Endodontic Canal Preparation: New Developments

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Shaping

Clinical goals
- antimicrobial efficacy
- avoid preparation errors

Mechanical goals
- providing space for obturation
- avoid instrument fracture

Where are we standing with this?
- rotary instruments have brought very significant improvement over the last 2 decades

"... the prepared canal should include the original canal; the apical constriction should be maintained; the canal should end in an apical narrowing; and the canal should be tapered from crown to apex."

ESE Consensus Paper 2006
**What is new?**

- NiTi properties
- Metallurgy
- Discussion

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**Accumulated Debris**

- Accessory anatomy blocked

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**Hard Tissue Debris**

- Superimposition shows blocked areas in green
- Volume can be quantified
The Self-Adjusting File

What is new?

NiTi properties

Metallurgy

Discussion

Root Canal Preparation with a Novel Nickel-Titanium Instrument Evaluated with Micro-computed Tomography: Canal Surface Preparation over Time

Ono A. Peters, DDS. MS, PhD, a Claudia Bossier, DDS, and Frank Pampol, Dr med dent

Uninstrumented Apices [%]

SAF 1.9mm

SAF 2.0mm

2min 3min 4min 5min 6min

Peters et al, 2010
Wide canal space: most d roots, bicuspids
- inadequate shape and insufficient cleaning
Ability of Chemomechanical Preparation with Either Rotary Instruments or Self-adjusting File to Disinfect Oval-shaped Root Canals

Joaõ E. Siqueira Jr, PhD; Valério R.B. Alves, PhD; Bernardo M. Almeida, DDS; Julio C. Nascimento de Oliveira, PhD; and Isabel N. Ríos, PhD

The Wave One System
Canal preparation using only one Ni-Ti rotary instruments: preliminary observations. 
*Int Endod J* 41: 339-344

**Aim**
- to describe a novel preparation technique using only two instruments

**Summary**
- the technique described begins with negotiation to working length with hand instrument to size .08
- the bulk of the shaping is done with a ProTaper F2 (tip size 25)
- the ProTaper is oscillated in a ATR electric motor that is programmed to generate reciprocating movements
- r.p.m. is set at 400, the angles of rotation are CW 144° CCW 72°
- instrumentation proceeds with very light apical pressure

**Results**
- several cases are presented where curved canals could be prepared with just one hand and one rotary instruments

**Discussion**
- the technique presented appears to be effective and safe
- the exact settings need to be confirmed and more research is needed

**The Wave One System**

**Engine-driven**
- reciprocating in special motor
- 3 sizes, small (21.06), primary (25.08), large (40.08)
- must be single use (plastic ring expands)
Material & Methods

- 20 maxillary molars had db and mb roots instrumented with ProTaper either in continuous rotation or reciprocation (CW140, CCW45 degrees)
- micro CT data was acquired and processed for canal transportation assessment (curvature, volume, surface, SMI, in-plane shift)
- parametric statistics were performed

Overall outcomes
- no increased incidence or severity of errors
- prepared surface and debris similar

Clinical data
- currently no studies available but case reports and in vitro data is encouraging

Conclusion
- Reciprocation is an “...attractive alternative method to prevent procedural errors during root canal shaping”
Material & Methods
- 90 curved canals in extracted teeth were carefully randomized
- canals were prepared to final size #50 with NiTi hand files, MTwo or ProTaper following manufacturers’ recommendations
- micro CT scans were acquired initially and after subsequent preparation steps
- prepared perimeters and canal outlines were determined
Increased Apical Enlargement

- Intended to increase efficacy
  - circumferential dentin removal
  - prepared canal surface

- Experimental data
  - does not lead to more complete preparation but with
    less flexible instruments may cause preparation errors

- Clinical conclusion
  - 

El Ayouti, 2011

Crazy Root Canals

Because you wouldn't want to tell your patient...

Changing the DNA of NiTi

HyFlex® CM
controlled memory NiTi files

- 100% more resistance to separation
- No shape memory + Extreme flexibility = Superior Canal Tracking
- Requires shape after sterilization = Multi-use

Testarelli et al, 2011
Martensitic Files

- Bendable

residual deformation

Temperature [°C]

100

Heat Treatment after Machining

- Surface topography

- not treated
- heat-treated (?) prototypes, heat treated and controls, 2010

Bending Properties of a New Nickel-Titanium Alloy with a Lower Percent by Weight of Nickel

Luca Testarelli, DDS, PhD,*, Gianluca Pizzino, DDS, PhD,*, Dina A. Sadik, DDS,† Valentina Vincenzi, DDS,‡ Alessio Gianstracceu, DDS,§ Nicola M. Grande, DDS, PhD, and Gianluca Gambatari, MD, DDS

<table>
<thead>
<tr>
<th>Instrument</th>
<th>g/cm</th>
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<tr>
<td>Hyflex</td>
<td>14.46 ± 2.7°</td>
</tr>
<tr>
<td>EndoSequence</td>
<td>46.01 ± 3.9°</td>
</tr>
<tr>
<td>Profile</td>
<td>64.18 ± 4.2°</td>
</tr>
<tr>
<td>Hero</td>
<td>67.11 ± 5.7°</td>
</tr>
<tr>
<td>FlexMaster</td>
<td>68.39 ± 4.9°</td>
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</table>

J Endod 2011, 37:1293-1295
Martensitic Alloys

- Flexibility
  - clearly greater than austentic initially
  - under "normal" fatigue condition extended lifespan

- Clinical data
  - currently no studies available but case reports and
    in vitro data is interesting

- Conclusion
  - need to reconsider fatigue testing norms
  - not clear how important fatigue is for single use

Cyclic Fatigue [5mm radius, 90°]

- Effect of metal conformation on fatigue lifespan

![Cyclic Fatigue Graph](prototypes, heat treated and controls, 2010)

Blue™ File Technology

- New raw material
  - the degree of shape memory is dependent on NiTi microstructure
  - this material promises to be much more fatigue resistant and more

![Blue™ File Technology](Dentsply Tulsa Dental to be released)
What is new?
Martensitic Nickel-Titanium Instruments for Coronal Flaring

Abstract

Discussion

The Vortex System

ProFile Vortex Rotaries

- Sizing
  - similar to ProFile, .04 & .06 tapers, #15 to #50 tips
  - offers sizes for many cases and shapes

- Benefits and limitations
  - supposedly more cutting efficient
  - M-wire may result in better fatigue resistance

- Research
  - Vortex may be the successor to GT/ProFile
  - there is limited published research on this file

Commentary

Renata Dornelles Morgental, DDS, MS, PhD, Patrícia Maria Poli Kopper, DDS, MS, PhD, Iria Antonio Poli de Figueiredo, DDS, MS, PhD, Fabiana Vieira Vier-Pelisser, DDS, MS, PhD

Methods:
A high correlation to data against dentin, but acrylic may not be a proper substrate when the intention is to assess cutting efficiency loss with repeated use.

Results:
- Cutting efficacy was highest in martensitic instruments used in lateral action (orifice modification)
- Cutting efficiency loss, area and length for notches 1 and 2 (first notches) and 4 and 5 (last notches) were significantly higher than those for notches 1 and 2 against acrylic.
- Acrylic was the most cutting efficient instrument in lateral action. An increase in rotational speed improved the cutting efficiency.
- Results against acrylic showed a strong correlation with the overall cutting efficiency.
ProTaper Next

- Research data
  - shaping potential good
  - not a minimal invasive instrument
  - fatigue-resistant, low torque when cutting apically

- Clinical “feel”
  - brushing motion preferred
  - fairly safe instrument re.: breakage

- Clinical outcomes
  - no data at this point

Shaping Assessment

What is new?

NiTi properties

Metallurgy

Discussion
Example of CT Data

Enlargement to #25, Paqué & Peters, unpublished

Summary of CT Data

- Uninstrumented area
  - 16.4±7.4%, range 8-29%, \textbf{apical} 23.2±10.7% (to X3)
  - very good values in small curved canals

- Minimal dentin thickness
  - 0.60±0.18mm (X2), 0.55±0.17mm (X3)
  - initial dentin thickness ~ 1.0mm

- Canal transportation
  - 70 to 120μm in apical and middle third

Paqué & Peters, 2013 AAE Meeting
Paqué & Peters, unpublished

Torque Tests

A B C D
Preparation

Erika S.J. Pereira, DDS, MS, and Ove A. Peters, DMD, MS, PhD

Abstract

Introduction:

The purpose of this study was to assess torque and force for simulated canal preparation with a new root canal instrument, ProTaper Next.

Methods:

(1–5) were used to prepare 36 artificial canals. Files were divided into 6 groups. Different settings of in-and-out movements to reach working length (3 or 4 insertions [ins]) were applied in each group (250 rpm/3 ins, 250 rpm/4 ins, 300 rpm/3 ins, 300 rpm/4 ins, 350 rpm/3 ins, 350 rpm/4 ins).

Peak torques (Ncm) as well as positive and negative forces (N) were registered. Analysis of variance and Tukey post hoc tests were applied.

Results:

Preliminary and negative force (P< .007) were measured in the group 350 rpm/4 ins. X1 showed the highest torque with all settings. X5 showed the highest positive force in all groups. X1 and X2 showed the highest negative force (> .0001), positive force (P< .002), and lower levels of peak torque as well as positive and negative forces.

Conclusions:

In-and-out movements still seem to have a risk of fracture in the clinical situation. Development continues to design rotaries that render shaping not only easier and faster but are also more likely to lead to improved outcomes, compared with stainless steel hand instruments.

First published research

- torque during shaping is low: 1.5 - 3Ncm
- higher RPM (300) is better than lower
- torque at failure (ISO 3630) is lower than working torque
Shaping

Torque Data in Plastic Blocks

- Torque at failure (ISO3630-1)
  - range from 0.35 to 2.87 Ncm for X1 to X5
  - similar or slightly less to ProTaper Universal

- Torque during simulated canal preparation
  - range from 1.6 to 2.8 Ncm for X1 to X5
  - higher compared to fracture torque

- Handling parameters
  - comparing rpm, higher speed is better
  - comparing in-and-out movement, gentle is better

Pereira et al, 2013 AAE Meeting

Fatigue Data

Weibull plots, Nguyen J Endod accepted

What is new?

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What is new?
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Assessment??

Torque Explained

- Torque is lever length times force
  - rotational axis, point of force K
Fatigue Explained

- Cyclic nature
  - repetitive action below elastic limit (high cycle)
  - sometimes beyond elastic limit (low cycle, <$10^5$)

Southwest Airlines accident

- "...jetliner had gone through about 39,000 cycles of pressurizing, generally a count of takeoffs and landings. Cracks can develop from the constant cycle of pressurizing for flight, then releasing the pressure."

- 2009
- 2011
Cyclic Fatigue in vivo

Hooke’s Law

Cyclic Fatigue in vitro

Effect of pseudoelasticity on fatigue lifespan?
Deformation Mechanisms

- Force
- Elastic behavior
- Pseudoelastic behavior

**Steel**

**NiTi**

**What is new?**

- NiTi properties
- Metallurgy
- Discussion

Nickel-Titanium Components

- **austenite (B2)**
  - hard, exists at room temperature for most endodontic instruments (with some exceptions)

- **martensite (B19')**
  - ductile, very flexible; trace amounts present in many endodontic instruments at room temperature

- **R-phase (R)**
  - ductile, stress- or temperature induced, a pre-martensitic phase that provides shape memory

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Components

- **austenite** (also found in iron)
  - *Austenite*, also known as **gamma phase iron**, is a metallic non-magnetic allotrope of iron. From about 900 to 1,400°C alpha iron undergoes a phase transition from body-centered cubic (BCC) to the face-centered cubic (FCC) configuration of gamma iron, also called austenite.

- **martensite** (also found in iron, steel)
  - **Martensite**, named after the German metallurgist Adolf Martens (1850–1914), most commonly refers to a very hard form of steel crystalline structure, but it can also refer to any crystal structure that is formed by diffusonless transformation.
    - for NiTi martensite is in a monoclinic configuration and more flexible than austenite

Nickel-Titanium Components

- **R-phase**
  - The **R-phase** transformation is best thought of as a second (or pre-) martensitic transformation that provides a small, nearly hysteresis-free shape memory and superelastic effect that exhibits virtually no degradation during cycling.
    - the name derives from the concept that the crystal lattice is rhombohedral (may in fact be trigonal)
The R-Phase

Martensitic Transformations in Ti-Ni-based Alloys

- B19 (orthorhombic, 2H) (Ti-Ni-Co)
- B2 (cubic) (Ti-Ni, solution-treated)
- B19' (monoclinic) (Ti-Ni-Fe, Ti-Ni aged)

Fig. 9. Three transformation paths in Ti–Ni-based alloys.

From Otsuka & Ren 2005

The R-Phase

- It is a bit obscure, even for a physicist
  - shows up through changes in electrical conductance, heat flow (total energy) or in stress-strain diagrams

![Stress vs Strain Diagram](from Duerig et al 2007)

R-Phase Crystal Lattice

![Crystal Lattice Diagram](from Duerig et al 2010)
Nickel-Titanium Properties

- Transition of crystal phases
- Temperature and strain-dependent

Clinical application
- Martensitic phase (at low temperature) is flexible
- Higher flexibility – less cutting (=efficiency?)

NiTi Phase Transformation

From Miyai et al 2006
Transition Temperatures [°C]

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<td>-10</td>
<td>-17</td>
<td>32</td>
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</table>

cooling  heating

From Miyai et al 2006

NiTi Phase Transformation

Stress [MPa]

Linear Strain [%]

2% austenite elastic
4% martensitic transformation
2% martensite elastic
2% martensite plastic
Appraisal I

- Thermal processing
  - drawn NiTi wire is work-hardened
  - heat treatment increases flexibility, fatigue resistance
  - downside: cutting ability is lower, high rpm required

- Martensitic files (*e.g.*, with shape memory)
  - current market share is small
  - martensitic files cannot utilize the pseudoelastic SIM transformation; rely on 2% recoverable strain

- Hybrid files (*e.g.*, segmental martensitic)
  - small market share
  - maybe a compromise but better?

What is here already...

- The alloy
  - thermal treatment: M-wire
  - surface treatment: electropolishing, PVD
  - cold treatment, nitrogen ion implantation
  - production process, twisting/stamping vs grinding

- Intelligent motors
  - torque control is a standard feature
  - may detect individual instruments

- Modified usage
  - glide path, single-patient use
  - change of sequence, hybrid techniques, etc.
Summary of Current Data

- GTX
  - fatigue resistance ↑ (p<0.001) compared to stock NiTi
  - similar torsional resistance
  - Johnson et al 2008

- TF (Twisted File)
  - flexibility ↑ compared to same size ProFiles (p<0.05)
  - fatigue resistance: TF > K3 = GTX (different sizes)
  - Gambarini et al 2008

- Comparisons
  - fatigue: EndoSequence>ProFile>TF> GTX; .06>.04
  - difference not significant for TF vs. ProFile
  - Fatigue, angle at fracture: GT=GTX; .06>.04
  - Multiple usage: GT, GT ↓ angle, torque at fracture
  - Larsen et al 2009

- Kell et al 2009

Incidence of Dentinal Defects after Root Canal Preparation: Reciprocating Versus Rotary Instrumentation


Material & Methods
- 100 central maxillary incisors were prepared with either Reciproc, WaveOne, ProTaper or MTwo
- teeth were embedded in Technovit, sectioned and observed under a stereomicroscope at 25x magnification
- complete cracks were defined as "a line extending from the root canal wall to the outer surface of the root"
- the numbers of complete and incomplete cracks was compared by parametric statistics

Bürklein et al J Endod in press
Microcracks are...
- difficult to detect
- associated with various events over the life of a tooth

Unshaped Control

Preparation Possibilities

“More of the same”
- refined instruments that are more efficient and safer
- easier market penetration but limited innovation

Minimal invasive
- limited enlargement and retained structural integrity
- specific set of challenges

Not at all
- specific non-instrumental techniques
- alternatively, vital pulp therapy or regeneration

Questions so far?