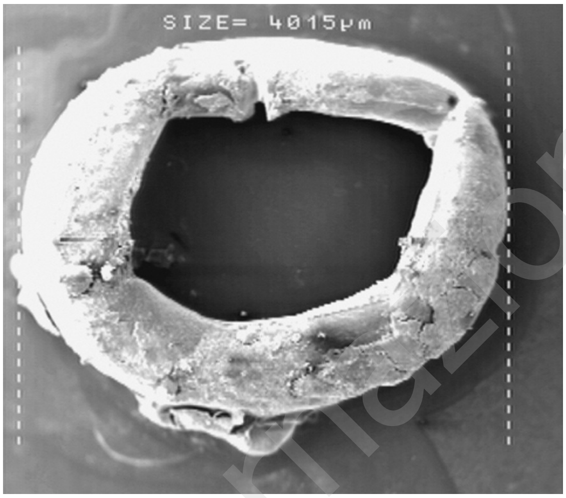

Figure 4
SEM micrograph of transparent elastomeric ligatures of ring type in latex (TR) after 4 weeks of permanence in oral cavity at original magnification x20.

At low magnification the grey, ring-shape, polyurethane ligatures (GR) (Fig. 6A, B) retain the initial rounded and bevelled ring design. Both the external diameter (+27%) and the internal diameter (+86%) increased ($p<0.0001$) while the thickness slightly decreased. The external border is continuous and regular, the internal one more squared and shows jagged edges with continuous and irregular extroversions and a partial detachment of a band of material. The surface remains homogeneous and smooth.

The morphological analysis of low-friction Slides (GS) is shown in Figure 7, they present reduced dimensional change: the structure is now asymmetric and arcuate. There is a slight increase in the length of base (16%), and side (14%) ($p<0.05$ and $p<0.001$), while there is a minor decrease in thickness (10%), not statistically relevant. The two internal cavities, no longer identical, assume a wider and irregular lozenge form. The surface remains invariably

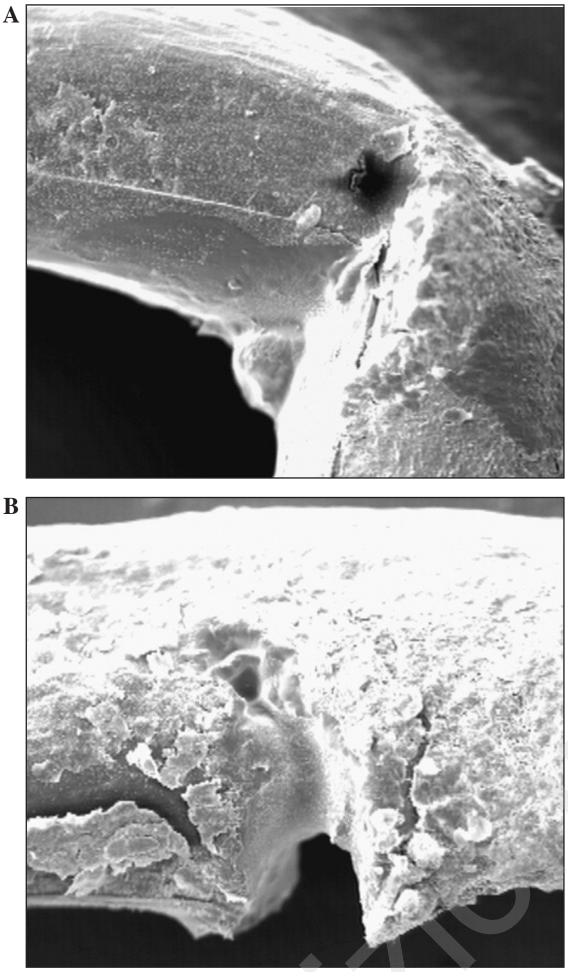

Figure 5
SEM micrograph of transparent elastomeric ligatures of ring type in latex (TR) after 4 weeks of permanence in oral cavity at original magnification x100 (**A**, **B**).

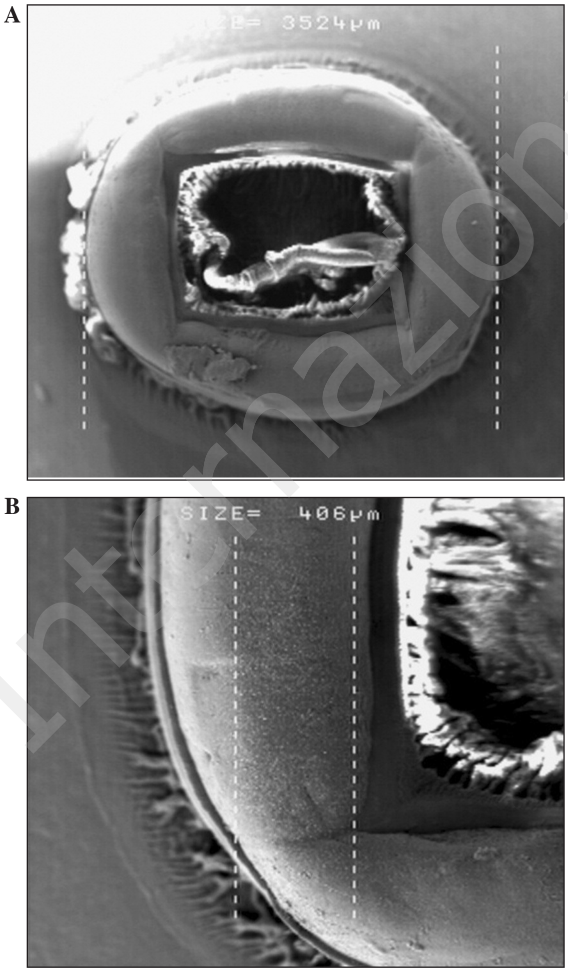

Figure 6
SEM micrograph of grey ligatures of ring type in polyurethane (GR) after 4 weeks of permanence in oral cavity at original magnification x20 (**A**) and x50 (**B**).

homogeneous and smooth but, around the edges of the two internal cavities and along the two external lateral deflections, continuous and irregular extroversions appear (Fig. 8).

x30 and x75 magnifications, allow to observe the interface between bracket, orthodontic arch and elastic module with the objective of determining the type of ligation that characterises each system.

The TR tighten around the bracket and the orthodontic arch constitute an intimate connection with both and create a tight and rigid-like connection between the two metal systems, so much so that the arch is perfectly inserted into the slot of the bracket (Fig. 9 A, B).

The GR ligature become modelled according to the anatomy of the bracket resting on the vestibular of the orthodontic arch and providing a strong bond that is able to ensure, during mechanical sliding, some possibility of movement of the arch in the slot (Fig. 10 A, B).

The GS achieve contact solely with the cervical and occlusal wings of the bracket, leaving suspended, in the form of a bridge, the central rectangular structure. In this fashion, the orthodontic arch is free to move both in the slot and in a space greater than that expected from the anatomy of the bracket (Fig. 11 A, B).

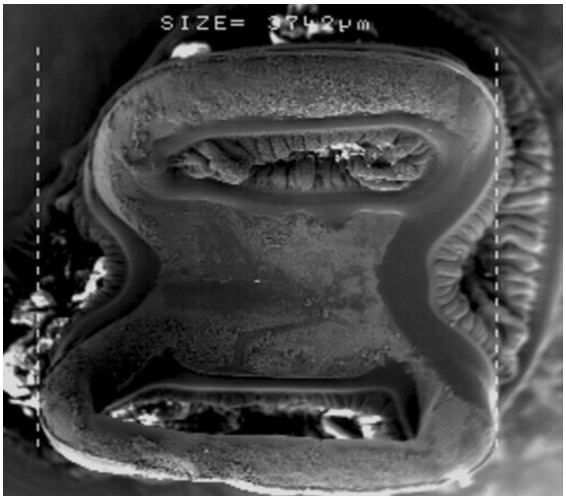

Figure 7
SEM micrograph of grey polyurethane Slide low-friction ligatures (GS) after 4 weeks of permanence in oral cavity at original magnification x20.

Figure 8
SEM micrograph of grey polyurethane Slide low-friction ligatures (GS) after 4 weeks of permanence in oral cavity at original magnification x50.

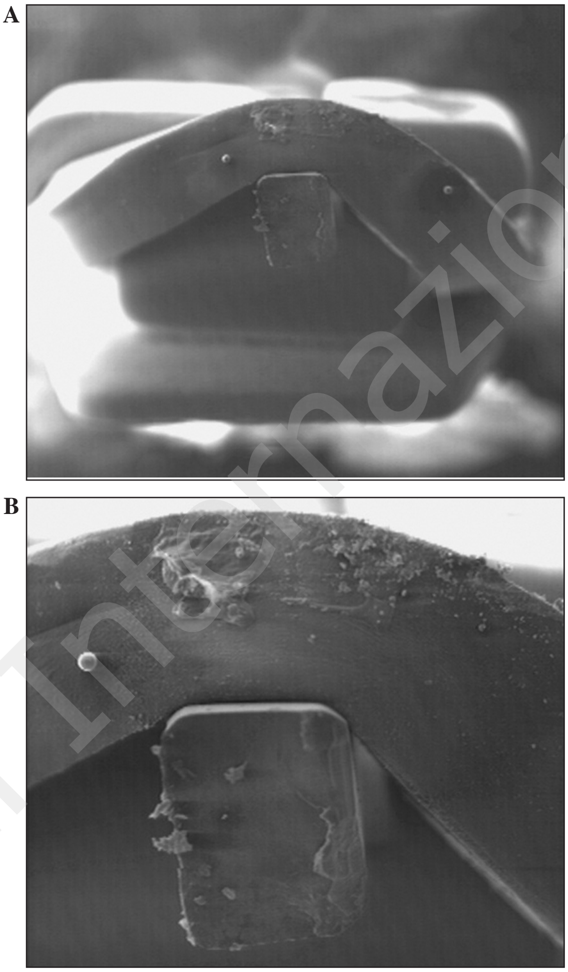

Figure 9
SEM micrograph of the interface between bracket, orthodontic arch and transparent elastomeric ligatures of ring type in latex (TR) after 4 weeks of permanence in oral cavity at original magnification x30 (**A**) and x75 (**B**).

Discussion

The SEM morphological analysis was performed, at different magnifications from x20 to x100, on all surfaces of the samples, both new and used. The base morphologies of the three elastic modules, the surface characteristics, the structural and dimensional changes after clinical use, the degree of deformation and deterioration in the oral cavity and finally the existing relationship to the ligature interface, bracket and orthodontic arch were evaluated.
The results have shown that the traditional elastomeric ring-shape ligatures lose their structural conformation and half of their elasticity within the experimental time of ligation. In particular, the transparent, ring-shape ligatures TR, as well as the grey, ring-shape ones GR, have shown similar behaviour with regard to the phenomena of dimensional variation. After a month, the volume increase is almost double

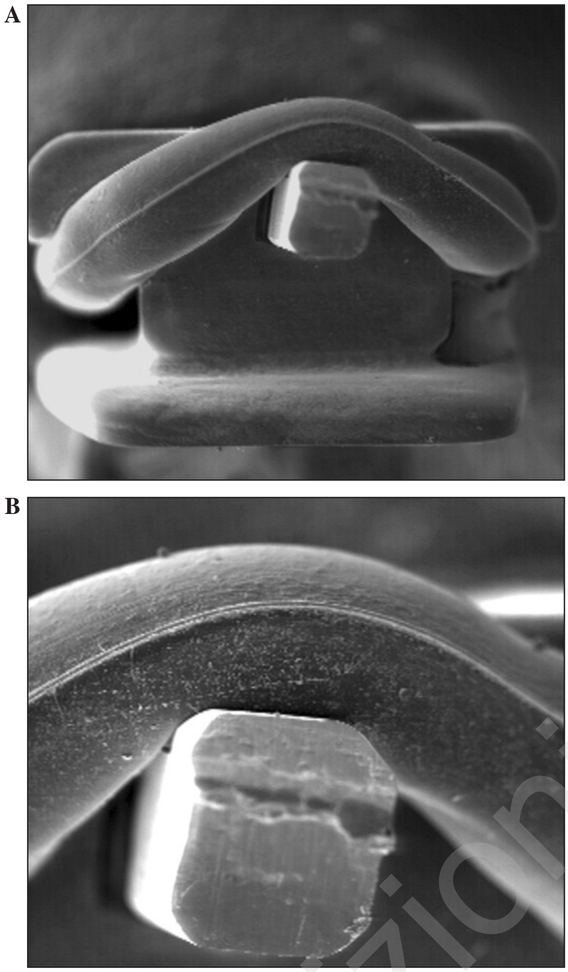

Figure 10
SEM micrograph of the interface between bracket, orthodontic arch and grey ligatures of ring type in polyurethane (GR) after 4 weeks of permanence in oral cavity at original magnification x30 (**A**) and x75 (**B**).

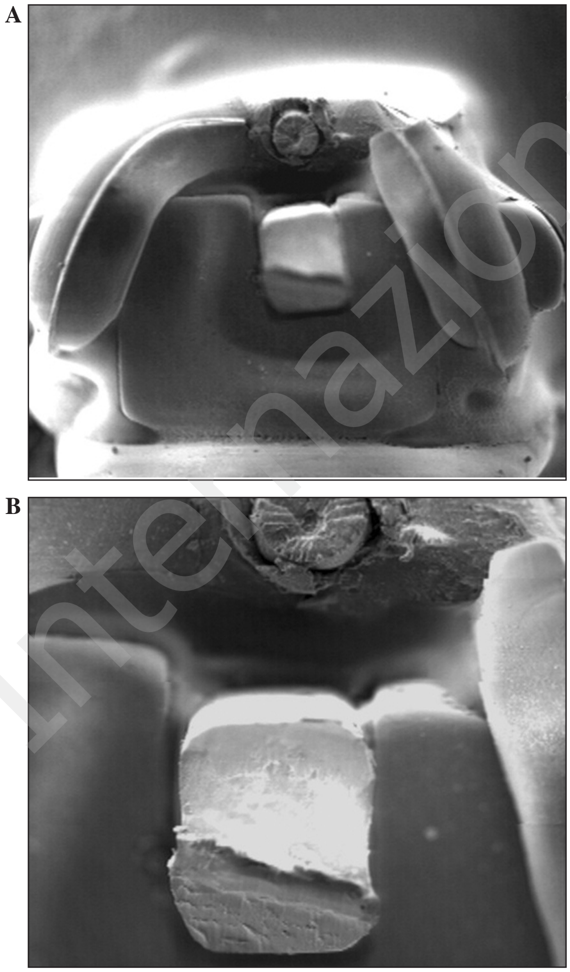

Figure 11
SEM micrograph of the interface between bracket, orthodontic arch and grey polyurethane Slide low-friction ligatures (GS) after 4 weeks of permanence in oral cavity at original magnification x30 (**A**) and x75 (**B**).

and the thicknesses decrease is evident, thus altering the ligation between the orthodontic arch and bracket slot, and more generally, the progress of tooth movement. They maintain, however, an irregularly shaped ring, becoming bevelled especially in the TR ligatures, characterised by an internal shape that, assuming the quadrangular conformation of the bracket, moves toward a deformation of a permanent type.
On the other hand, the surface alteration is strictly dependent on the material used. In the case of low-friction Slide ligatures GS and of the GR, the polyurethane, on termination of clinical use, shows no significant variations, maintaining homogeneity and smoothness except in zones of greater contact, where indentations and extroversions are generated by wear and friction. Contrarily, the initially smooth surface of the transparent ligatures TR has a behaviour similar in all of its parts, deteriorating and becoming so rough and porous as to constitute a substrate for the adhesion of plaque and organic residues.
Finally, after clinical use the low-friction Slide ligatures GS show greater deformation while maintaining the dimensional values rather unchanged. The length of the base is slightly in-

creased, these appearing in anasymmetrical and arcuate form while the two internal cavities, which constitute the only element of retention to the bracket, present significant alterations, either in form, larger and more irregular, or insurface. The absence of contact between the orthodontic arch and body of ligature, produced, in the same time interval, minor structural deformation and alterations on all the surfaces at the bracket-orthodontic archwire interface. The morphology of the GS ligature, ensures on one hand, a good ligation between the systems, on the other hand, a greater freedom of movement of the archwire in a space broader than that normally offered by the slot of the orthodontic bracket. The Slide morphology permits a better distribution of the forces.

Conclusions

The absence of contact observed between archwire and Slide low-friction ligatures, associated to little dimensional changes, indicated a better mechanical behaviour of Slide system. The interesting results from the morphological evaluation led us to conduct further in-depth study of the biomechanical characteristics of the Slide ligating system.

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Correspondence to:
Roberta Condò
E-mail: roberta.condo@uniroma2.it