THEORETICAL EVALUATION OF NICKEL-TITANIUM MTWO® SERIES ROTARY FILES

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ABSTRACT

Nickel-Titanium rotary files are a technological development that enables dentists to prepare irregularly shaped root canals without altering them. Unfortunately, these files may fracture without any prior visible warning signs. The aim of this study was to perform a theoretical evaluation of the mechanical behaviour of Mtwo® Nickel-Titanium rotary files for endodontics, in order to determine which of the files in the basic series are most likely to fracture. Mathematical models of the Mtwo® basic file series were analyzed using the finite elements method. Bending and torsion loads were applied to the files both under normal conditions and under extreme conditions, to determine which of them had the highest Von Mises stresses. When the approximation was similar to normal use, none of the file models reached the maximum limit of failure by fracture. When used inadequately, file models 10/0.04 and 25/0.06 had the highest Von Mises stresses for bending and torsion, respectively. Thus, it is recommended that Mtwo® files10/0.04 and 25/0.06 should be used once only, to prevent fractures.

Key words: *endodontic instruments, nickel titanium alloy.*

EVALUACIÓN TEÓRICA DE LAS LIMAS ROTATORIAS DE NÍQUEL TITANIO DE LA SERIE MTWO®

RESUMEN

Las limas rotatorias de Níquel-Titanio son un avance tecnológico que permite al odontólogo llevar a cabo tratamientos en conductos con morfologías irregulares, sin alterarlas. Lamentablemente estos instrumentos pueden fracturarse sin presentar señales visibles que permitan prevenir este accidente. Por lo tanto el objetivo del presente estudio fue evaluar teóricamente el comportamiento mecánico de las limas rotatorias de Níquel-Titanio para uso en endodoncia Mtwo® para determinar cuál de los instrumentos de la serie básica es el que presenta mayor probabilidad de fractura. Con este fin se realizó un análisis por medio del método de los elementos finitos utilizando modelos matemáticos de los instrumentos de la serie básica de las limas Mtwo®. A estos instrumentos se les aplicaron cargas de flexión y torsión en condiciones normales y en condiciones extremas, para determinar cuáles presentaban los esfuerzos de Von Mises más altos. En una aproximación similar al uso normal, ninguno de los modelos de las limas alcanzó el limite máximo de falla por fractura. Ante un uso inadecuado, los modelos de las limas 10/0.04 y 25/0.06 mostraron los esfuerzos de Von Mises más altos tanto a flexión como a torsión respectivamente, por lo tanto se recomienda dar un solo uso a la lima 10/0.04 y a la lima 25/0.06 de Mtwo® para prevenir la fractura de estos instrumentos.

Palabras clave: *instrumentos endodónticos, aleación niquel titanio.*

INTRODUCTION

Biomechanical root canal preparation is the stage of endodontic treatment during which microbial pathogens – present as a result of dental pulp necrosis and decomposition – are removed, and probably the most important stage in non-surgical endodontic treatment[1,2].

Disinfection is achieved by mechanical cleaning plus the use of irrigants and medicaments. It Root canal enlargement and preparation are essential to facilitate the flow of disinfectants and help with its definitive filling[1,2] .

Small-calibre instruments, endodontic files in particular, are used for biomechanical preparation. They were originally made of carbon steel, later on of stainless steel, and currently there are also files made of Nickel-Titanium alloys[3-6].

One of the most important requirements for an ideal endodontic file is that it should not deteriorate or fracture[7].

The incidence of Nickel-Titanium rotary file fractures is reported as 5% to 21%, depending on its design[7]. The fracture of an endodontic file inside the root canal is a procedural accident which significantly reduces endodontic success[8], because the fractured fragment blocks the apical third of the canal and prevents eradication of the infection. The highest endodontic treatment failure rates occur when the initial diagnosis is necrotic pulp[7-10].

Moreover, a fractured file inside a root canal is of concern to the patient, who of course will not wish to retain a piece of metal which has been impossible to extract from his tooth, and may even sue the dentist[7].

Among of the most popular file designs in Latin America is Mtwo®, which has an italic S-shaped cross-section and widely-spaced flutes.

The memory and superelasticity properties of Nickel-Titanium mean that these files show no visible deformation during endodontic treatment. This is at the same time their greatest and most dangerous disadvantage, because the operator does not notice any deterioration until the file fractures. It has been attempted to overcome this problem by recommending that Nickel-Titanium files be used once only, but in Latin American countries their high cost necessitate a rational application to this measure, since not all files in one series are equally likely to fracture. Thus, a recommendation is needed regarding which files may be used more than once, and which should definitely be discarded after one use due to the high probability of undergoing fracture if used again.

There are two ways in which an endodontic file can fail inside a root canal: torsional failure and bending failure. Torsional failure happens when part of the instrument becomes trapped in a section of the canal and the driving motor continues to turn, causing the file to fracture. Bending failure happens when the instrument acts on canals with moderate to severe curvature. Repeated compression and tension on the instrument at each revolution may cause fracture. A study of the tendency of Nickel-Titanium files to suffer torsional or bending fracture showed that torsional facture occurs in 55.7% of fractured files, while bending fatigue occurs in 44.3%[11].

Torsional and bending fracture can be evaluated by experimental methods, as well as by theoretical systems such as the finite elements method.

The basic Mtwo® set is made up of 4 files with different tapers, 10 / 0.04, 15 / 0.05, 20 / 0,06 and 25 /0,06, and although they work on the entire length of the canal, they are used from smallest to largest diameter in order to shape the root canal gradually.

It would be useful to general dentists or endodontics specialists to know which file in the series should be given special attention in order to prevent fracture. Thus, the aim of this study was to use finite elements analysis to determine which file in the Mtwo® series may theoretically have greater probability of fracture.

MATERIALS AND METHODS

Model construction

A reverse engineering process was performed at the metrology laboratory at the School of Engineering of Colombia National University. Measurements of Nickel-Titanium rotary files were taken with a Carl Zeiss Jenna profile projector, with a resolution of 0.01 mm, for geometric characterization and contour plotting of the files.

Measurements of the Mtwo® files were taken on the instrument profile at the widest and narrowest points along the entire longitudinal axis of the active part only.

Tensile stress test to determine the behaviour of the Nickel-Titanium alloy

The ASTM F2516 – 07 Standard[12] test method for evaluating of Nickel-Titanium superelastic materials, which provides a typical stress-strain curve for their behaviour (Fig. 1), was used as a reference for an experimental study using a Universal Testing Machine for tensile stress loads (Shimadzu model AG-IS), which yielded a graph of the real behaviour of the Nickel-Titanium alloy.

The test consisted of measuring tensile stress on a Nickel-Titanium (NiTiNOL) specimen 0.4 mm in diameter and 150 mm long. The specimen was subjected to traction up to 6% strain at a speed of a 0.04 mm/min. Subsequently, the wire was unloaded at 7 MPa and then subjected to traction until it fractured at a speed of 0.4 mm/min.

The experiment yielded a curve which was very similar to the one reported in standard ASTM F2516-07[12] so it was decided to apply data from the stress-strain curve obtained to a simulation by means of finite element analysis. The following data were found for mechanical properties: Young's modulus 31650 MPa, maximum limit of failure by fracture 1270.588 MPa, yielding point 352.941

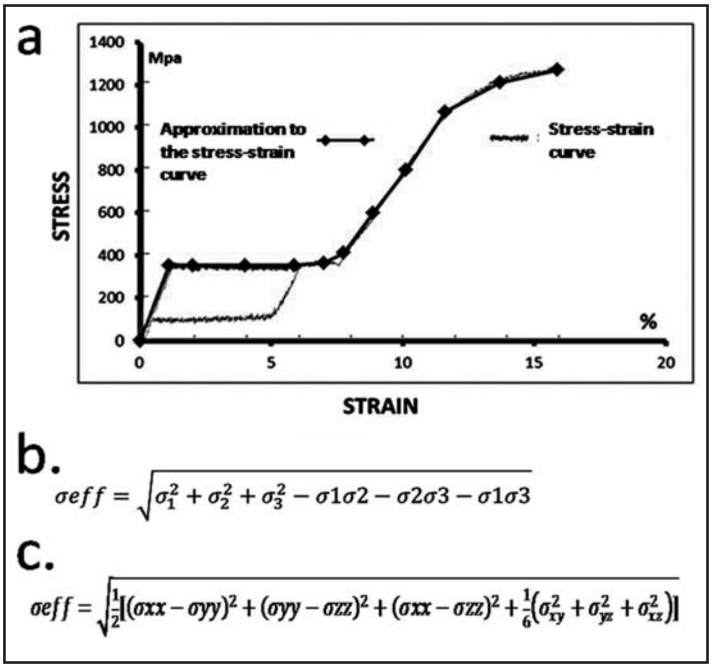

Fig. 1: a. Stress-strain curve and multi-linear approximation to the behavior of a nickel-titanium alloy. b. Equation used by the Autodesk® Simulation Multiphysics software to calculate Von Mises stresses. c. Equation used by Autodesk® Simulation Multiphysics software to calculate Von Mises stresse on Cartesian coordinates.

MPa, Poisson ratio 0.3 and density of the material 6.450 g/cm³.

The software Autodesk Inventor Professional® was used to construct each instrument based on the plots by estimating the working axis and generating the cutting helix around it, after which the characteristic Mtwo® "italic S" cross section was applied. *The Von Mises with Kinematic Hardening material curve* was selected, because it allows an elastic-plastic material to be programmed, thus approaching the real behaviour of a Nickel-Titanium alloy. Previous studies have reported the use of this material model for analyzing finite elements with other software such as Ansys® and Abaqus®[13-16]. The model also allows a behaviour curve to be programmed according to known data, which may be either experimental or previously reported in the literature. Our study was able to program the material behaviour curve according to the experimental tensile test performed on the Nickel-Titanium specimen.

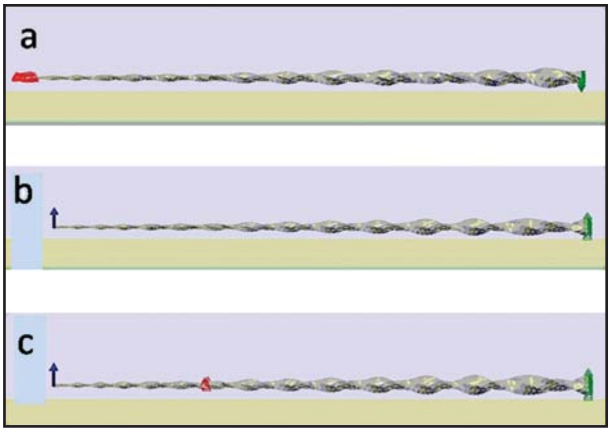

Fig. 2: a. Restriction at the tip and torque applied at file handpiece. b. Restriction in cantilever at the handpiece and force applied to the tip of the file. c. Restriction in cantilever at the handpiece and at 4 mm from the tip of the file, force applied at the tip.

Table 1: Number of elements and nodes per file.

	Elements	Nodes
10/0.04 Mtwo®	2041	881
15/0.05 Mtwo®	2045	761
20/0.06 Mtwo®	2344	934
26/0.06 Mtwo®	2228	901

Numerical analysis of the failure criterion used in the finite element analysis

In order to perform failure analysis taking into account the Von Mises criterion, the Autodesk® Simulation Multiphysics software uses equation b (Fig. 1), where *σ eff* is the Von Mises equivalent stress and *σ1, σ2* and *σ3* are the principal stresses. The software can also perform the calculation using equation c, (Fig. 1), where *σxx, σyy* and *σzz* are the principal stresses applied in each element into which the model has been discretized, expressed in terms of Cartesian coordinates.

Meshing and application of stresses and restrictions on the 3-D CAD Mtwo® Nickel-Titanium rotary files

Autodesk® Simulation Multiphysics software was used for finite element analysis for a study on three-dimensional models based on the Brick element with 8 nodes and three degrees of freedom. In some cases it was combined with the tetrahedral element with 4 or 5 nodes, and also considered a number of elements which would enable an acceptable computing time (Table 1).

To simulate the file being trapped inside the canal and the consequent torsion the file is subject to, restrictions were applied to all degrees of freedom at the end of the file which is in contact with all the walls of the canal (Fig. 2a). We used the torque recommended by the manufacturer: 1.2 N.cm for file 10/0.04, 1.3 N.cm for file 15/0.05, 2.1 N.cm for file 20/0.06 and 2.3 N.cm for file 25/ 0.06. In addition, high torque was used to evaluate the behavior of the file under extreme conditions.

To simulate bending, a restriction in cantilever was applied to all file models, as reported by Kim *et al.*[14-16] A 1N load was applied to the tip of the file models (Fig.2 b) and a restriction was placed at 4 mm from the tip, to simulate the flexion a file undergoes when working in an apical curve (Fig.2 c). Finally, a 5N load – much higher than the previous ones – was applied, to determine the bending behavior of the file in this situation.

RESULTS

Results for Bending

Under normal working conditions, no file reached the failure limit. File 10/0.04 had the highest Von Mises stress. However, under extreme conditions, files 10/0.04 and 15 /0.05 might fail and fracture, with file 10/0.04 being the most likely to fracture (Fig. 3, Table 2).

Results for Torsion

Here again, under normal working conditions, no file reached the failure limit, with file 20/0.06 having the highest Von Mises stress. However, upon applying high torque to simulate extreme working conditions, only file 25/0.06 reached the failure by fracture limit (Fig. 4, Table 3).

Figure 5 shows the result of the finite element analysis for the files which had the highest Von Mises stresses and the situations in which they occurred.

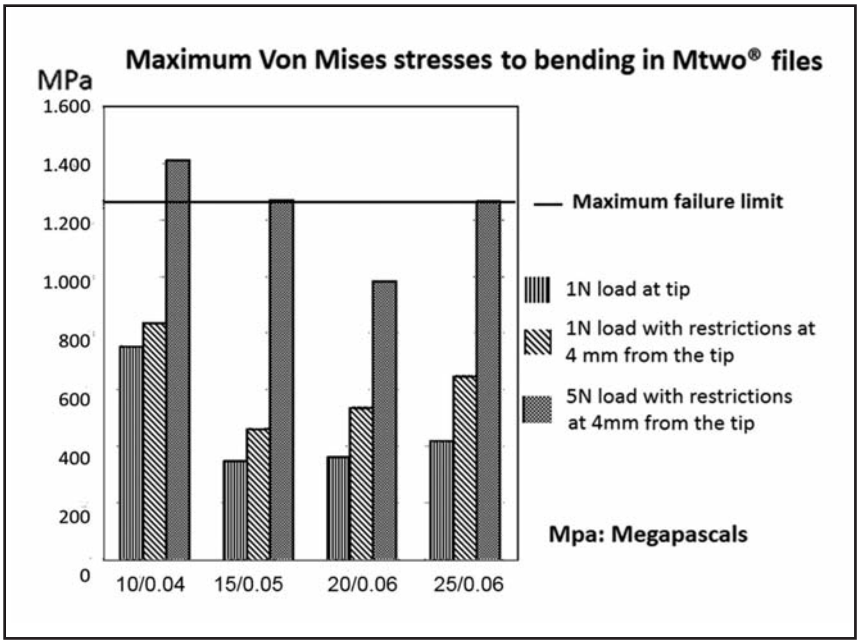

Fig. 3: Bending results for Mtwo® files.

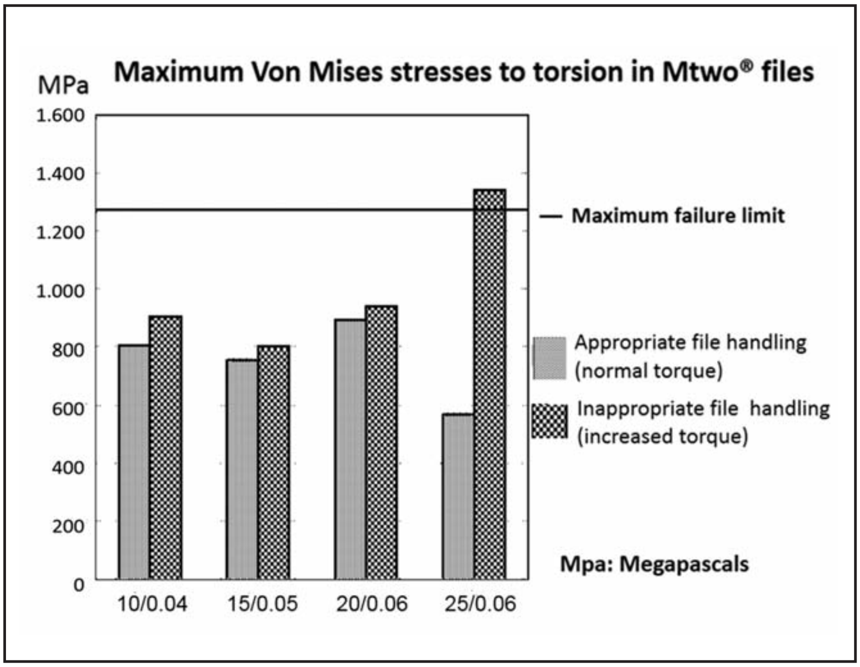

Fig. 4:Torsion results for Mtwo® files.

Table 2: Bending results for Mtwo® files.

Bending Load- File Type	10/0.04	15/0.05	20/0.06	25/0/06
1N at the tip	753.354 MPa	347.698 MPa	360.684 MPa	421.193 MPa
1N with restriction at 4mm from the tip	837.825 Mpa	460.650 MPa	536.646 MPa	648.025 MPa
5N with restriction at 4mm from the tip	1413.288 MPa	1270.930 MPa	984.267 MPa	1268.770 MPa
MPa: MegaPascals				

Table 3: Torsional results for Mtwo® files.

Torque – File type	10/0.04	15/0.05	20/0.06	25/0.06
Normal Torque	805.566 Mpa	756.870 MPa	895.147 Mpa	570.479 MPa
Increased Torque	906.705 MPa	804.179 MPa	941.204 MPa	1342.840 MPa
MPa: MegaPascals				

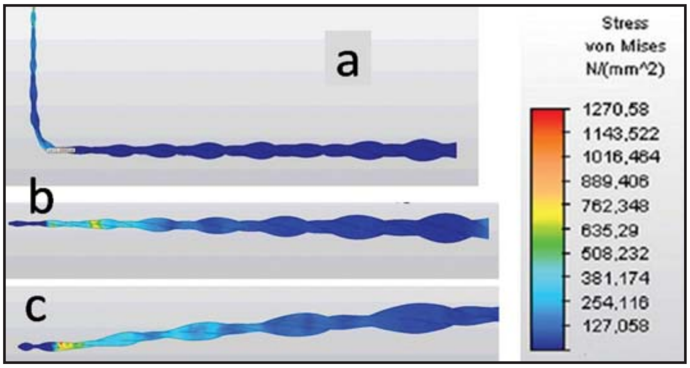

Fig. 5: Files with the highest Von Mises values:
a. File 10/0.04 with restriction in cantilever and restriction at 4mm from the tip with 5N force applied to the tip.
b. File 20/0.06 with restriction at the tip and 4N torque applied at the file handpiece.
c. File 25/0.06 with restriction at the tip and 4N torque applied at the handpiece.

DISCUSSION

Because this is a simulation, not all clinical conditions can be replicated exactly. Nevertheless, appropriate approximations allowed the Nickel-Titanium rotary files to be evaluated mechanically.

Turpin *et al.*[17] evaluated torsion and bending by taking a segment of file and placing restrictions on one of its surfaces while applying torque on the opposite surface. They used 0.25 Nmm torque of to evaluate torsion, reporting that this value was selected because it is used by rotary instrument engine. In fact, the torque in enginesis much higher than 0.25 Nmm because they are programmed in Ncm. It should be noted that this fault in the approach appears in several of the finite element analyses reported in the literature[14-18].

In order to simulate bending behavior, a 1N load at the tip of the file has been reported[14-16]. Applying the same load to all files allows evaluation under equal conditions of the Von Mises equivalent stresses which could lead to file failure. Regarding torsion, the approximations reported in the literature place restrictions in cantilever on the file and apply torque to the tip of the file[14-16]. In reality, files do not undergo this type of stress, but rather, the restrictions should be located at the most apical part of the canal, where the file touches the walls of the canal, and torque should be on the handpiece, i.e. the point at which the file is connected to the engine. Our results show that Mtwo® file 10/0.04 had the highest Von Mises equivalent stress, thus, it may have the greatest tendency to failure by fracture due to bending stress. However, the results also seem to indicate that it is the most flexible file. Thus, the operator should be especially careful when using it. Nevertheless, being the most flexible file enables it to be used for endodontic treatment of irregularly shaped canals. It should be noted that if this file is used in a canal with moderate to severe curvature, it should not be reused for another treatment, since its mechanical properties may have been irreversibly altered, which may lead to a high possibility of fracture by bending if it is used again. Mtwo® file 25/0.06 had the lowest Von Mises stress, suggesting that it may be the most resistant to facture by bending, but at the same time, the least flexible file in the series, therefore using it for endodontic treatment of canals with abrupt curves in an inappropriate manner (e.g. not following the proper order in the series of instruments) might lead to procedural accidents such as ledges, apical transportations or perforations of the root canal. For excessive load on the file (5N) with restriction at 4mm from the tip, it was interesting to observe that all files surpassed the bending limit for failure by fracture except file 20/0.06, suggesting that it would be less likely to fail than the others when dealing with a very abrupt curve.

In this study, file 20/0.06 of the Mtwo® series showed the highest value for Von Mises stress to manufacturer-recommended torque without reaching the failure by fracture limit. With higher torque, file 25/0.06 showed the highest Von Mises stress and reached the failure by fracture limit. However, an interesting finding was that even when used inadequately, the other files of the Mtwo® series did not reach the failure by fault limit, suggesting that they may have temporary resistance to failure by fracture in the event of a procedural error.

Lee *et al.*[19], found a correlation between the number of cycles that a file is used until it fractures (cyclic fatigue) and the maximum Von Mises stress in the instrument before failure. They suggest that as the number of cycles increases prior to fracture, the value of maximum Von Mises stress value decreases, i.e. in this case, the file would be more resistant to fracture, whereas if the file withstands few cycles prior to fracturing, the value of the maximum Von Mises stress increases and the file would be less resistant.

On this basis, we will compare the results of clinical studies evaluating cyclical fatigue in Mtwo® files to the results of our study.

Plotino *et al.*[20] found that when there was severe curvature, the Mtwo® file 25/0.06 had the fewest rotations prior to fracture was (72 rotations). When the file worked under normal conditions, file 10/0.04 had the highest number of rotations prior to fracture (885 rotations). These are similar to the results of our study, which found that under difficult working conditions, file 25 /0.06 had highest Von Mises stress to torsion, and under normal working conditions, file 10 /0.04 had the lowest Von Mises stress to rotation.

Inan *et al.*[21] found that Mtwo® file 10/0.04 was the most likely to fracture by bending, in agreement with our study. File 25/0.06 came second, also in agreement with our analysis. Another study by Inan *et al.*[22] on the Mtwo® series found that file 20/0.05 was the least resistant to torsional fracture, again in agreement with our study.

To conclude, when Mtwo® series files are used in an endodontic treatment, special care should be taken in the use of files 10/0.04 and 25 /0.06. They should be used once only, otherwise there is a high risk of fracture. However, in a root canal with moderate to severe curvature, file 10/0.04 is recommended because it is highly flexible and may respect the original root canal shape, avoiding accidents such as ledges or perforations.

Similarly, caution is advised when using file 25/0.06 for which permeabilization or patency procedures are recommended to allow it to work freely in the root canal without the tip becoming trapped.

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