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Novel Analysis of Endodontic File Manipulation Using a Newly Developed Apparatus for Recording Force and Torque Values with Real-time Lissajous Curve Display

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Abstract

This study aimed to evaluate the usefulness of visualized mechanical action exerted *in vitro* during root canal preparation. The newly developed Apparatus for Recording Force and Torque values with Real-time Lissajous curve Display (ARFTRLD) was used. Ten volunteers were enrolled into the study. They manipulated a file using a watch-winding motion in a root canal model block while viewing their trajectories. Data were collected from each participant twice. During the second data acquisition session, a fixed target was superimposed on the screen, and the participants were instructed to move their trajectories within the target. During a predetermined interval in the first and second sessions, the numbers of data points within the target were compared. For the next analysis, the data from the second sessions were used to extract the watch-winding motion pattern. The numerical data were translated into letter sequences, and patterns were matched with regular expressions designed for analysis. The numbers of matched letters and data points within the target were compared. The analyses revealed that participants were able to alter their trajectories toward the target and the location and torque pattern control were not correlated. The ARFTRLD will be useful for objective evaluation.

Keywords: Lissajous curve; Endodontic file manipulation; Force and torque values; Regular expression; Root canal

Introduction

Root canal preparation is a critical step in endodontic treatment. An inadequately shaped root canal becomes an inadequately obturated root canal [1], and canal shaping that alters the original canal taper is a risk factor associated with failure of endodontic treatment [2].

Endodontic instruments have been improved or modified in cross-sectional and longitudinal design, in the alloy material used, and in the mode of file motion [3-7]. A variety of file products is currently used in endodontic practice, including conventional stainless steel files.

The operability of those file products are not the same. A few factors that are probably related to sensation during the operation were investigated among file designs or products, such as “screw-in force” [8], flexibility [9,10], or vibration [11]. Additionally, the operator could recognize the difference in operability between the three file products, i.e., a conventional stainless steel hand file, and a rotary and a reciprocating file system, when it is first used [12].

There is the diversity among operators concerning their experience with file product use. Several *in vitro* studies reported the differences between experts and novices in root canal preparation [13,14]. However, the differences in manipulation brought about those results were not clear because the findings were mainly derived from the comparison of pre and post-operative root canal shape. Another study indicated the importance of preclinical training for NiTi rotary instruments [3]. However, there are few reports on objective evaluation method for file manipulation in training.

Analysis of the mechanical action exerted with an endodontic instrument is one method for investigating phenomena that occur during root canal preparation. The potential usefulness of a waveform display of the mechanical action to investigate the operator’s file instrumentation has been suggested. For example, the student-participants’ adaptation to their waveform movements and their ability to reproduce the endodontists’ waveforms has been described [15]. Additionally, possible inter-operator comparability with the newly developed apparatus has been noted [16].

The mechanical action in previous studies [15-17], in which participants were enrolled for root canal preparation, was displayed graphically over time using torque-time and force-time curves.

A novel mechanical model, in which force and torque values exerted by file manipulation were classified into four distinct groups corresponded to the four quadrants of a Cartesian plane, was implemented in this study. Contrary to previous studies, a display format with the Lissajous curve was used in our study. A newly developed Apparatus for Recording Force and Torque values with Real-time Lissajous curve Display (ARFTRLD) was used. The ability to control trajectory using the visual information was evaluated using two post-recording numerical analyses.

Regular expressions have been used in pattern matching with character strings, and also applied as motif descriptors in bioinformatics [18]. We applied them to extracting the particular file

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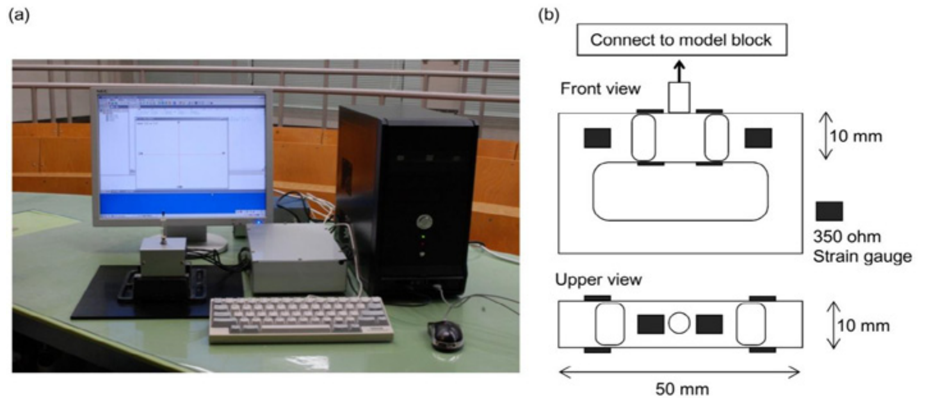

Figure 1: An Apparatus for Recording Force and Torque values with Real-time Lissajous curve Display (ARFTRLD).
(a) Front view of the ARFTRLD; (b) Structure of the force/torque transducers. Four parallel beams were placed symmetrically to sense force (inner) and torque (outer). The outer and inner beams are orthogonal. The transducers were composed of the all-element varying Wheatstone bridges with strain gauges.

manipulation mode, and used them to verify the hypothesis that there was a correlation between two file control abilities.

Material and Methods

Mechanical model

A two-axis force/torque model was introduced in this study. Force and torque were treated as linearly independent vectors. The direction of force exerted by file manipulation was classified into coronal (UP) and apical (DOWN) directions. Similarly, the direction of torque was categorized into clockwise (CW) and counterclockwise (CCW) directions. We define intervals on a Cartesian plane: UP = $\{y \mid y > 0\}$, DOWN = $\{y \mid y < 0\}$, CW = $\{x \mid x > 0\}$, and CCW = $\{x \mid x < 0\}$. In this display format, sampled force and torque values are represented as a Lissajous curve, i.e. force–torque curve.

Apparatus

A computer-based apparatus was newly developed for the study (Figure 1a). The apparatus was divided into two parts: the sensor unit and the computer unit. The components of the sensor unit were force/torque transducers, instrumentation amplifiers, 12-bit analog-to-digital converters, digital isolators, and a 32-bit microcontroller. The force/torque transducers were composed of all-element varying Wheatstone bridges [19] with the strain gauges (KFG-2-350-C1-23; Kyowa Electronic Instruments, Tokyo, Japan) bonded onto an aluminum alloy element with parallel beam structure (Figure 1b). In the computer unit, an IBM PC compatible computer was used. The software for the apparatus was written in C or Perl (Table 1) [20]. The sensor unit and the computer unit were linked with a Universal Serial Bus to a Universal Asynchronous Receiver Transmitter (USB-to-UART) bridge. The straight root canal model block (S8; Nissin Dental Products, Kyoto, Japan) was modified to be connected to the force/torque transducer and used for data acquisition at a sampling rate of 200 Hz. The apparatus had two major functions: real-time display, and recording. Recorded data was used in the post-operative analysis.

Analysis for location control

One of the authors who is a dentist and 10 volunteers participated in the study. They were right-handed and had normal or corrected-to-normal vision. The participants consisted of sixth-year students from the Faculty of Dentistry and dentists with less than one year of clinical experience. All participants gave their informed consent in accordance with the guideline of the Ethics Committee of the Faculty of Dentistry Niigata University (26-R46-12-10). Before data acquisition, the author manipulated a size 40 K-file (Mani, Utsunomiya, Japan) using a watch-winding motion (1), and the exerted force and torque values were recorded. The area of CW and CCW motions was enclosed with a rectangle-line frame on the screen, and the frame area was defined as a target area in the analysis. Data acquisition software was configured to turn on or off the target frame with a software command.

Table 1: Software functions of the apparatus.

Sensor unit:
1) Interrupt generation by timer match (every 5 milliseconds);
2) Regulation of A/D* converter with SPI** protocol for data acquisition;
3) Calculation of the average of eight data points sampled every 5 milliseconds;
4) Data conversion from decimal value to ASCII*** hexadecimal character;
5) Serial communication.
Computer unit:
1) Serial communication;
2) Data conversion from ASCII*** character to decimal value;
3) Real-time force-torque curve display with/without the frame target;
4) Data storage;
5) Data analysis.

*A/D: Analog-to-Digital
**SPI: Serial Peripheral Interface
***ASCII: American Standard Code for Information Interchange

The participants were instructed to manipulate a size 40 K-file using a watch-winding motion for at least 20 seconds while watching the real-time force-torque curve during preparation. The exerted force and torque values were recorded twice from each participant. A new K-file and a new root canal model block preflared 13 mm in length with size 2 Gates-Glidden drills (Mani) were used in each measurement. During the second data acquisition, a fixed rectangle-line target was superimposed on the monitor screen, and the participants were directed to keep their trajectory moving within the target area as widely as possible. In the data intervals during which

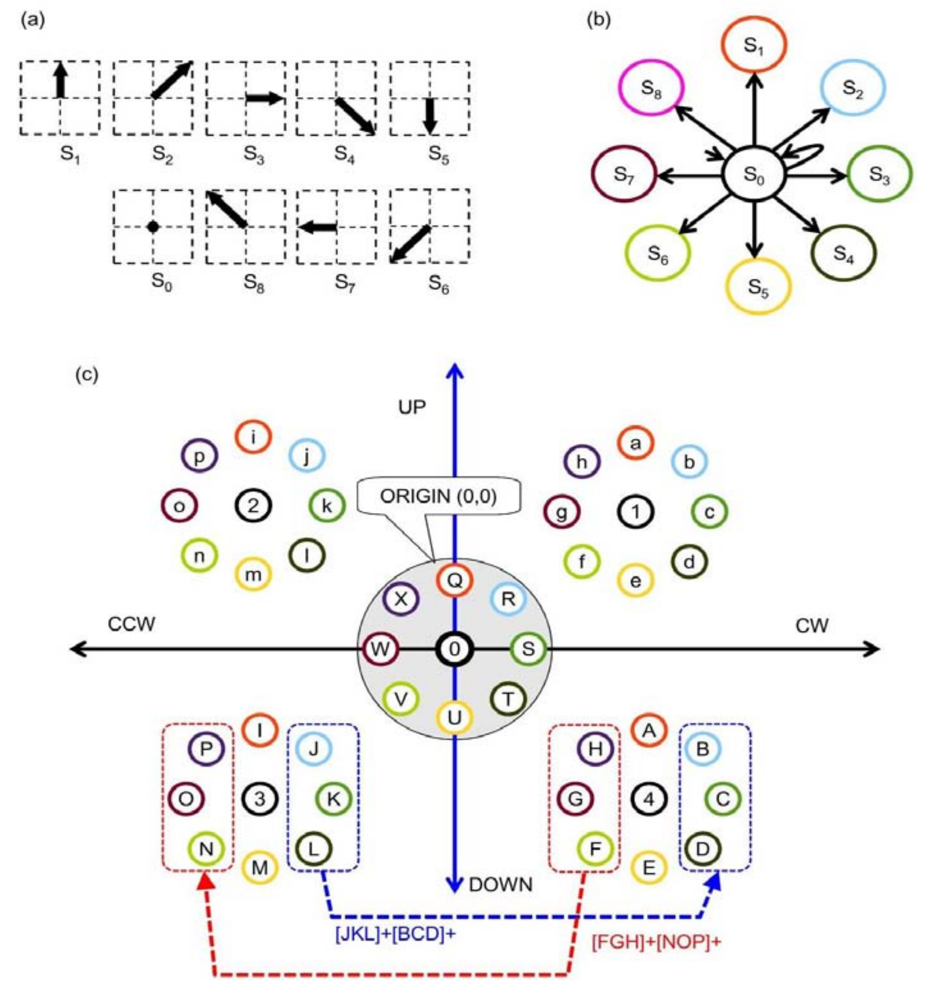

Figure 2: Procedure for extracting the watch-winding motion interval.
(a) The similarity between elements in the set VELOCITY and the directions of data-point movement. The elements "positive" and "negative" of the set DELTA were assigned a unit length in the figure, and the force and torque DELTAs were represented on the y-axis and x-axis, respectively; (b) Part of the state transition diagram of the possible transitions from the present state. Transpositions between state S0 and another element of set VELOCITY are possible, with the exception of the first and end data point movements; (c) The Cartesian product of the set VELOCITY and the set POSITION. Two regular expressions for searching the watch-winding motion patterns were also indicated. Forty-five elements were uniquely named using an alphanumerical character.

the participants manipulated the file in the model block, the leading 5 seconds of recorded data were deleted because they included the transition from the movement start-up. Then, the subsequent 10 seconds of data were used for the analysis. The numbers of points within the hidden and displayed target areas were counted with the developed software using the magnitude of the relationship between the coordinate values. A Wilcoxon signed-rank test (GNU R Version 2.13.0) was used for statistical analysis. The level of significance was set at $P < .05$.

Analysis of torque pattern control

The data from the second measurement in the analysis for location control were also used in this analysis. Before the analysis, the data were processed using a simple moving average of 20 data points for noise reduction. Two regular expressions were used to extract the watch-winding motion intervals from the synchronous force and torque data. The torque-time curves were assumed to be smooth.

The deltas were calculated in both the torque and the force data at each sampling time point, except the first and the last points. The delta at the arbitrary sampling time T was calculated between the next and previous sampling data point, i.e., delta(T) = data(T + 1/200 seconds) – data(T – 1/200 seconds). At each sampling time, the calculated delta was classified with its sign into one of the three elements in a newly defined set: DELTA = {positive, zero, negative}. The Cartesian products were then taken between the two DELTAs calculated from the force and torque data at identical sampling time points.

The Cartesian product of two sets A and B, denoted by A X B, is defined as the set of all ordered pairs composed with each element of A and B: A X B = $\{(x, y) \mid x \in A, y \in B\}$. Therefore, the nine ordered pairs of the product between the two DELTAs were defined as a new set: {(zero, zero), (positive, zero), (positive, positive), …, (positive, negative)}. Here, the elements of the product were assumed to have nine states: set VELOCITY = {S0, S1, S2, …, S8}. The direction of the data point movement at an arbitrary sampling time was classified into one of the elements of the set VELOCITY (Figure 2a). The data stream represented by the nine elements in the set VELOCITY can be regarded as state transitions among the nine elements (Figure 2b).

In addition, the position of the data point on the Cartesian plane was classified into five areas in this analysis. The origin of the Cartesian plane was described as 'ORIGIN'. Thus, a new set POSITION was defined as: POSITION = {ORIGIN, CW ^ UP, CCW ^ UP, CCW ^ DOWN, CW ^ DOWN}.

For convenience, each data point on x = 0 or y = 0 (except x = y = 0) was classified into the area of x > 0 or y > 0, respectively. Then, the Cartesian product of the VELOCITY and POSITION sets were taken at each identical sampling time. The 45 elements of the product were uniquely named single alphanumerical characters (Figure 2c). In this manner, each data point was assigned to one of the discrete directions of movement on the Cartesian plane, and they were finally translated into letter sequences.

To extract the watch-winding motion, we assumed that the motion consisted of two parts: the movement from the third quadrant to the fourth quadrant of the Cartesian plane with positive torque delta, and its reverse movement. Two regular expressions [JKL]+[BCD]+ and [FGH]+[NOP] were used for pattern matching (Figure 2c). Letter sequences that were 2000 characters long, which were identical to the 10-second time interval of the analysis for location control, were tested. The lengths of matched letter sequences were then counted. Additionally, the numbers of the data points within the rectangle target area were counted from each identical data set. A Spearman's rank correlation coefficient (GNU R version 2.15.1) was used for the analysis between the two paired groups. The level of significance was set at $P < .05$.

Results

Location control

In the first measurement, the number of data points located within the hidden target ranged from zero to 396 (mean = 83.5, standard deviation (SD) = 139.8), but in the second measurement with the displayed target, the number of the counted points ranged from 503 to 1591 (mean = 978.2, SD = 410.7). There was a significant difference between the two paired groups ($P < .01$).The result indicated that participants were able to alter their trajectories toward the target (Figure 3).

Torque pattern control

In the pattern-matching results, the number of matched characters ranged from 389 to 1993 (mean = 1362.9, SD = 620.1), and the number of data points in the target ranged from 501 to 1701 (mean = 932.9, SD = 454.8). There was no correlation between the two score groups ($P = 0.37$, Rho = 0.32).

Discussion

In a measurement based on a two-axis force/torque model, the torque value might be partly lost in the case of a curved root canal [15]. Conversely, a study of rotary instruments that move along a fixed axis indicated that torque sensors placed between motor and rotating instruments only yielded exact measurement values in curved canals [21]. In our study, files were handled manually. To avoid interference between force and torque, straight root canal model blocks were used, and the acquired data were analyzed without the assumption of a strict linear relationship between mechanical inputs and sensor outputs.

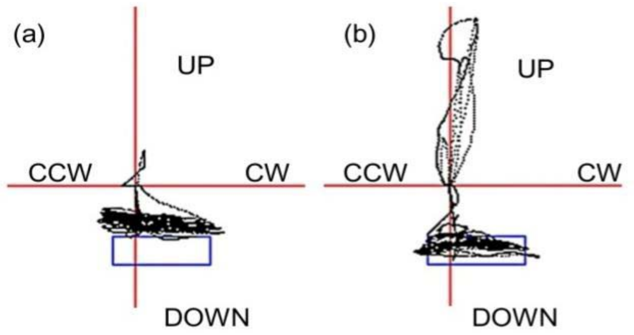

Figure 3: An example of the torque-force curve records.
(a) First measurement; (b) Second measurement. Both sets of measurement data were taken from an identical operator. In (a), the target frame that was not drawn during data acquisition was used for reference.

In our study, small data amplitude around the origin, which was attributed to the noise and the offset voltage of the circuit, would greatly reduce the reliability of the analysis because the data were analyzed after being categorized based on the signs of their values. To minimize this limitation, a linear discriminate function [22] with independent variables of force and torque was introduced. The function was used to classify the data into two states: whether the file was being manipulated in the root canal or not. The data values of the interval that was classified as "not being manipulated" were then converted to zero values.

In a preliminary study in which participants performed a root canal preparation of the same epoxy resin canal block without designating a particular file manipulation mode, there was a negative correlation between the mean values of the force in the CW ^ DOWN area and the total working time ($P < .05$). Additionally, a positive correlation was observed between the working time in the CCW ^ UP area and the total working time ($P < .05$). In the epoxy resin model block, excessive force toward the root apex easily caused file binding into the root canal. During the observation, file manipulation in the CCW ^ UP area was used mainly for unbinding the file from the root canal. The watch-winding motion might be a preparation mode that can increase the mean value of the force in the CW ^ DOWN area without excessive force because force is constantly directed toward the apex of the root.

In the torque pattern analysis, the null hypothesis, which was that there was no correlation between the two scores from the different evaluation methods, was not rejected. Therefore, there are two possibilities in the interpretation of the statistical result: a failure to reject the false null hypothesis, or a true null hypothesis. In the latter case, more than two distinct skills might have been used in the watch-winding motions in this study: location control and torque pattern control. We thought not all of the participants were dexterous who simultaneously performed two tasks precisely. The apparatus (ARFTRLD) also can evaluate the effect of training for the file manipulation mode used in this study. However, further investigation should be needed to solve the question. The analysis of file manipulation is limited with its low reproducibility. The analyses used in this study are relatively robust to that limitation because data was analyzed in ordinal scale. We believe that real-time display and objective evaluation used in this study allows novel *in vitro* approach for evaluation and education on file manipulation.

The results of this study depended on the assumptions that force–torque curve was smooth and that the data of force and torque was of ordinal scale. A situation, in which the direction of force axis oscillateswidely apart from the root canal axis of a model blocks during manipulation, the latter assumption might be questionable. In the case, outputs of the force/torque sensor cannot be assumed independent and interference between force and torque changes frequently. This limitation was mainly due to the two-axis force/torque sensor structure.

The results of the location control analysis indicate that visual information used in this study was effective for real-time feedback of file manipulation with a watch-winding motion, i.e., the regulation of static force and dynamic torque. The effectiveness of the visual information for the regulation of dynamic force was not clear in this study, but the visual information in the real-time Lissajous curve may also be effective for the regulation of dynamic force, such as that used in root canal preparation using NiTi rotary instruments. This is based on a study involving participants' adaptation of their reaching movements when holding the handle of an apparatus to test their motor skills in a velocity-dependent force field [23]. Additionally, there were no severe constraints in file manipulation with the apparatus used in the study because files were used without remodeling. The mechanical model in this study allows an objective assessment of the file manipulation mode and allows real-time feedback to operators under these experimental conditions.

Thus, we conclude that the apparatus described in this study can display visual information from real-time force/torque curves, which can be useful in investigating, teaching, and training for root canal preparation.

Conclusion

In this study, participants were able to alter their trajectories of real-time force-torque curves toward the fixed rectangle-line target on the same monitor screen and participants' abilities of location and torque pattern control were not correlated. Although the analysis of file manipulation is limited with its low reproducibility, the Lissajous curve expression of file manipulation and the motion analysis with regular expression allows novel *in vitro* approach for evaluation and education on file manipulation.

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References

1. West JD, Roane JB. Cleaning and shaping the root canal system. Cohen S, Burns RC, editors. In: Pathways of the pulp. 7th edn. Mosby.1998; 203-257.
2. Santos SM, Soares JA, Costa GM, Brito-Junior M, Moreira AN, de Magalhaes CS. Radiographic parameters of quality of root canal fillings and periapical status: a retrospective cohort study. J Endod. 2010; 36: 1932-1937.
3. Peters O. Current Challenges and Concepts in the Preparation of Root Canal Systems: A Review. J Endod. 2004; 30: 559-567.
4. Metzger Z, Teperovich E, Zary R, Cohen R, Hof R. The self-adjusting file (SAF). Part 1: respecting the root canal anatomy--a new concept of endodontic files and its implementation. J Endod. 2010; 36: 679-690.
5. Ye J, Gao Y. Metallurgical characterization of M-Wire nickel-titanium shape memory alloy used for endodontic rotary instruments during low-cycle fatigue. J Endod. 2012; 38: 105-107.
6. Roane JB, Sabala CL, Duncanson MG, Jr. The "balanced force" concept for instrumentation of curved canals. J Endod. 1985; 11: 203-211.
7. Yared G. Canal preparation using only one Ni-Ti rotary instrument: preliminary observations. Int Endod J. 2008; 41: 339-344.
8. Ha JH, Cheung GS, Versluis A, Lee CJ, Kwak SW, Kim HC. 'Screw-in' tendency of rotary nickel-titanium files due to design geometry. Int Endod J. 2015; 48: 666-672.
9. Nakagawa RK, Alves JL, Buono VT, Bahia MG. Flexibility and torsional behaviour of rotary nickel-titanium PathFile, RaCe ISO 10, Scout RaCe and stainless steel K-File hand instruments. Int Endod J. 2014; 47: 290-297.
10. Elnaghy AM, Elsaka SE. Evaluation of the mechanical behaviour of PathFile and ProGlider pathfinding nickel-titanium rotary instruments. Int Endod J. 2015; 48: 894-901.
11. Choi DM, Kim JW, Park SH, Cho KM, Kwak SW, Kim HC. Vibrations Generated by Several Nickel-titanium Endodontic File Systems during Canal Shaping in an Ex Vivo Model. J Endod. 2017; 43: 1197-1200.
12. Kwak SW, Cheung GS, Ha JH, Kim SK, Lee H, Kim HC. Preference of undergraduate students after first experience on nickel-titanium endodontic instruments. Restor Dent Endod. 2016; 41: 176-181.
13. Al-Omari MA, Aurich T, Wirtti S. Shaping canals with ProFiles and K3 instruments: does operator experience matter? Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2010; 110: e50-55.
14. Munoz E, Forner L, Llena C. Influence of operator's experience on root canal shaping ability with a rotary nickel-titanium single-file reciprocating motion system. J Endod. 2014; 40: 547-550.
15. Blum JY, Machtou P, Esber S, Micallef JP. Analysis of forces developed during root canal preparation with the balanced force technique. Int Endod J. 1997; 30: 386-396.
16. Diop A, Maurel N, Oiknine M, Patoor E, Machtou P. A novel platform for *in vitro* analysis of torque, forces, and three-dimensional file displacements during root canal preparations: application to ProTaper rotary files. J Endod. 2009; 35: 568-572.
17. da Silva FM, Kobayashi C, Suda H. Analysis of forces developed during mechanical preparation of extracted teeth using RaCe rotary instruments and ProFiles. Int Endod J. 2005; 38: 17-21.
18. Sigrist CJ, Cerutti L, Hulo N, Gattiker A, Falquet L, Pagni M, et al. PROSITE: a documented database using patterns and profiles as motif descriptors. Brief Bioinform. 2002; 3: 265-74.
19. Kester W, Bryant J, Jung W, Wurcer S, Kitchen C. Sensor signal conditioning. Jung W, editor. In: Op Amp Applications Handbook. 1st edn. Newnes. 2004; 227-304.
20. Stevens WR, Rago. SA. Advanced Programming in the UNIX Environment. 3rd edn. Boston: Addison-Wesley. 2013.
21. Peters OA, Barbakow F. Dynamic torque and apical forces of ProFile.04 rotary instruments during preparation of curved canals. Int Endod J. 2002; 35: 379-389.
22. Bishop CM. Pattern recognition and machine learning. New York: Springer. 2006.
23. Shadmehr R, Mussa-Ivaldi FA. Adaptive representation of dynamics during learning of a motor task. J Neurosci. 1994; 14: 3208-3224.