Force Levels of Nickel Titanium Initial Archwires

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Since the development of the edgewise appliance, clinicians have sought the ability to use light forces without complicated mechanical delivery methods. In recent years, self-ligating brackets have helped make this a realistic goal, but have also prompted orthodontists to take a closer look at the forces exerted at the beginning of treatment.

The shape of the initial archwire—whether solid, multistranded, or looped—imparts a unique force level, strictly because of its physical characteristics. The material composition of the wire also affects its force characteristics. Metallurgical advances have produced initial archwires that can deliver light forces even under extreme physical deformation.

This article compares the force levels generated by four different categories of initial archwires made of highly flexible nickel titanium alloys.

Materials and Methods

The three-point bend test is commonly used to compare the force deflection characteristics of wires because it virtually eliminates extraneous variables and is easily repeatable. A special three-point bending fixture and probe were fabricated for the present study (Fig. 1). The probe was attached to the upper crosshead of an Instron testing machine* equipped with a 100N load cell, and the test fixture was placed on a flat platform connected to the bottom crosshead of the testing machine.

Testing was carried out on a relatively straight posterior section of each archwire, which was supported in the test fixture by two .1875"-diameter stainless steel rods. These rods had .034"-wide slots cut in them to a depth of .063" to keep the archwire from sliding laterally. The test span of the archwire, measured between the central axes of the two support rods, was 14.8mm. Thin metal bands were used to support the archwires outside the test span.

The deflection rate was set at 1mm/minute, which was considered slow enough to prevent any self-heating or -cooling of the nickel titanium archwires from latent heat effects of the austenite-to-martensite stress-induced phase transformation during loading, or the reverse transformation during unloading. The entire testing assembly was placed in a thermally regulated chamber set to body temperature (37°C) and allowed to reach thermal equilibrium before testing. A thermocouple was attached to the test fixture to monitor its temperature during each test.

Representative samples of 44 commercially available nickel titanium archwires were selected, in four categories:

*Model 4206-006, Instron Corporation, 825 University Ave., Norwood, MA 02062; www.instron.com.

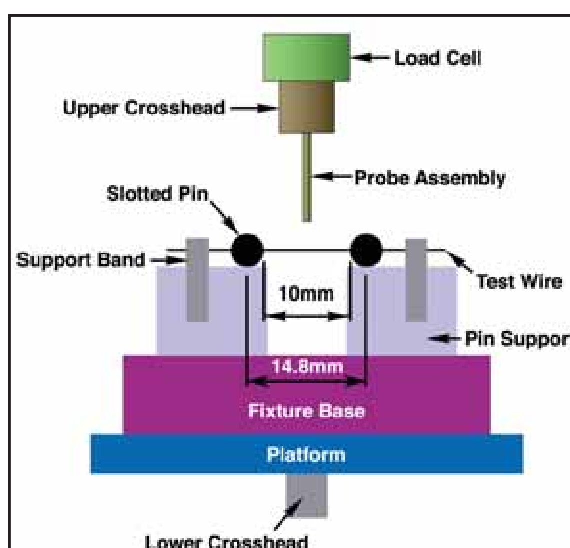

Fig. 1 Testing assembly.

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1. *Traditional nickel titanium.* This commonly used alloy is formed by melting a mixture of approximately 55% nickel and 45% titanium (by weight) into an ingot under vacuum, followed by solidification and hot and cold working. A "stabilized" nickel titanium archwire was manufactured as early as 1972 under the brand name Nitinol.[1] This wire was processed to produce a "linear superelastic" effect that would approximate the elastic behavior of stainless steel. Nitinol, however, was much less stiff than stainless steel and could be deformed to a much larger degree before deformation became permanent. In the early 1980s, the material was further refined and described by Burstone and colleagues as "superelastic" nickel titanium.[2] This alloy, which is being used in essentially the same form today, provides a "non-linear superelastic" effect. With its well-known loading and unloading force/deflection plateaus, the wire produces near-constant force delivery under increasing wire deflection.

2. *Heat-activated nickel titanium.* The only difference between this increasingly popular alloy and a traditional nickel titanium archwire is that the heat-activated nickel titanium has a "transformation temperature" (austenitic finish temperature) that is above room temperature, but below body temperature. In other words, the wire is soft at room temperature (about 25°C), but stiffens when placed in the mouth (about 37°C). As a result, it is more easily engaged in malaligned brackets. The transformation temperature of a traditional nickel titanium archwire is generally between 0°C and 10°C. Because the force exerted by the wire is proportional to the difference between its transformation temperature and its working temperature, heat-activated archwires tend to impart less force than traditional nickel titanium archwires.

3. *Copper nickel titanium.* These wires, which were introduced in the late 1990s, are manufactured with the addition of small amounts of copper or copper and chromium. Their loading and unloading forces are closer, and the tolerance range of transformation temperature is therefore narrower, than in a traditional nickel titanium archwire. The copper nickel titanium wire undergoes a physical transformation during loading and unloading that is virtually identical to that of traditional nickel titanium, however, and thus does not necessarily produce lighter forces.

4. *Multistranded coaxial nickel titanium.* Orthodontists have known for some time that they could gain significant mechanical advantages by replacing a solid wire with one made up of multiple smaller wires. Multistranded round coaxial and braided rectangular stainless steel initial archwires were commonly used in the late 1970s and early 1980s. More recently, Hanson applied the same mechanical principles to solid nickel titanium archwires and developed a seven-stranded round coaxial nickel titanium archwire, which became commercially available in 1995.[3]

Results

Table 1 shows the loading and unloading forces measured at deflections of 1mm, 2mm, and 3mm. The loading force is generated by the archwire during its deflection into the archwire slot, but is never transmitted to the dentition. The unloading force is of more clinical interest, because it more closely approximates the forces that cause tooth movement during orthodontic treatment. In testing initial archwires, the 3mm deflection is the most noteworthy because of the degree of deformation required for initial tooth movement.

The multistranded coaxial nickel titanium archwire demonstrated a significantly lower unloading force at a 3mm deflection than any of the other wires (Fig. 2). The 55g of force imparted by the .016" wire was the lowest force recorded in the entire study, and the force produced by the .020"

TABLE 1
LOADING AND UNLOADING FORCE LEVELS OF INITIAL NICKEL TITANIUM ARCHWIRES

			Deflection/Loading Force (g)			Deflection/Unloading Force (g)		
Wire Type*	**Sample (Manufacturer)**	**Wire Size**	**1mm**	**2mm**	**3mm**	**1mm**	**2mm**	**3mm**
HA	Tensic[b]	.012"	145	170	172	65	67	78
HA	Flexus[a]	.012"	155	183	195	90	80	82
HA	Reflex HA[j]	.012"	152	180	188	63	63	102
HA	BioStarter[c]	.012"	170	190	193	80	80	105
NiTi	Reflex[j]	.012"	160	210	230	100	117	118
NiTi	Rematitan Lite[b]	.012"	150	210	220	105	142	140
CuNiTi	Damon Optimal Force[g]	.013"	223	278	280	164	175	161
HA	Therm-A-Form Ultra[f]	.014"	200	260	275	58	60	80
HA	Reflex HA[j]	.014"	230	260	270	66	66	88
HA	Flexus[a]	.014"	230	285	305	100	100	110
HA	Thermaloy[h]	.014"	225	260	290	65	75	110
HA	BioStarter[c]	.014"	255	285	295	100	105	123
HA	Ovation Sentalloy Accu[d]	.014"	238	300	315	130	125	125
HA	Tensic[b]	.014"	260	315	320	120	130	140
NiTi	Reflex[j]	.014"	280	380	400	160	190	170
NiTi	Align SE 200[g]	.014"	265	345	360	160	180	180
NiTi	Nat Arch Form III[a]	.014"	328	395	410	215	205	195
NiTi	OrthoForm III[k]	.014"	270	395	430	180	220	205
CuNiTi	Damon Optimal Force[g]	.014"	306	400	407	220	250	234
Coax NiTi	Supercable[i]	.016"	40	73	80	37	57	55
HA	Reflex HA[j]	.016"	330	420	455	75	92	120
HA	Therm-A-Form Ultra[g]	.016"	340	410	440	68	80	122
HA	Thermaloy[h]	.016"	330	390	410	80	95	150
HA	Nitinol HA[k]	.016"	355	435	460	165	175	180
HA	Ovation Sentalloy Accu[d]	.016"	385	465	492	182	185	200
HA	Flexus[a]	.016"	390	490	490	180	200	230
NiTi	Nat Arch Form III[a]	.016"	508	600	620	285	270	260
NiTi	Rematitan Lite[b]	.016"	460	590	640	270	280	275
NiTi	Align SE 200[g]	.016"	460	620	640	270	320	300
NiTi	SE OrthoForm III-O[k]	.016"	420	640	720	260	320	300
NiTi	Nat Arch Form I, Force I[a]	.016"	470	610	620	280	340	320
NiTi	Reflex[j]	.016"	520	700	710	260	328	340
Coax NiTi	Supercable[i]	.018"	75	125	135	60	80	85
HA	Thermaloy[h]	.018"	450	520	550	90	120	200
HA	Flexus[a]	.018"	500	600	650	140	180	240
HA	Tensic[b]	.018"	515	590	610	148	182	240
HA	Reflex HA[j]	.018"	490	640	620	140	185	240
HA	OrthoForm I-T[k]	.018"	545	635	680	220	250	260
HA	Ovation Sentalloy Accu[d]	.018"	580	690	740	250	272	280
NiTi	Align SE 200[g]	.018"	640	760	790	300	320	330
NiTi	Nickel Titanal[e]	.018"	560	790	720	260	325	360
NiTi	Reflex[j]	.018"	660	840	820	280	325	365
NiTi	Nat Arch Form III[a]	.018"	715	850	890	410	420	420
Coax NiTi	Supercable[i]	.020"	110	180	195	95	115	105

*HA = heat-activated nickel titanium; NiTi = traditional nickel titanium; CuNiTi = copper nickel titanium; Coax NiTi = multistranded coaxial nickel titanium.

Brand names are trademarks of their respective companies.

a American Orthodontics Corporation, 1714 Cambridge Ave., Sheboygan, WI 53081; www.americanortho.com.
b Dentaurum, 10 Pheasant Run, Newtown, PA 18940; www.dentaurum.com.
c Forestadent USA, 2301 Weldon Parkway, St. Louis, MO 63146; www.forestadent-usa.com.
d GAC International, Inc., 355 Knickerbocker Ave., Bohemia, NY 11716; www.gacintl.com.
e Lancer Orthodontics, 253 Pawnee St., San Marcos, CA 92068; www.lancerortho.com.
f Masel, 2701 Bartram Road, Bristol, PA 19007; www.maselortho.com.
g Ormco, 1717 W. Collins Ave., Orange, CA 92867; www.ormco.com.
h Rocky Mountain Orthodontics, Inc., 650 W. Colfax Ave., Denver, CO 80204; www.rmortho.com.
i SPEED System Orthodontics, 298 Shepherd Ave., Cambridge, ON, N3C 1V1 Canada; www.speedsystem.com.
j TP Orthodontics, Inc., 100 Center Plaza, La Porte, IN 46350; www.tportho.com.
k 3M Unitek, 2724 S. Peck Road, Monrovia, CA 91016; www.3Munitek.com.

wire was only 105g. The unloading force measured for the smallest copper nickel titanium archwire (.013") was about three times greater than that of the smallest multistranded coaxial nickel titanium archwire (.016").

The heat-activated nickel titanium archwires generated much lower force levels than those of traditional nickel titanium archwires of comparable diameter. The force of the smallest traditional nickel titanium archwire (.012") exceeded the force of the largest multistranded nickel titanium archwire (.020") at 3mm of deflection. On the other hand, the .014" traditional nickel titanium wires generated 20% less force, and the .014" heat-activated nickel titanium wires 47% less force, on average, than the .014" copper nickel titanium archwire.

Discussion

In 1932, Schwarz defined optimal force as “the force leading to a change in tissue pressure that approximated the capillary vessels’ blood pressure, thus preventing their occlusion in the compressed periodontal ligament”.[4] This concept has been supported by many other authors, including Reitan,[5] Rygh and colleagues,[6] Proffit,[7] and Ren and colleagues,[8] but its conversion to a numerical value has eluded researchers and clinicians.

In the absence of conclusive research, common sense dictates that lighter forces are advantageous for histological, biomechanical (action vs. reaction), and patient-comfort reasons. Orthodontists continue to move toward lighter force levels, especially with the introduction of self-ligating bracket designs and superelastic alloys.

As a general rule, the transformation temperature of a nickel titanium alloy can be increased simply by increasing the ratio of titanium to nickel. This is the difference in composition between heat-activated and traditional nickel titanium archwires. Because the unloading force is directly proportional to the difference between the transformation temperature and the working temperature (mouth temperature), elevating the transformation temperature decreases the alloy’s unloading force.

The addition of copper to a nickel titanium alloy can also increase the transformation temperature. It has the potential to narrow the tolerance range of the transformation temperature and thus reduce the difference between loading and unloading forces. As the results of this study show, however, it is questionable whether such effects are clinically relevant.

Multistranding has historically been used to increase the flexibility and reduce the unloading

Fig. 2 Unloading force levels at 3mm deflection of initial archwires.

forces of archwires. Engineering formulas for traditional linear elastic materials such as stainless steel indicate that a seven-stranded coaxial wire of .016"-.018" diameter will exert approximately 10% of the force of a solid wire of comparable diameter, assuming there is no interstrand friction.[9] Although this type of analysis cannot be directly applied to superelastic nickel titanium due to its non-linear behavior, it is clear from the present study that multistranding of nickel titanium wire can profoundly reduce the forces imparted by archwires.

The following cases demonstrate the benefits of allowing initial Supercable** multistranded coaxial nickel titanium archwires to fully express themselves.

Case 1

A 14-year-old female presented with severe bimaxillary crowding. After the four first premolars were extracted, an initial .016" Supercable archwire was engaged in the maxillary arch (Fig. 3A). Six weeks later, a mandibular .016" Supercable archwire was inserted, and the maxillary archwire was restopped (Fig. 3B). Occlusal bonding material (SPEED Bumps) was added to prevent occlusal trauma to the mandibular second molar brackets.

The patient was seen at seven-week intervals to restop the wire ends as the archwires migrated distally. After 20 weeks, the Supercable archwires were replaced with maxillary .018" and mandibular .017" × .022" nickel titanium archwires and mandibular power chain (Fig. 3C). During this period, the patient showed a significant vertical and distal descent of the maxillary canines, simultaneous anterior bite closure, and general alignment of the dentition without mesial migration of the posterior teeth.

**Trademark of SPEED System Orthodontics, 298 Shepherd Ave., Cambridge, ON, N3C 1V1 Canada; www.speedsystem.com.

Case 2

This 14-year-old male patient had impacted maxillary canines that had recently been exposed, with apically repositioned periodontal flaps. A segmental .016" Supercable archwire was seated in the auxiliary slots of the maxillary incisor SPEED brackets and the main archwire slots of both canine brackets, in conjunction with a maxillary .017" × .022" SPEED archwire (Fig. 4A).

Six weeks later, as the canines rapidly erupted without incisor flaring, the segmental archwire was restopped distal to the first premolars (Fig. 4B). After another eight weeks, a continuous .016" nickel titanium archwire could be placed (Fig. 4C).

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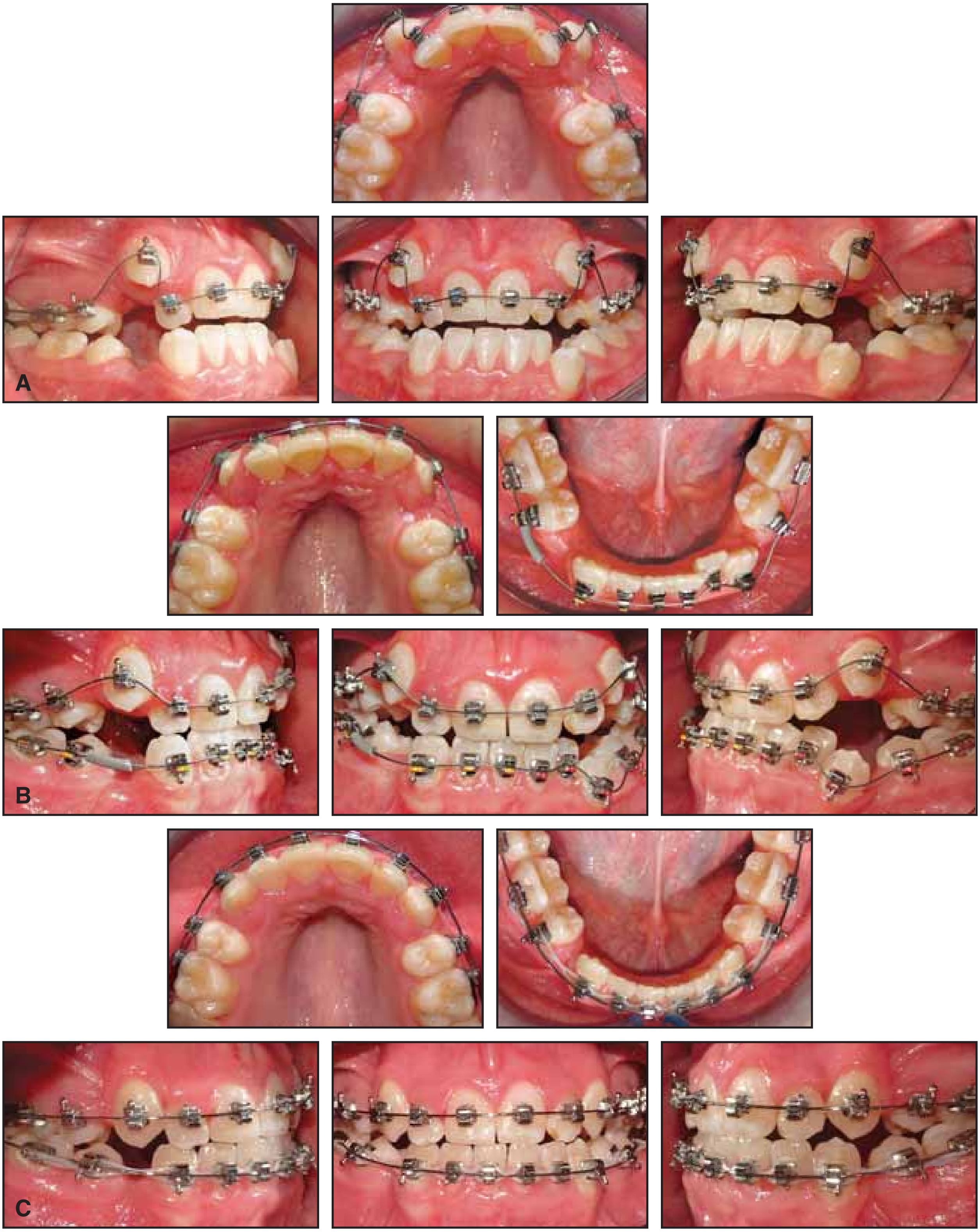

Fig. 3 Case 1. A. Initial engagement of maxillary .016" Supercable archwire in 14-year-old female patient with severe bimaxillary crowding, after four first premolar extractions. B. Placement of mandibular .016" Supercable archwire six weeks later, with SPEED Bumps added to prevent occlusal trauma to mandibular second molar brackets. C. Patient after 20 weeks of treatment, with maxillary .018" and mandibular .017" × .022" nickel titanium archwires and mandibular power chain in place.

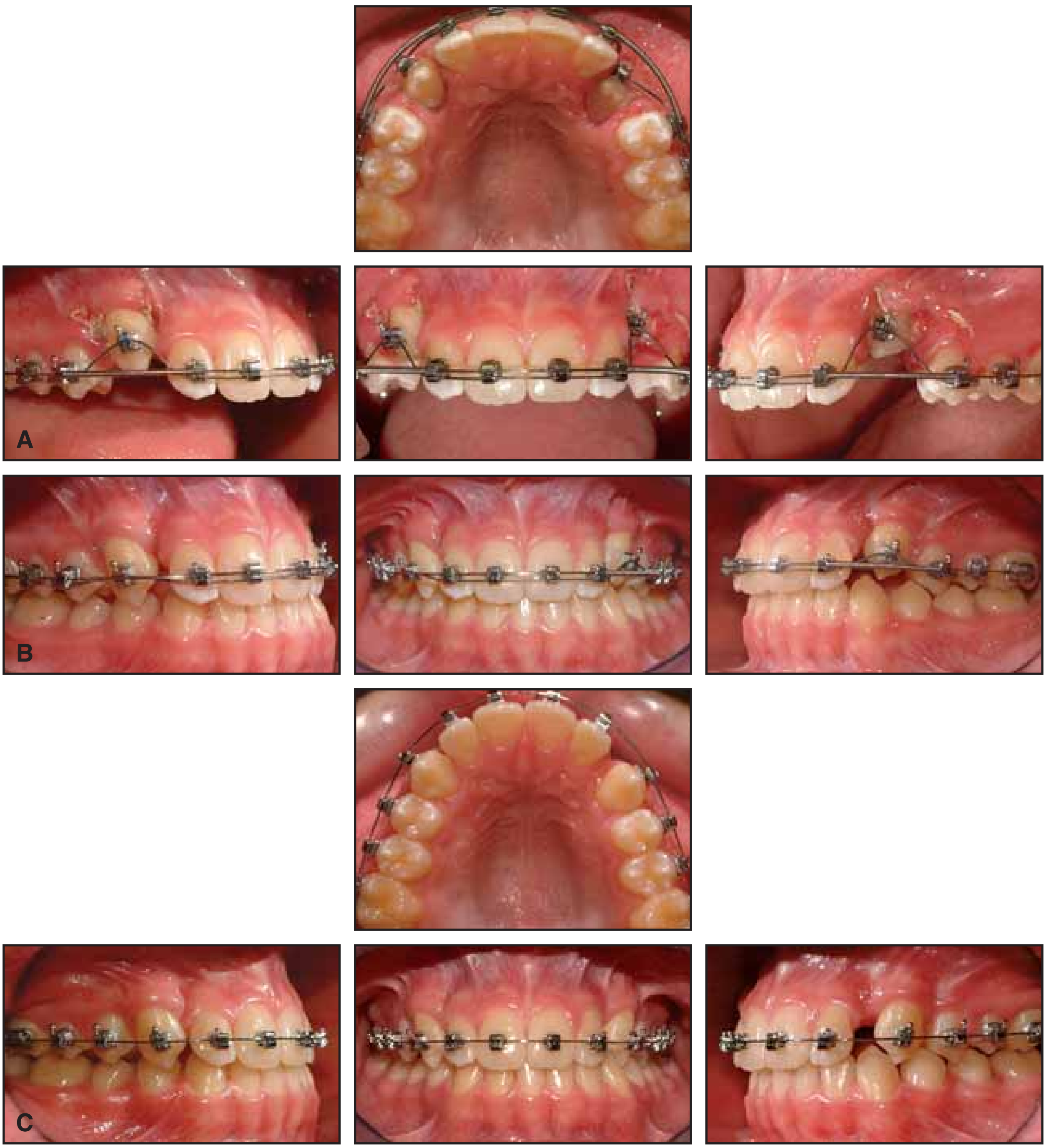

Fig. 4 Case 2. A. 14-year-old male patient with recently exposed impacted maxillary canines and apically repositioned periodontal flaps. Segmental .016" Supercable archwire seated in auxiliary slots of SPEED maxillary incisor brackets and main archwire slots of canine brackets, in conjunction with .017" × .022" SPEED archwire. B. Segmental archwire restopped distal to first premolars six weeks later, following rapid canine eruption without incisor flaring. C. Continuous .016" nickel titanium archwire placed after another eight weeks.