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EMG-Biosensor for Operator'S Force Measurement During Rotary Root Canal Instrumentation Using Three Different Rotary Systems.

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KEYWORDS

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ABSTRACT:
Recent developments in design of endodontic files are mostly concerned with geometric details, with emphasis on the cross-sectional design. However, the material properties have also earned important developments. Ideally, a nickel-titanium (Ni-Ti) file should have excellent mechanical properties (measured by both the ultimate tensile strength and fatigue strength), it should be flexible enough to avoid canal perforation and damage, and its hardness should be great enough for a good cutting efficacy in the canal (1).

Introduction:

Recent developments in design of endodontic files are mostly concerned with geometric details, with emphasis on the cross-sectional design. However, the material properties have also earned important developments. Ideally, a nickel-titanium (Ni-Ti) file should have excellent mechanical properties (measured by both the ultimate tensile strength and fatigue strength), it should be flexible enough to avoid canal perforation and damage, and its hardness should be great enough for a good cutting efficacy in the canal [(1)].

The electromyography (EMG) signal is a biomedical signal that represents electrical activity produced by muscles during its contraction representing neuromuscular activities. EMG signal acquires noise while traveling through different tissues. Moreover, the EMG detector, particularly if it is at the surface of the skin, collects signals from different motor units at a time which may generate interaction of different signals. Detection of EMG signals with powerful and advance methodologies is becoming a very important requirement in biomedical engineering. The main reason for the interest in EMG signal analysis is in clinical diagnosis and biomedical applications. [(2)]

In comparative biology, EMG is arguably the most commonly used tool for investigating muscle function during locomotion (timing and magnitude). An integrated analysis of EMG, kinematic, and anatomical information can provide an accurate picture of the function of individual muscles during movement [(3)]. Most of our understanding of the role of individual muscles in movement is founded on such analysis.

The use of EMG as an indicator of the mechanical function of a muscle is challenged by the fact that the EMG reflects the electrical, not the mechanical, events of a contraction. It has long been recognized that any interpretation of EMG as a measure of the timing or magnitude of muscle force requires caution [(4)].

EMG has traditionally been used for medical research and diagnosis of neuromuscular disorders. However, with the advent of ever shrinking yet more powerful microcontrollers and integrated circuits, EMG circuits and sensors have found their way into prosthetics, robotics and other control systems [(5)]. *In-vivo* sensory setups were used mainly in dentistry to simulate and analyze dental implant stress, in order to check out implant quality [(6)].

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Protaper Ultimate file has a specific parallelogram cross section geometry with variable acute angles at different lengths of the instrument was applied on all files. By using specific alternating off-set machining manufacturing process, the files possess a geometry in which the center of mass of the instrument is not aligned with the center of rotation. This reduces the stress level during cutting and increases the available space for debris removal. HyFlex EDM file manufactured from the controlled memory wire treated with Electric Discharge Machining, has a triangular cross section with large inner core that increases the surface area of its cross section (at D16 = 1.19 mm^2) [7]. On the other hand, Twisted File manufactured with R-phase alloy using a twisting method and a special surface treatment to reduce the surface irregularities. It exhibits a triangular cross section.

Breakage of NiTi rotary files, regardless of the manufacturer, probably is related to the dentist failing to follow the directions for use; operator-related factors have been suggested to be probably the most important attribute for instrument breakage [8]. Apical pressure exerted by operator on rotary file during instrumentation is a very important parameter that may lead to file separation. Torsional failure does not only occur when the file is locked in the canal wall but it may also be a result of excessive pressure submitted by the operator. According to **Sattapan et al [9] and Alapati et al [10]**, this was the main cause of instrument failure.

Manufacturers recommend that rotaries should be advanced until slight resistance is met but the recommendations differ regarding the exact hand movements. Most rotaries are used with a gentle pecking motion; Twisted file rotaries are recommended to be continuously advanced while ProTaper Ultimate files should be used in an outward brushing motion in all canals, especially those that exhibit an irregular cross-section, or with a light inward pecking motion to progressively advance toward the working length. Always cradle the handpiece in the webbing between the thumb and index finger. It is difficult to determine exactly the apically exerted force in the clinical setting but manufacturers stress that a very light apical touch is needed [11].

In this study, an attempt was made to measure the amount of force exerted by the operator's hand on three tested files with different material properties during clinical practice, to compare if the file type and design have an impact on the amount of force needed using a specially designed device **(Biosensor)**.

Materials & Methods:

a) Patient selection and preparation:

A total of 18 patients in private dental practice seeking conventional endodontic treatment in an upper first or second molars, within age group of 25-50 years were selected, regardless of their gender.

A routine access cavity was performed by the same operator, followed by rubber dam application. Glide path was then attained using K- file #10, working length was measured using Ipex apex locator, canal pre-flaring was done using Gates Glidden drills from size 2 to 3 and finally irrigated using distilled water.

The biosensor was used during the preparation of the distobuccal root only after making sure that it had a Type 1 root canal configuration according to Weine's [12] classification.

b) Patient classification:

Patients were divided randomly into 3 groups (n=6), according to the type of file used for root canal preparation.

- Group 1; canal prepared using ProTaper Ultimate F2 (25/0.08 variable taper)
- Group 2; canal prepared using Twisted File (25/0.06).
- Group 3; canal prepared using Hyflex EDM file (25/0.06).

c) The Biosensor:

This device was specially developed for this research under supervision of an electrical engineer; it uses the EMG signal to find the relation between muscle

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activity and the pressure applied on the file. EMG signal represents the muscle activity only and there is no direct relation between EMG signal and force (Fig. 1a and 1b). To relate measured muscle activity to total force applied to a tooth through file, in which readings generated by very sensitive weight sensor were recorded while EMG signal is being measured via the biosensor. Weight of a thing is actually the force by which the earth attracts its mass. As a result, weight sensors measure force which is a representation of the body mass. Comparing the average of the measured EMG to data got from weight sensor, a relation is constructed and can be used as a learning data to calculate forces from measured EMG signals directly though interpolation and extrapolation, provided that all tests are completed by the same person. This should be done for every type of files before proceeding with tests as a sort of calibration.

To get the EMG signal for one muscle, two electrodes were usually used. One electrode was placed on the middle of the muscle to get the voltage signals that represent the muscle activity in addition to noise on the skin. The other electrode was placed on the end of that muscle for the purpose of acquiring the noise signal only on the skin near the main electrode. A differential amplifier was used to get and amplify the difference between the signals from the two electrodes, hence removing the effect of noise. This difference was very small in the range of microvolt, so an amplifier was necessary to amplify the raw signal to reasonable values before further processing stages which may add noise as noise is usually in u-Volt range too. A third electrode (black) was needed as a reference; it was placed on skin above a non-muscular area and then connected to the circuit ground (electrical reference). After the first amplification stage, the EMG signal was rectified and further amplified to be in the range of 0V to 5V (Fig. 1c).

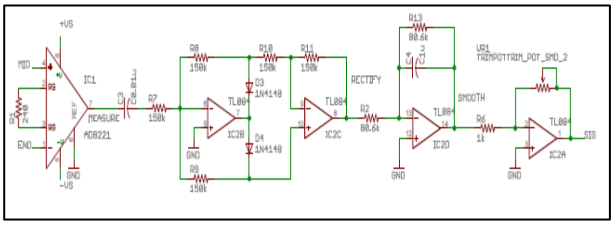

Figure 1a, Circuit diagram of the biosensor

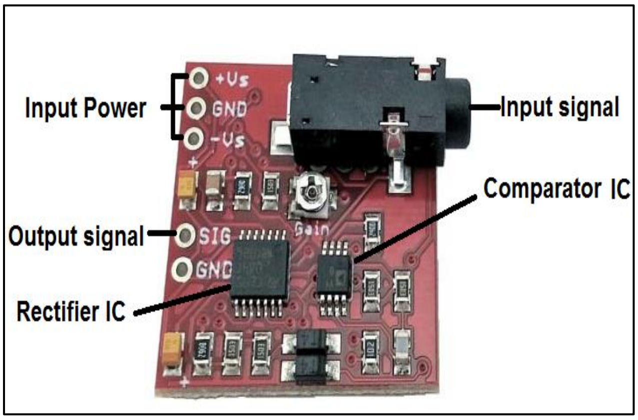

Figure 1b, Image showing the Biosensor

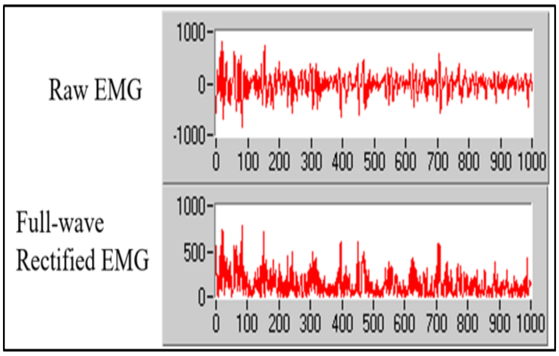

Figure 1c, Raw vs Rectified EMG Signal

d) Connection of the biosensor to operators forearm:

In all groups, to advance the file to the full working length a Pecking motion, i.e. vertical oscillations with amplitude from 2-4mm [13], was used. Anatomically, movement of the wrist and fingers is responsible of applying vertical oscillations to the file while grasping the endodontic hand-piece. [14]

Nearly all of the superficial muscles of the forearm are responsible for wrist and finger movements. They were divided in ***Table (1)*** into anterior and posterior groups [15] (Fig. 2a, b, c).

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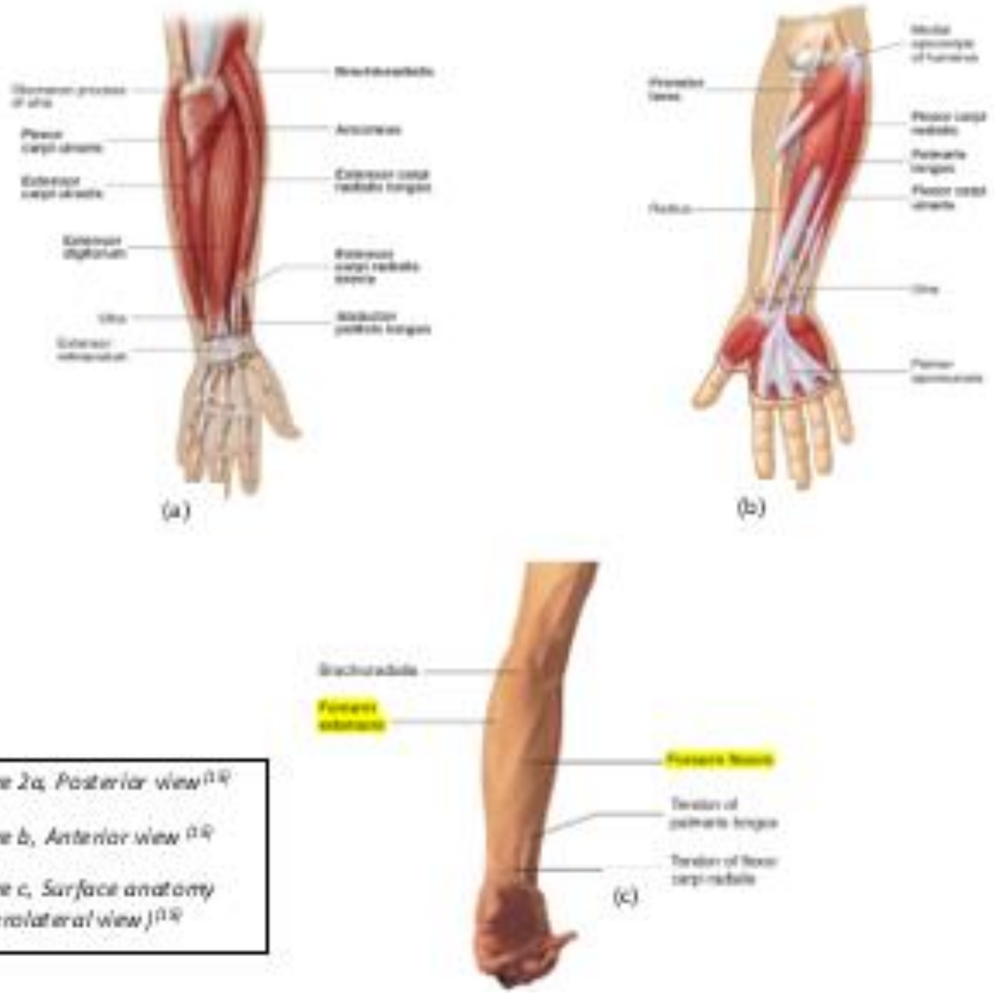

Figure 2a, Posterior view [19]

Figure b, Anterior view [19]

Figure c, Surface anatomy (anterolateral view) [19]

Table 1, Muscles of forearm responsible for wrist and finger movements

Anterior		Posterior	
Flexor carpi ulnaris	Flexes and adducts wrist	Extensor carpi ulnaris	Extends and adducts wrist
Flexor carpi radialis	Flexes and abducts wrist	Extensor carpi radialis (2 muscles)	Extends and abducts wrist
Flexors digitorum (2 muscles)	Flex fingers	Extensor digitorum	Extends fingers

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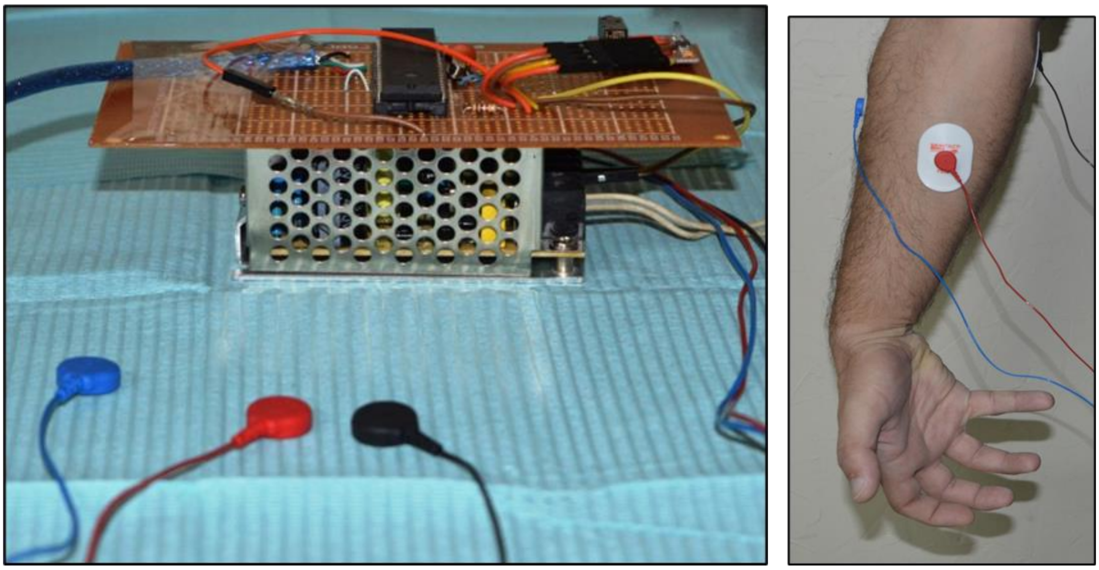

Figure 3 (a), Photograph of the Biosensor and its control Figure 3 (b), Photograph showing connection of electrodes to operator's hand

There are two muscle groups responsible for wrist movement (the forearm flexors and extensors), not one. The distance between the two groups is not too long for noise to vary by considerable value. So, the two-electrode system was used to measure the difference between the EMG signals for the flexors and extensors muscle groups directly, considering nearly the same noise magnitude and spectrum on the two groups. The flexors muscle group had higher effect on how much pressure the wrist provides, so the electrode connected to the positive input of the differential amplifier, was placed on the flexors (red). The other electrode connected to the negative terminal, was placed on the extensors (blue). The higher the difference between the two signals, the higher the flexors muscle group activity and higher wrist pressure. As the difference between the signals was used, the noise should be removed as it exists on both electrodes (Fig. 3 a, b).

The difference was amplified as mentioned before and could be easily read by the analog-to-digital converter unit (ADC) which was embedded in the microcontroller (MCU). To guarantee the speed and accuracy, data processing was done on the PC side only after completing the test. The embedded system was enrolled to retrieve the raw data and delivering it to PC program via USB connection.

The specially designed program received the raw data from the device and stored it as .txt file. After the test is completed, the data was processed to transform the EMG signal to equivalent force using the training data prepared before the test.

At this point, apparatus was ready for measurement of force applied by operator's wrist and fingers on rotary file. File was advanced through canal using pecking motion till working length was reached; the operator had to denote when to start and when to stop and a volunteer simultaneously clicks on the start and stop icons on the PC application. Graphs were plotted and records were saved.

e) Mean calculation and statistical analysis:

Quantitative data were presented as mean, median, standard deviation (SD), range (Minimum – Maximum) and 95% Confidence interval (95% CI) for the mean values. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Force data showed non-parametric distribution. Kruskal-Wallis test was used to compare between the three groups.

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The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBMSPSS (IBM Corporation, NY, USA) Statistics Version 20 for Windows.

Results

a) Average volt/time graphs :

A line graph was plotted for each patient on the PC application during testing with the correspondent volt values. An average line graph was plotted for each group of patients tested with different files by calculating the mean volt/time from the recorded results (Fig. 4 a).

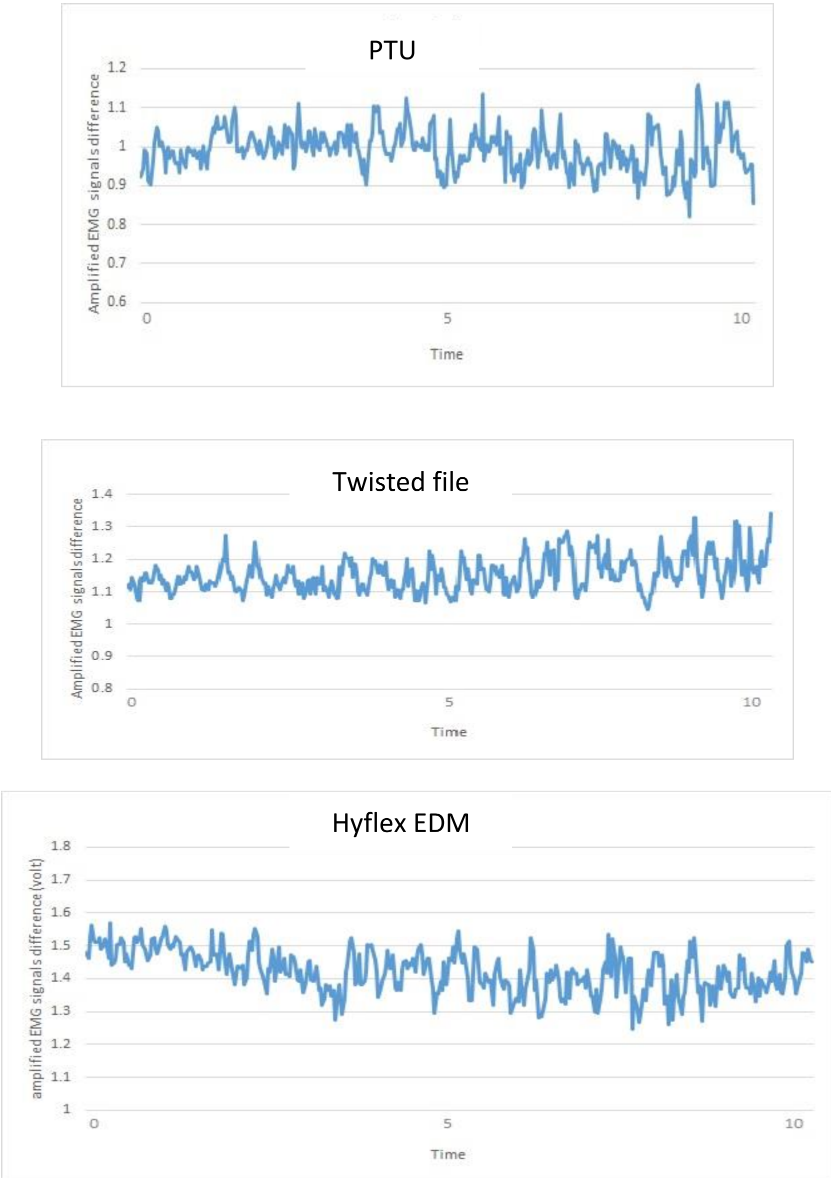

Figure 4 (a)

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b) **Comparison between the three groups**

Each file was tested in six patients, the mean force exerted for each patient was calculated and then the mean force for each group of patients was recorded corresponding to each file. The HyFlex EDM group recorded the highest mean (0.578 N) followed by the Twisted File (0.383 N) and finally the Prptaper Ultimate with the lowest mean force (0.314 N).

Although the HyFlex EDM file showed the highest mean of force value followed by Twisted file then Protaper Ultimate File, but Kruskal-Wallis test showed that there was no statistically significant difference between the three groups (*P*-value = 0.293). Mean, standard deviation (SD), median, range and 95% Confidence Interval (95% CI) values of force data are presented in (Table 2) (Fig. 4b).

Table 2: Descriptive statistics and results of Kruskal-Wallis test for comparison between force values in the three groups

Group	Mean	SD	Median	Minimum	Maximum	95% CI	
						Lower bound	Upper bound
Hyflex	0.578	0.259	0.734	0.254	0.769	0.321	0.862
Twisted	0.383	0.152	0.294	0.277	0.580	0.221	0.544
Ultimate	0.314	0.118	0.319	0.181	0.439	0.188	0.441

**: Significant at P ≤ 0.05*

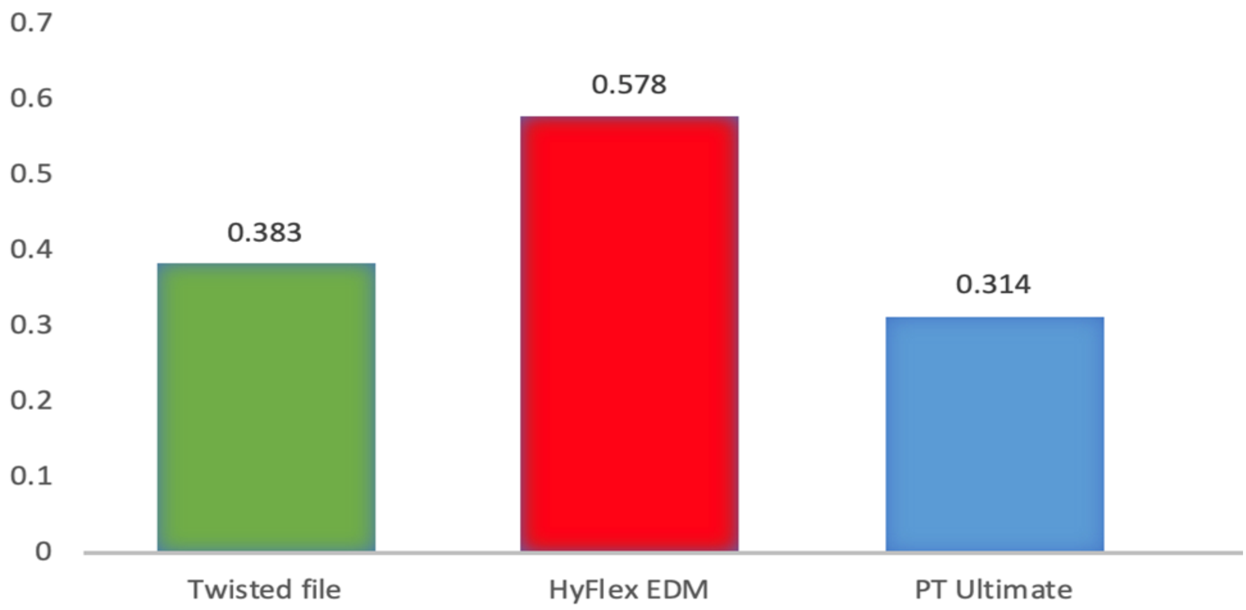

Figure 4 (b), Bar chart representing mean and standard deviation values of force in the three groups

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Discussion

Recent developments in design of endodontic files are mostly concerned with geometric details, with emphasis on the cross-sectional design. However, the material properties have also earned important developments. Ideally, a Ni-Ti file should have excellent mechanical properties (measured by both the ultimate tensile strength and fatigue strength), it should be flexible enough to avoid canal perforation and damage, and its hardness should be great enough for a good cutting efficacy in the canal. [8]

Whether the mechanical properties of rotary files are dependent on material properties and manufacturing process or geometric design is a debate between previous studies. They all agree that both parameters have an influence but which has the dramatic effect. Some authors stressed on that the potential mechanical performance of a Ni-Ti instrument is determined by its geometry (17, 21). On the other hand, several authors claimed that the material properties are the most important factor (24).

ProTaper Ultimate has specific parallelogram cross section geometry with variable acute angle at different angles of the instrument. This improved the cutting efficiency and positively influenced the flexibility and unwinding resistance of the file. This file has alternating offset machining manufacturing process in which the center of mass of the instrument is not aligned with the center of rotation. This reduces the stress bevel during cutting and increases the available space for debris removal. The file is gold plated after manufacturing. [24]

While, HyFlex EDM files are manufactured by means of electrical discharge machining (EDM process). This innovative manufacturing process using spark erosion to harden the surface of the NiTi file resulting in superior fracture resistance and improved cutting efficiency. Moreover, Hyflex EDM files offer trusted controlled memory effect and regenerative properties. The file has triangular cross section in the coronal third, trapezoidal in the middle and quadratic in the apical part. [21,22,23]

On the other hand, Twisted Files are created by converting a raw NiTi wire from the austenite phase into the R-phase by means of a thermal procedure. It exhibits a triangular cross section and has 9 threads along its working part, which is also 16mm in length. [20]

The biosensor used in this study was to approximately measure the force submitted on the rotary files by the muscles of operator's forearm, this device was based on the principal of EMG which involves measuring muscle activation via electric potential. This device used the EMG signal to find the relation between muscle activity and the pressure applied on the file. Many studies have shown the promise of EMG driven musculoskeletal models to estimate muscle forces and predict human joint moments over a limited set of test data [16].

The mean calculated force for the three tested files showed no statistically significant difference, this may be attributed to fact that all the files tested were used in the same motion (pecking), so that the biosensor could produce similar volt/time graphs from which mean force could be calculated. Another reason for the non-significance may be due to the level of training of the operator performing, a trained operator can have the skill of standardizing the pressure exerted regardless of the instrument used. This was in full agreement with **Yared et al [17],** who specified that operator experience was an important factor in manipulation of rotary instrumentation and consequently avoiding instrument separation.

Although there was no statistical significant difference, but still HyFlex EDM files required the highest mean force this may be the consequence of the unwinding that happens to the flutes during performance requiring slightly more pressure to introduce the file to full working length. The Protaper Ultimate required the lowest mean force. This could be a result of the parallelogram cross section and reduced coronal taper. Thus, requiring lighter apical pressure by the operator.

Twisted files also cut dentin efficiently with more uniform cutting than machined nickel-titanium endodontic files as proved by **Fayyad and Elgendy [18]** and hence may require lighter apical pressure by the operator compared to HyFlex EDM.

The off - centered core that elaborates the swaggering effect and variable tapers along the length of the ProTaper Ultimate file may also be two important parameters that have contributed to the results of this study, as both features

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enable the file to disengage from surrounding boundaries (51).

Conclusion

Amount of force exerted on a rotary file by an operator depends on the cutting efficiency of the instrument and level of training of the operator. The biosensor is a useful recommendation for measuring muscle exerted compaction forces during different obturation techniques.

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