Design and validation of the most updated technologies in endodontics by means of FEM

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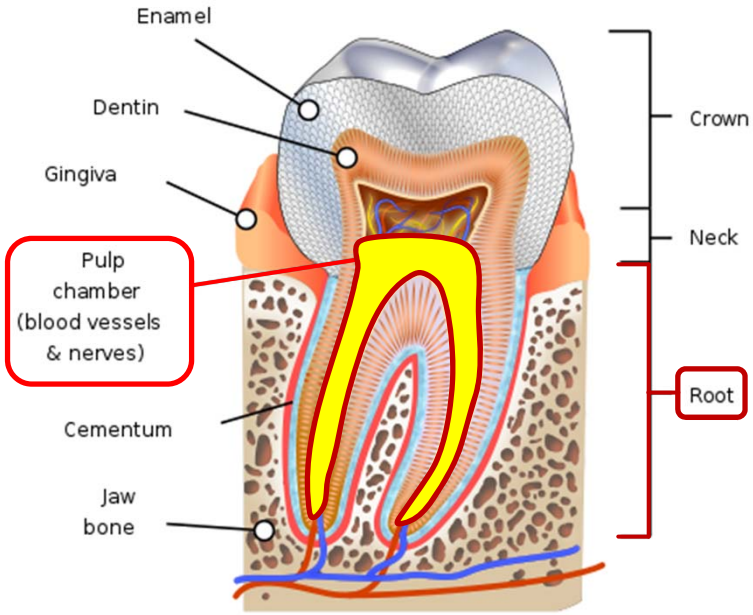
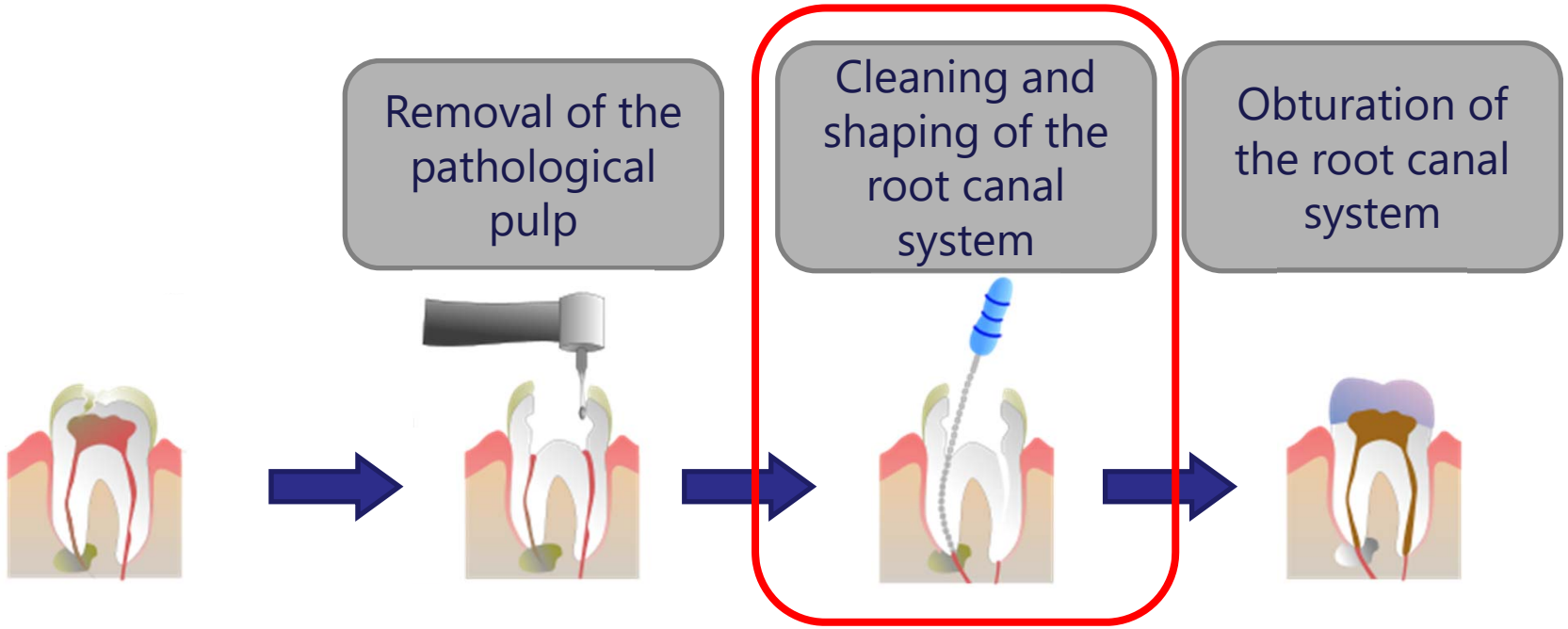
- Introduction
- Virtual design of files:
  - static loads
  - fatigue
  - canal transportation and pressure distribution
- Conclusions

What is ENDODONTICS?

- Endodontics is the dental specialty concerned with the study and treatment of the dental pulp
- The main purpose of endodontics treatment or *root canal therapy* is:
  - remove the pathological pulp
  - clean and shape the root canal system
  - disinfect the contaminated root canals
  - obturate (fill) the root canal system



What is ROOT CANAL THERAPY?



Cleaning and shaping of the root canal system is made with ***endodontics files***

ENDODONTICS FILES: what are they?

- Endodontic files are surgical instruments used by dentists when performing root canal treatment
- The use of this tool facilitates the chemical disinfection and a shape conducive to obturation

ENDODONTICS FILES: how are they made?

- Nickel-titanium shape memory alloy is used
- It is a superelastic alloy which allows it to undergo greater stresses compared to stainless steel

Introduction: endodontics files

- Files have a reduced risk of file fracture
- They return to its initial shape through heating after strain
- This reduces the risk of deformation within the root canal as forces of compression and tension are absent
- Many nickel-titanium files are available

http://www.schottlander.com/product/endodontics/race-rotary-niti-files/race-original-introductory-kits:

http://www.dentalproductshopper.com/profile-vortex

ENDODONTICS TREATMENT: the most critical points

File separation
(instrument breaks)

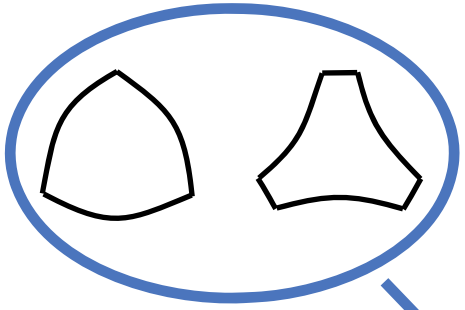
Canal transportation
(deviation from original anatomy)

Pressure distribution
(against root canal)

Application of the Finite Element Method (FEM) to study these problems

Virtual design of files: static loads

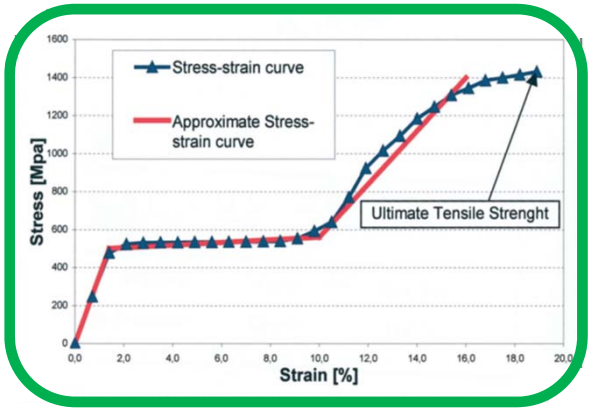
FILE GEOMETRY



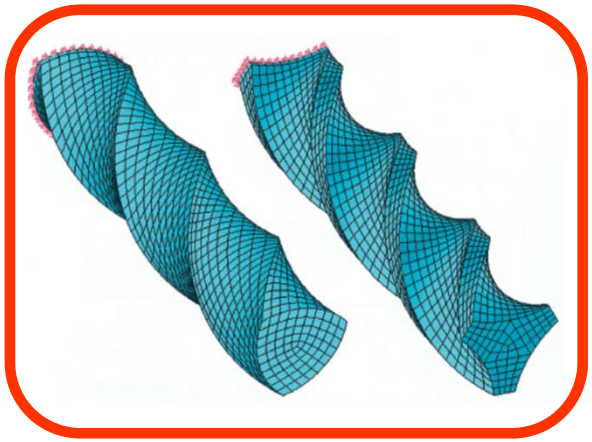
STATIC LOADS

BENDING & TORSION

MATERIAL PROPERTIES

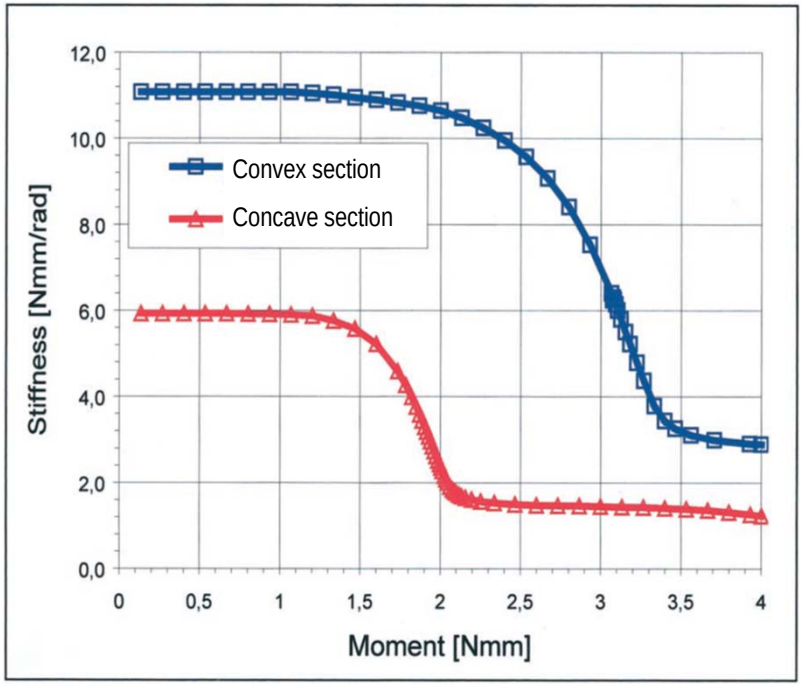


FEM MODEL



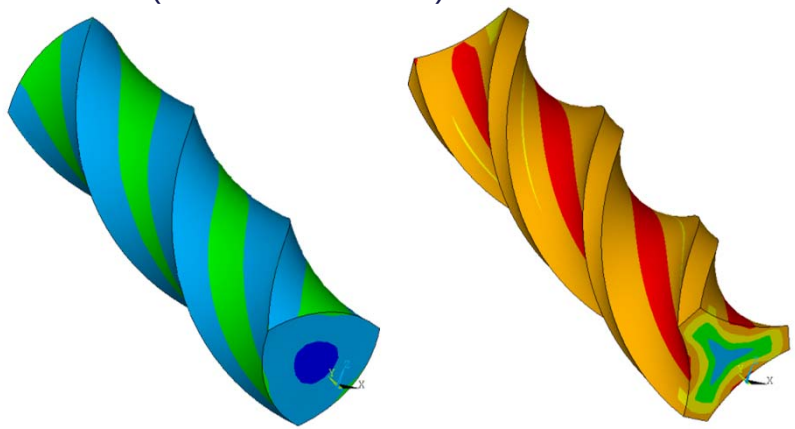
Virtual design of files: static load

- Evaluation of the stress field on the file
- Prediction of static failure
- Analysis of the characteristic rigidity curves



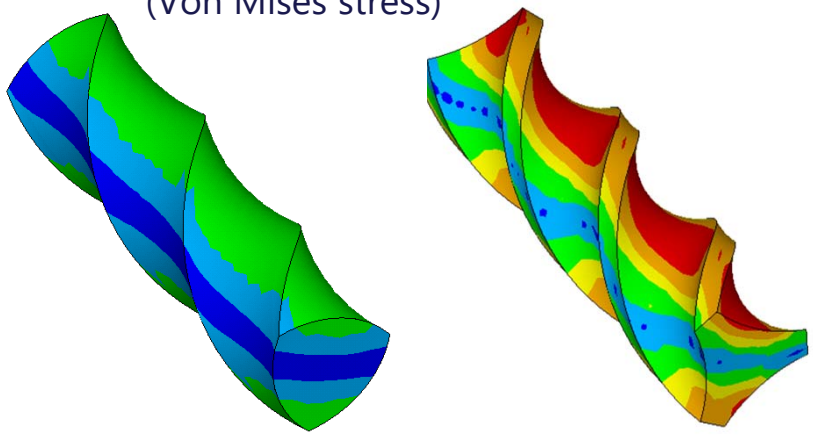
TORSION

(Von Mises stress)



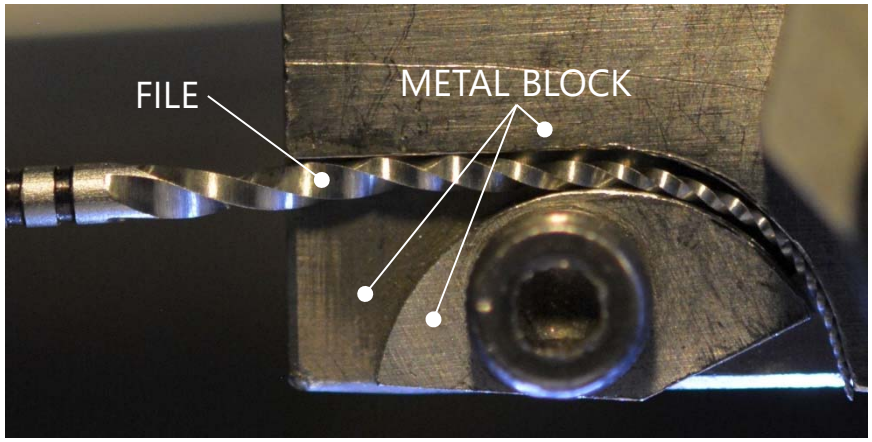
BENDING

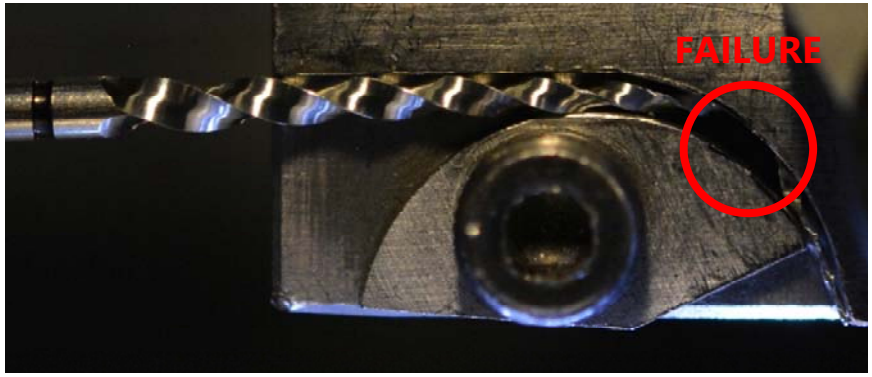
(Von Mises stress)



Virtual design of files: fatigue

- File duration is measured with experimental tests:
  - File is inserted in a metal canal
  - The canal has fixed geometry and it is made with metal blocks
  - File is put in rotation at constant speed up to failure
  - The number of cycle to failure (revolutions) is recorded





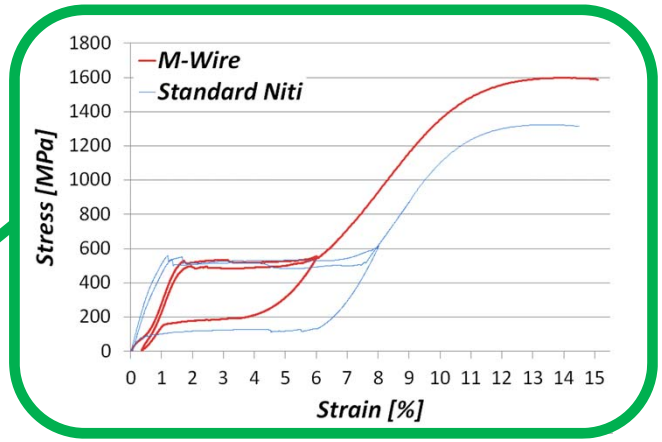
Virtual design of files: fatigue

Design process for fatigue life prediction

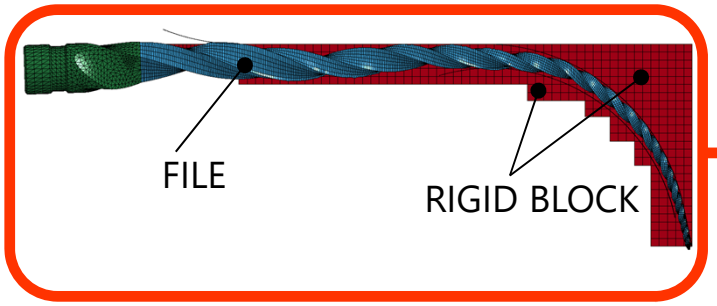
GEOMETRIES

- Metal canal
- File

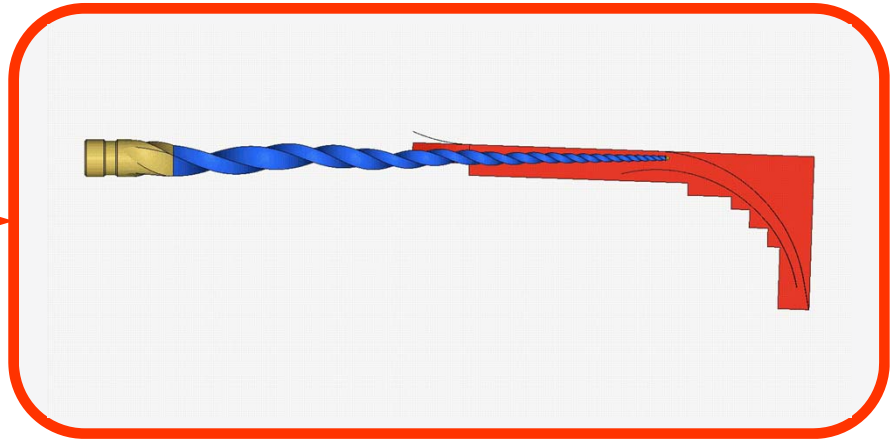
MATERIAL PROPERTIES



FEM MODEL



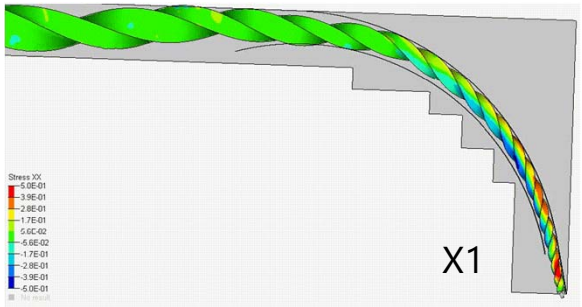
FEM ANALYSIS

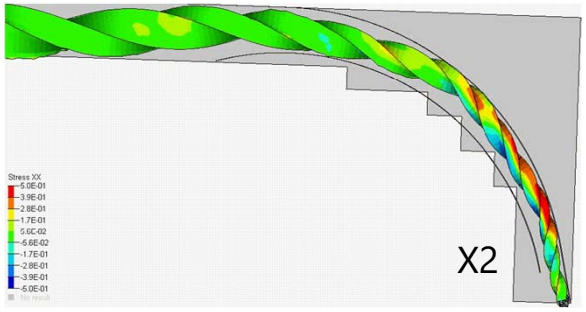


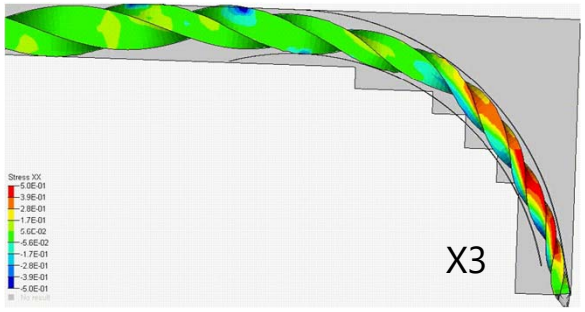
Virtual design of files: fatigue

- The design process for fatigue life prediction were applied to three different files: Protaper Next X1, X2, X3

- FEM analysis were used to define the stress state on the files





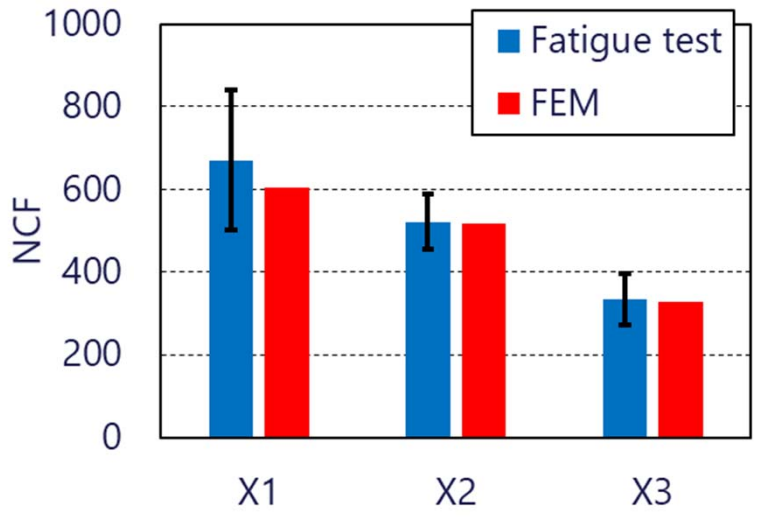


- The stress state of the files were elaborated with a C-S criterion for Multiaxial Random Fatigue developed by Carpinteri (2012)

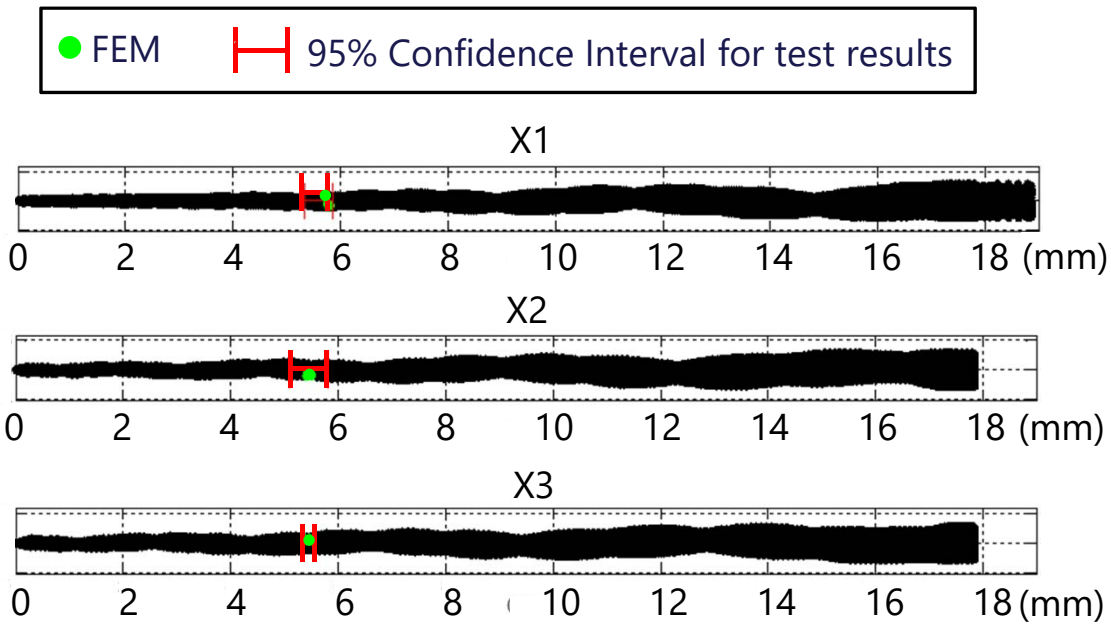
Definition of the fatigue life of the files

Virtual design of files: fatigue

- The main results examined from the analysis were:
  - The number of cycles to failure (NCF)
  - The fracture length and location from the file tip



Fracture location



Excellent agreement between numerical and experimental results

Validation of the virtual method

Virtual design of files: canal transportation

- Canal transportation: deviation from original anatomy
- Virtual evaluation of the pressure applied by the file to the canal wall

GEOMETRIES:

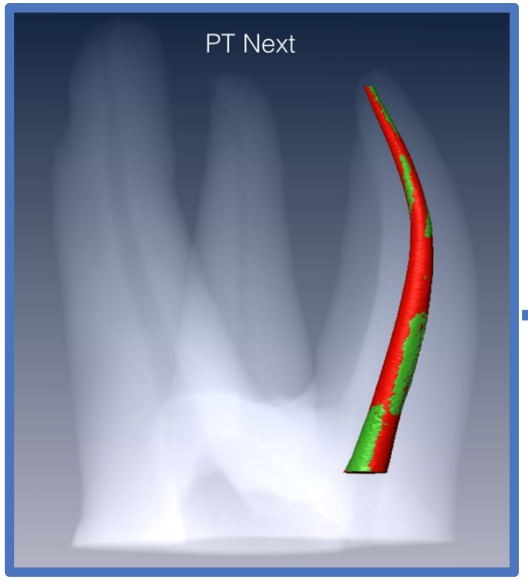
- **File geometry**
- **Canal geometry:** micro-CT post-instrumentation

MATERIAL PROPERTIES:

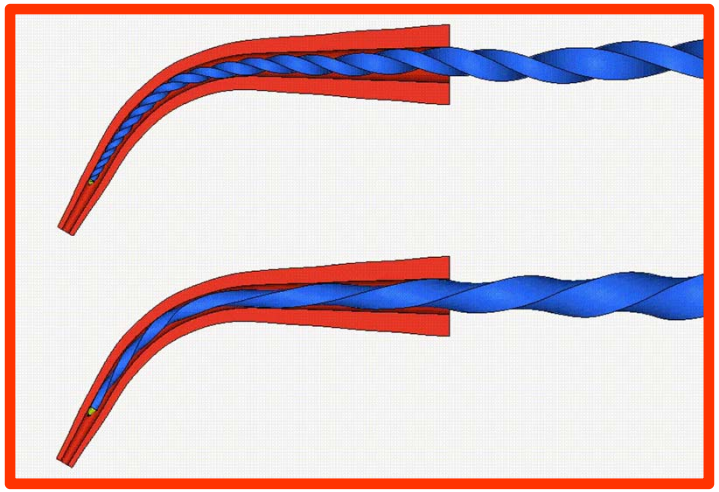
- **Ni-Ti shape memory alloy** for file
- **Dentin** for canal

BOUNDARY CONDITIONS:

- **Insertion**
- **Rotation**

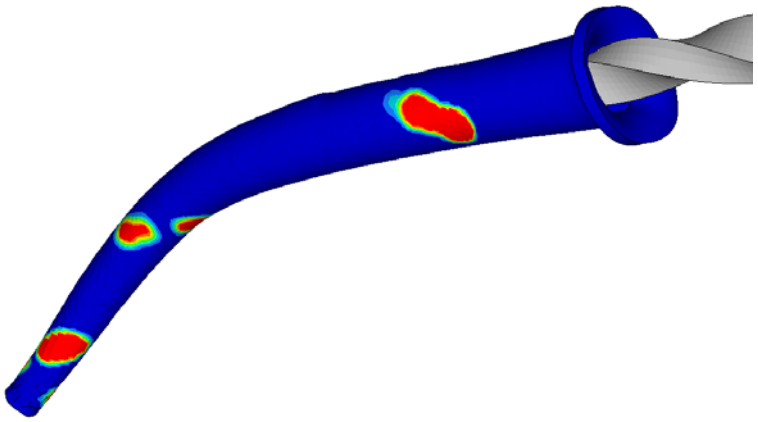


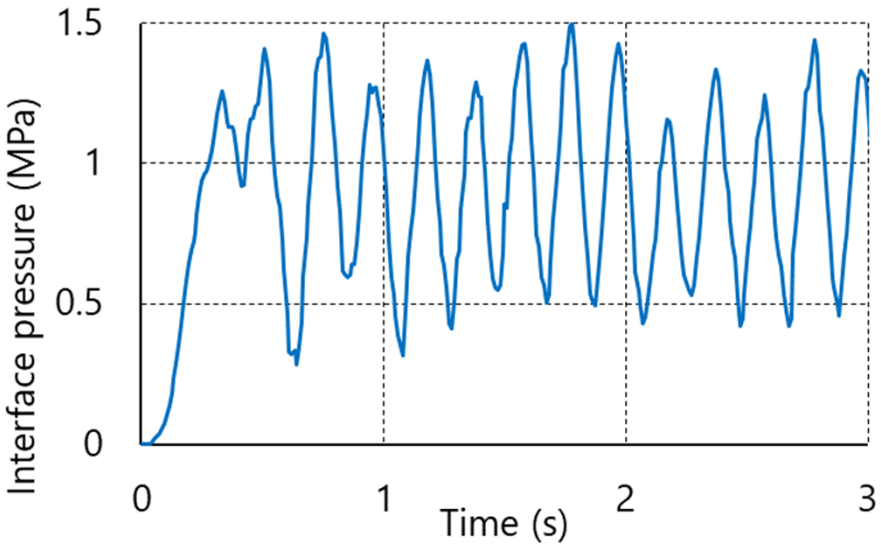
FEM MODEL



Virtual design of files: canal transportation

- Analysis of:
  - Contact points
  - Pressure distribution:
    - Maximum pressure location
    - Average pressure history

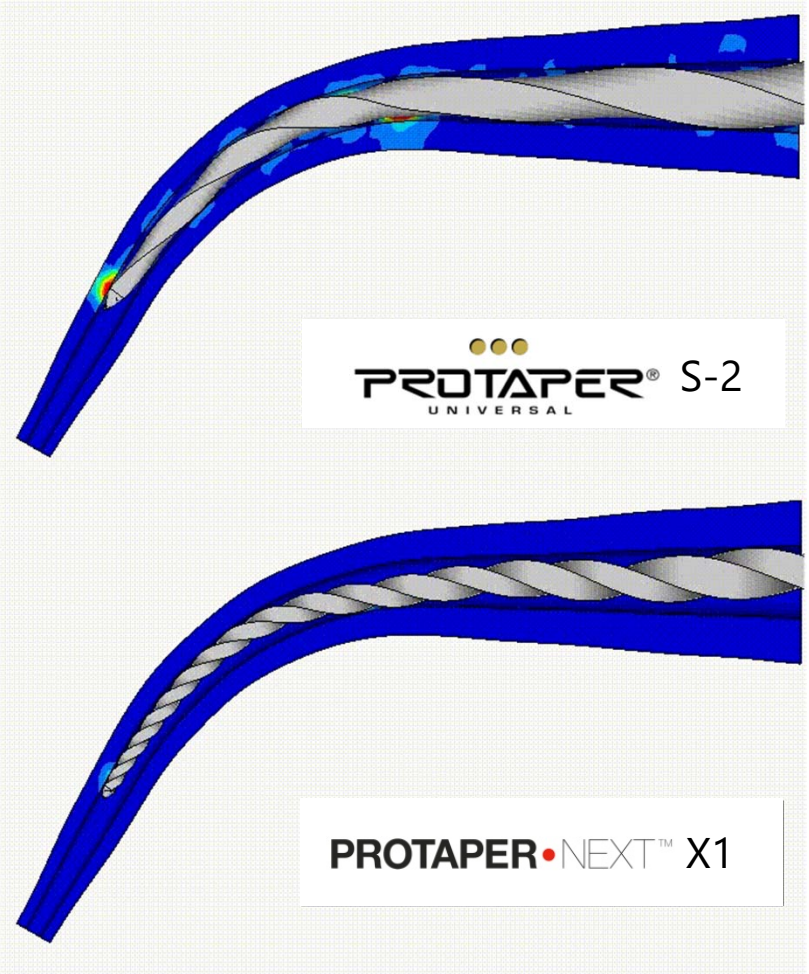




Virtual design of files: canal transportation

- Comparison between two different files:
  - Protaper Next X1
  - Protaper S2

FE Analysis can be useful to define the best instrument for the treatment



Virtual design of files: canal transportation

- Virtual analysis of pressure on resin block in vitro testing

- Comparison between two different file:
  - Protaper Next X2

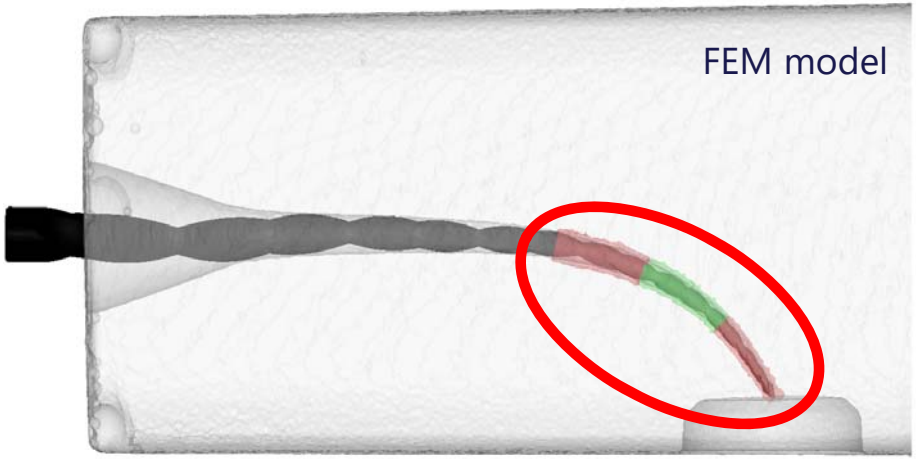
  - BioRace 3

In vitro testing block

http://dentsplymea.com/products/endodontics/endodontic-accessories/endo-training-blocs

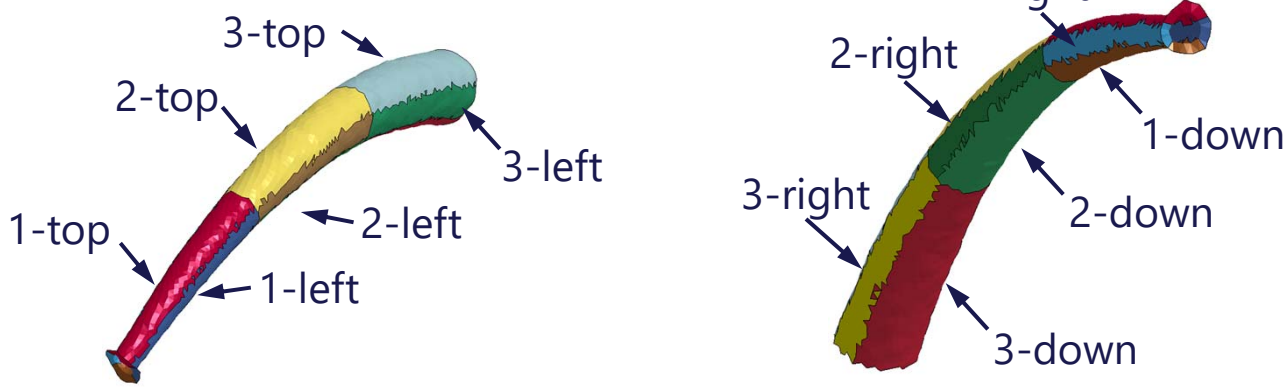
http://www.diadent.com/products/misc.htm

- Focus on the apical part of the block



Virtual design of files: canal transportation

- The apical part was divided in three zones to study in more detail the pressure distribution



- Two different type of simulations were performed:
  - File is pushed on the block canal
  - File is constrained on the tip and it is pulled out from the block
- The average pressure history on the different canal zones were recorded and elaborated to study the canal transportation

Virtual design of files: canal transportation

- A new variable to quantify canal transportation
- The loss of thickness is proportional to the integral of the pressure wrt time

$$\Delta h = k \int p(t)dt \qquad \Delta h_{rel} = \frac{\Delta h_{wear}}{k} = \int p(t)dt$$

1. Evaluation of the relative thickness loss in 3 zones and 2 sides for 2 loading conditions

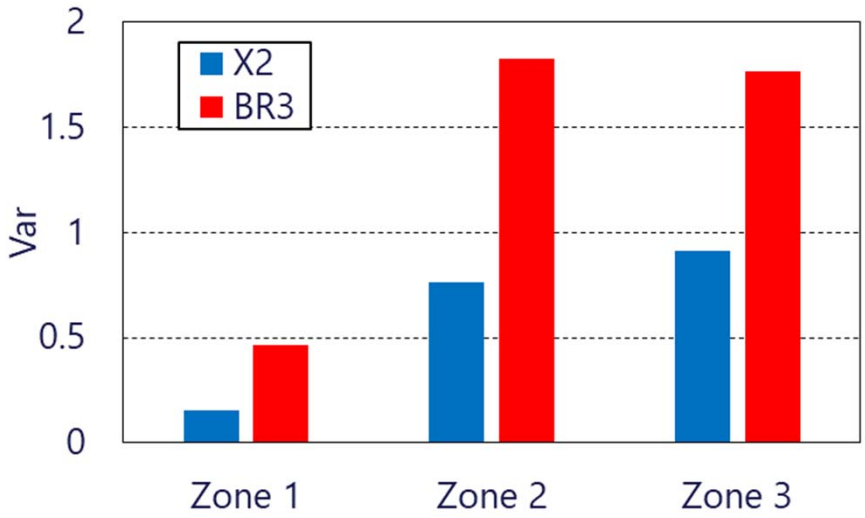
$$\Delta h_{rel,Zone,Side,Load} = \int p_{Zone,Side,Mode} dt$$

2. Evaluation of the average between the 2 loading conditions

$$\overline{\Delta h}_{rel,Zone,Side} = \frac{\Delta h_{rel,Zone,Side,Pull} + \Delta h_{rel,Zone,Side,Push}}{2}$$

3. Evaluation of the absolute variation between top and down, normalized wrt the average

$$Var_{Zone} = \frac{\left|\overline{\Delta h}_{rel,Zone,Top} - \overline{\Delta h}_{rel,Zone,Down}\right|}{\frac{\overline{\Delta h}_{rel,Zone,Top} + \overline{\Delta h}_{rel,Zone,Down}}{2}}$$



- Var parameter should be minimized
- The use of the Protaper Next X2 has to be preferred

Conclusions

- Nickel-titanium shape memory files are used for endodontics treatments
- Between the most critical points in the endodontics treatments there are:
  - Instrument failure
  - Canal transportation
  - Pressure distribution against root canal
- FEM can be successfully used to predict:
  - Fracture and fatigue life of files
  - Pressure distribution against root canal
- FEM can be successfully applied in the design of new file with new geometries

Design and validation of the most updated technologies in endodontic by means of FEM

Thank you for your attention

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