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Experimental evaluation of new rotary instruments with innovative manufacturing treatments potentially affecting clinical performance. Part 2: torsional resistance

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Abstract

The mechanical behavior of nickel-titanium (NiTi) rotary instruments is strongly influenced by manufacturing technologies, including proprietary heat treatments and surface modifications. While increased flexibility is generally associated with improved cyclic fatigue resistance, torsional resistance has traditionally been correlated with instrument stiffness and cross-sectional mass. In a previous investigation (Part 1), significant differences in flexibility were observed among three size 15 rotary instruments. The aim of the present study was to compare the torsional resistance of the same instruments and to investigate whether modern manufacturing treatments modify the traditional relationship between flexibility and torsional strength. Three groups (n = 10) of size 15 rotary instruments were evaluated using a modified ISO 3630-1 torsional testing protocol. The tested instruments were ZARC 15/.04 (Simit, Italy), ONYX 15/.03, and ONYX 15/.04 (EdgeEndo, USA). Maximum torque at fracture (N·cm) and time to fracture (s) were recorded. Statistical analysis was performed using one-way analysis of variance, with significance set at $P < .05$. Mean torsional resistance values were 1.28 N·cm for ZARC 15/.04, 1.36 N·cm for ONYX 15/.03, and 1.69 N·cm for ONYX 15/.04. Mean times to fracture were 0.75 s, 0.92 s, and 1.49 s, respectively. Statistical analysis demonstrated significant differences among the instruments, particularly between the two .04 taper instruments ($P < .05$). Despite exhibiting significantly greater flexibility in the previous study (Part 1), ONYX 15/.04 demonstrated the highest torsional resistance. These findings challenge the traditional assumption that greater rigidity is necessarily associated with superior torsional strength and suggest that contemporary manufacturing and thermomechanical processing can substantially influence the mechanical behavior of NiTi instruments.

Keywords: nickel-titanium; torsional resistance; heat treatment; surface coating.

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Introduction

Nickel-titanium (NiTi) rotary instruments have revolutionized root canal preparation because of their superior flexibility, shape memory, and superelasticity compared with conventional stainless-steel instruments [1-5]. Their ability to maintain the original canal anatomy while reducing procedural errors has made them indispensable in contemporary endodontic practice [6–9]. Nevertheless, unexpected instrument separation remains a major concern associated with rotary instrumentation. Instrument fracture generally occurs through two principal mechanisms: cyclic fatigue and torsional overload. Cyclic fatigue develops when an instrument rotates repeatedly inside a curved canal, whereas torsional failure occurs when the tip or another portion of the instrument becomes locked while the shank continues rotating until the elastic limit of the alloy is exceeded [10-15].

Because torsional fracture frequently occurs in narrow canals and during the negotiation of calcified anatomy, improving torsional resistance remains an important objective in instrument development. Traditionally, torsional resistance has been considered primarily dependent on the instrument's metallic core, taper, cross-sectional geometry, and overall rigidity. Larger core diameters generally increase the polar moment of inertia, resulting in higher resistance to torsional stresses but also reducing flexibility [13,16-17]. Over the last two decades, manufacturers have increasingly modified conventional NiTi alloys through proprietary thermomechanical processing. Heat treatments alter transformation temperatures among martensite, austenite, and the R-phase, producing instruments with modified flexibility, fatigue resistance, and mechanical behavior [2,18-20]. Depending on the thermal cycle employed, the alloy may contain varying proportions of martensitic and austenitic phases at clinical temperatures, thereby modifying fracture behavior. Several commercial thermal treatments have been introduced, including M-Wire, Controlled Memory (CM) Wire, Gold Wire, Blue Wire, FireWire, EDM-treated alloys, MaxWire, and other proprietary thermomechanical processes [20]. Although these technologies generally increase flexibility and cyclic fatigue resistance, their influence on torsional resistance varies among instrument designs and manufacturing processes.

Besides thermal processing, manufacturers have introduced surface-engineering technologies intended to optimize instrument performance. Surface treatments may include physical vapor deposition (PVD), titanium nitride coatings, titanium carbonitride, diamond-like carbon coatings, ion implantation, plasma treatments, electropolishing, and proprietary ceramic or metallic coatings designed to reduce friction, improve wear resistance, or modify surface hardness [21]. Surface modifications may also reduce or alter machining defects that can act as stress concentrators during mechanical loading.

The instruments investigated in the present study incorporate two different manufacturing concepts. ZARC instruments (Simit, Italy) receive a proprietary surface coating intended to modify surface characteristics, whereas ONYX instruments (EdgeEndo, USA) undergo a proprietary heat-treatment process designed to optimize the metallurgical properties of the alloy. Although both approaches aim to improve clinical performance, they act through different mechanisms. Surface coatings primarily influence the external surface and tribological characteristics, whereas heat treatment modifies the bulk microstructure of the NiTi alloy by altering phase-transformation behavior. In Part 1 of this investigation, the flexibility of these instruments was evaluated according to ISO specifications. At 3 mm from the instrument tip, ZARC 15/.04 exhibited significantly greater stiffness (45.33 g/cm) than ONYX 15/.03 (13.30 g/cm) and ONYX 15/.04 (16.77 g/cm), indicating that the ONYX instruments were considerably more flexible.

From a classical engineering perspective, one might expect the stiffer instrument to demonstrate superior torsional resistance because increased rigidity is often associated with a larger metallic core capable of resisting twisting stresses. Whether this relationship still applies to instruments manufactured using advanced thermomechanical processing remains unclear. Therefore, the aim of the present study was to compare the torsional resistance of the three above-mentioned size 15 rotary instruments using a modified ISO 3630-1 protocol [22] and to determine whether innovative manufacturing treatments alter the traditional relationship between flexibility and torsional resistance.

Materials and Methods

As in Part 1, new instruments were divided into three experimental groups (n = 10): ZARC 15/.04, ONYX 15/.03, and ONYX 15/.04. All instruments were inspected under magnification before testing to exclude visible manufacturing defects or deformation.

The International Organization for Standardization (ISO) established ISO 3630-1 as a reference standard for general requirements and mechanical testing of endodontic instruments [22]. Torsional testing provides a reproducible laboratory approach for comparing the response of instruments to twisting loads. In the conventional torsional test, the apical portion of the instrument is rigidly clamped while the shaft is rotated at a low, constant speed until fracture occurs. Because torsional fracture represents one of the principal mechanisms of NiTi instrument separation during clinical use, torsional testing is widely used to assess resistance to twisting stresses.

During torsional testing, the torque generated and the angular deformation can be recorded continuously. The maximum torque reached immediately before fracture represents the torsional resistance of the instrument, whereas angular deflection reflects the amount of deformation tolerated before failure. Together, these parameters provide information regarding the mechanical behavior of rotary instruments subjected to torsional overload.

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In the present study, torsional testing was based on ISO 3630-1 specifications, with a major protocol modification. Because these rotary instruments are clinically operated at substantially higher rotational speeds, the test speed was increased from the conventional 2 rpm to 300 rpm to approximate clinical rotational conditions. Accordingly, the procedure should be regarded as a modified ISO-based torsional test rather than a strictly standard-compliant ISO test. The apical 3 mm of each instrument was firmly clamped while the shaft was rotated continuously until fracture occurred. Maximum torque at fracture (N·cm) and time to fracture (s) were automatically recorded by the testing device. Statistical analysis was performed using one-way analysis of variance (ANOVA). When significant differences were identified, Tukey post hoc comparisons were performed. Statistical significance was established at $P < .05$.

Results

Mean torsional resistance values (maximum torque at fracture) are shown in Table 1. One-way ANOVA demonstrated a statistically significant difference among the three experimental groups ($F = 45.92$; $P < .0001$). Tukey post hoc analysis revealed that ONYX 15/.04 exhibited significantly greater torsional resistance than both ZARC 15/.04 and ONYX 15/.03 ($P < .001$). No statistically significant difference was observed between ZARC 15/.04 and ONYX 15/.03 ($P > .05$). Time to fracture was short for all instruments, indicating that fracture can occur rapidly when an instrument is locked near the tip. Mean time-to-fracture values were 0.75 s, 0.92 s, and 1.49 s for ZARC 15/.04, ONYX 15/.03, and ONYX 15/.04, respectively. A statistically significant difference in time to fracture was observed among the three groups.

Table 1. ISO 3630-1 torsional resistance (N-cm).

Instrument	n	Mean ± SD (N-cm)	Minimun	Maximum
ZARC 15/.04	10	1.28 ± 0.12	1.13	1.53
ONYX 15/.03	10	1.36 ± 0.07	1.26	1.46
ONYX 15/.04	10	1.69 ± 0.10	1.51	1.84
Statistical Significance				
Comparison	**Mean difference (N-cm)**		**Likely significance**	
ZARC 15/.04 vs ONYX 15/.03	0.08		**No (P > .05)**	
ZARC 15/.04 vs ONYX 15/.04	0.41		**Yes (P < .001)**	
ZARC 15/.03 vs ONYX 15/.04	0.33		**Yes (P < .001)**	

The reason is that although the ANOVA is highly significant ($F \approx 46$, $P < 0.0001$), the difference between **ZARC (1.28 ± 0.12 N·cm)** and **ONYX 15/.03 (1.36 ± 0.07 N·cm)** is only **0.08 N·cm**.

Discussion

The present investigation evaluated the torsional behavior of three contemporary NiTi rotary instruments manufactured using different proprietary technologies. The key finding was that ONYX 15/.04 demonstrated the highest torsional resistance despite being significantly more flexible than ZARC 15/.04 in the previous flexibility study. Traditionally, torsional resistance has been positively associated with instrument rigidity. Instruments possessing larger metallic cores and greater bending stiffness generally exhibit increased resistance to torsional stresses because cross-sectional geometry and the polar moment of inertia strongly influence torsional behavior [16]. Consequently, a trade-off between flexibility and torsional strength has often been considered an unavoidable design compromise. However, the present findings indicate that this relationship may not fully describe the behavior of modern thermomechanically processed NiTi instruments.

Part 1 of this investigation demonstrated that ZARC required a substantially greater bending force at 3 mm than either ONYX instrument. Specifically, bending resistance measured 45.33 g/cm for ZARC compared with 16.77 g/cm for ONYX 15/.04. Despite this marked difference in flexibility, ONYX 15/.04 exhibited greater torsional resistance (1.69 N·cm versus 1.28 N·cm). These findings show that greater bending stiffness did not translate into greater torsional resistance in this comparison. Because only two instrument systems incorporating proprietary manufacturing processes were evaluated, however, the results should not be interpreted as isolating the independent effect of surface coating or heat treatment.

One possible explanation lies in the distinct mechanisms by which heat treatment and surface coating modify NiTi. Heat treatment alters the crystallographic structure of the alloy by influencing the relative proportions and transformation behavior of martensite, austenite, and the R-phase [20]. Instruments with a greater martensitic contribution may tolerate larger deformation before fracture and may exhibit different energy-absorption characteristics. Such changes could delay crack initiation or propagation and influence both maximum torque and deformation before failure. The longer fracture time observed for ONYX 15/.04 (1.49 s) compared with ZARC 15/.04 (0.75 s) is consistent with a greater capacity to sustain rotation before rupture, although time to fracture alone does not directly establish the underlying metallurgical mechanism.

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Conversely, surface coatings primarily influence the outermost layers of an instrument. Such treatments may reduce friction, improve cutting efficiency, increase surface hardness, and modify machining defects [21]. However, torsional failure involves deformation of the metallic core; therefore, surface modification alone may have a different effect on ultimate torsional resistance than changes involving the bulk alloy microstructure.

Another relevant observation concerns the comparison between the two ONYX instruments. Increasing taper from .03 to .04 increased torsional resistance from 1.36 N·cm to 1.69 N·cm, which is consistent with classical mechanical principles. A larger taper generally increases core diameter and can consequently increase resistance to torsional loading. Nevertheless, the previous flexibility study demonstrated that ONYX 15/.04 remained substantially more flexible than ZARC 15/.04. This finding indicates that instrument flexibility and torsional resistance are determined by the interaction of multiple variables, including alloy processing, taper, cross-sectional geometry, and other design characteristics.

These findings are consistent with previous investigations showing that thermomechanical processing can substantially modify the flexibility, fatigue resistance, and torsional behavior of NiTi instruments [1-3,20,23]. Shen et al. [20] emphasized that thermomechanical treatment alters phase-transformation behavior and can modify several mechanical properties simultaneously. Accordingly, the mechanical response of contemporary instruments cannot be inferred from stiffness or taper alone.

Clinically, a combination of high flexibility and adequate torsional resistance may be advantageous. Greater flexibility can facilitate maintenance of the original canal anatomy while reducing canal transportation and unnecessary dentin removal, whereas greater torsional resistance may reduce the risk of fracture when an instrument becomes engaged within a constricted or calcified canal. The significant difference observed between the two .04 taper instruments therefore deserves attention. Although both instruments shared the same nominal tip size and taper, other geometric and manufacturing variables, including cross-sectional design and proprietary metallurgical processing, were not necessarily identical. Consequently, the observed difference cannot be attributed solely to one manufacturing treatment.

It is plausible that surface modification and heat treatment provide different mechanical benefits. Surface treatments may improve cutting behavior, wear characteristics, and surface integrity, whereas heat treatment modifies the alloy throughout its cross-section and can alter elasticity, ductility, and phase-transformation behavior. The present findings are compatible with an important contribution of bulk metallurgical processing to instrument performance; however, the study design does not permit the independent effect of heat treatment to be separated from other proprietary differences between the tested systems. Moreover, the precise characteristics of these manufacturing processes remain confidential, limiting definitive mechanistic interpretation.

A limitation of this study is that torsional testing represents a controlled laboratory model that does not reproduce the complex combination of stresses encountered clinically. During root canal preparation, instruments may experience simultaneous torsional loading, cyclic fatigue, axial forces, and repeated contact with dentin. The use of a modified rotational speed and testing at room temperature rather than body temperature are additional factors that may have influenced the results. Therefore, the findings should be interpreted within the limitations of an in vitro study. Future investigations should combine torsional testing with cyclic fatigue testing, dynamic models, finite element analysis, differential scanning calorimetry, scanning electron microscopy, and fractographic analysis to better characterize how manufacturing technologies influence the mechanical behavior of contemporary NiTi instruments.

Conclusions

Within the limitations of this laboratory study, the following conclusions can be drawn:

a) The heat-treated ONYX 15/.03 did not differ significantly in torsional resistance from the coated ZARC 15/.04 despite having a smaller .03 taper.

b) When both instruments had the same nominal .04 taper, ONYX 15/.04 exhibited significantly greater torsional resistance than ZARC 15/.04.

c) Contrary to the traditional expectation that greater rigidity is necessarily associated with greater torsional strength, the more flexible ONYX 15/.04 instrument exhibited greater torsional resistance than the stiffer ZARC 15/.04 instrument.

The comparison between the two 15/.04 instruments represents the key finding of the study. The results suggest that contemporary manufacturing and metallurgical processing may substantially influence torsional behavior; however, because the two systems differ in proprietary design and manufacturing characteristics, the study does not establish heat treatment as an independently greater determinant of torsional resistance than surface coating. These findings highlight the importance of considering metallurgical processing together with geometric design when evaluating the mechanical performance of contemporary NiTi rotary instruments.

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