Assessment on the Precision of the Orthodontic Bracket Slot Dimensions Using Micro-computed Tomography (Micro-CT)

Nasser D Alqahtani

ABSTRACT

Aim: To evaluate the precision of the orthodontic bracket slot dimensions of 0.022 inch and to compare them with those of the manufacturers’ specifications.

Materials and methods: The slots of upper-right central incisor brackets (n = 5) from 11 commercial bracket systems of three different manufacturers (3M Unitek: Victory Mini Metal, Clarity, SmartClip, Clarity SL; ORMCO/SYBRON: Mini Diamond Twin, Damon Q, Damon Clear; Dentsply/GAC: Ovation, Mystique, In-Ovation R, In-Ovation C) were measured. The orthodontic brackets were scanned using micro-computed tomography (micro-CT), and the bracket slots were measured using micro-CT images. The slot was measured at four different surfaces (occlusal, gingival, base, and face) for both mesial and distal sites. Data were subjected to ANOVA and unpaired t-tests. A p-value of ≤0.05 was considered statistically significant.

Results: All brackets had slot dimensions that were significantly larger (p < 0.05) than the stated 0.022 inch. 3M-victory were 11.99% larger (0.02509 inch) and the closest to the stated dimension and the ORM-Damon C were 24.07% larger (0.02948 inch) than the quoted slot size of 0.022 inch. Comparison between mesial and distal sides showed that 91% of the bracket slots were asymmetrical at their bases and 100% asymmetrical at their faces. All of the bracket system showed divergent walls from base to face with values ranging from 1.96 (3M-SmartClip) to 26.58% (ORM-Damon C).

Conclusion: The actual measurements of 11 bracket systems from three different manufacturers were more substantial than the manufacturers’ specifications, and the walls of the slots diverged from the bracket bases in all of the tested bracket system.

Clinical significance: Orthodontic bracket slot dimensions vary significantly from that of the manufacturers’ specification. The orthodontist should anticipate such shortcomings and be able to modify treatment mechanics through additional wire bending in three spatial planes.

Keywords: Micro-CT, Orthodontic bracket, Self-ligating brackets, Slot dimension.

The Journal of Contemporary Dental Practice (2021): 10.5005/jp-journals-10024-3047

INTRODUCTION

Researchers have assessed the dimensions and precision with which medical devices are made and have thus confirmed that variations do occur in all industrial processes. The machining techniques itself are prone for several irregularities. Injection molding, for example, appears to have more rounded corners than precision grinding and machining techniques. In clinical orthodontics, the straight-wire technique allows clinicians to move teeth in three dimensions using only straight wires. This is accomplished by the tooth moving forces that are produced as a result of the intimate fit between archwire and the bracket slot. Any discrepancy between the archwire and the bracket slot would result in an inadequate transfer of forces to the tooth and supporting tissues. Furthermore, any variations in orthodontic bracket slot profile have an impact on torque play and third-order torque expression. Thus it is of concern to orthodontists to know bracket slot accuracy and the several methods used in the production of such orthodontic brackets.

Clinicians usually assume that the manufacturers correctly specify the dimensions of the brackets and wires. Studies, however, have demonstrated dimensional discrepancies in brackets and archwires, often leading to excessive torsional play. As a result, torque, especially in the incisors in extraction cases, is inadequately controlled, thereby compromising the clinical outcomes. Previous studies comparing the precision of the orthodontic bracket slots have shown results that are against the manufacturer’s specification.

Digital methods have been incorporated into dental practice due to their precision, usability, and flexibility in gathering information regarding dental therapies for the diagnosis, treatment planning, fabrication of prosthesis and appliances, and for research purposes. Previous studies have used several devices and methods to measure slot dimensions. These include precision pin gauges, single-axis Maxtascan 100, scanning electron microscopy, microhardness tester equipped with an automatic reading system, and stereomicroscope.

In recent years, the applications of micro-CT system for research purpose have been profoundly increasing. The system is equipped with high-resolution detectors, which allow projections to be rotated through multiple viewing directions to produce 3D sample images. The imaging procedure is non-destructive, and thus
the internal characteristics of the same sample can be examined several times and remains accessible after scanning for mechanical testing.\textsuperscript{15} Furthermore, the exponential increase in the image resolution provided by the micro-CT systems facilitates accurate viewing or measurements of the samples.\textsuperscript{16,17}

Consequently, the present study aimed to evaluate the precision of the conventional, ceramic, and self-ligating orthodontic bracket’s slot dimension of 0.022 inch and compared them with those of the manufacturers’ specification using micro-CT system. Furthermore, the precision of the slot dimension between mesial and distal sites was compared, and the parallelism of the bracket slot was determined.

**Materials and Methods**

The slots of five upper-right central incisor brackets (conventional, ceramic, and self-ligating brackets) from 11 commercially available bracket systems of three different manufacturers (3M Unitek: Victory Mini Metal, Clarity, SmartClip, Clarity SL; ORMCO/SYBRON: Mini Diamond Twin, Damon Q, Damon Clear; Dentsply/GAC: Ovation, Mystique, In-Ovation R, In-Ovation C) were measured in 0.022-inch dimension using micro-CT system. The study was conducted at College of Dentistry Research Centre (CDRC), King Saud University. The details of the bracket system used in this study are presented in Table 1.

**Micro-computed Tomography (μ-CT) Scanning of Brackets**

The orthodontic bracket slot was scanned with μCT (Skyscan 1172, Bruker micro-CT, Kontich, Belgium), a compact, desktop X-ray system for non-destructive 3D sample reconstruction with a high spatial resolution. The instrument acquires transmission images using a fully distortion-corrected 11Mp X-ray camera based on charge-coupled device (CCD) fiber-optic camera coupled to a scintillator. The acquired cross-section images are reconstructed into 3D models for further analysis. The μ-CT was operated at 100 kV and 50 µA under standard resolution with 360° rotations of the projections around the vertical axis and a camera exposure time of 1700 ms. The X-rays were filtered with a 1-mm-thick aluminum filter for the variations in the sensitivity of polychromatic radiations.

The measurement of 35 bracket slot μ-CT images was repeated two weeks later and the reliability of the measurements was analyzed using intraclass correlation coefficient (ICC). An ICC values ranging from 0.75 to 0.90 were observed that indicated good reliability of the repeated measurements.

**Results**

The sagittal view of the μ-CT images of the maxillary right central incisors brackets used for measurements is presented in Figure 2.

The slot dimensions measured at four surfaces (occlusal, gingival, base, and face) of the bracket systems at mesial and distal sites are presented in Tables 2 and 3, respectively. Slot dimension at occlusal surface of the bracket ranged from 0.018 to 0.048 inch and 0.018 to 0.049 inch at the mesial and distal sites, respectively. The slot dimensions at gingival surface of the bracket ranged from

| Manufacturer | Brand | Catalogue no. |
|-------------|-------|---------------|
| 3M Unitek | Victory Series Mini-Metal | 3 017-547 ROTH |
| Monrovia, California, USA | Clarity | 6400-122 ROTH |
| ORMCO/ SYBRON | Mini-Diamond Twin | 351-0130 |
| Orange, California, USA | Damon Q | DM-Q 5-Standard Torque |
| Dentsply/GAC | Ovation | 82-112-00 |
| Bohemia, New York, USA | Mystique | KIT 110-532-11 |
| In-Ovation R | KIT 89-055-22 |
| In-Ovation C | KIT 100-532-00 |

![Image](image_url) Fig. 1: Cross-sectional view of a metal bracket demonstrating the measurement surfaces
Table 2: Mean slot dimensions of the brackets in 1/1000\textsuperscript{th} inch (Mesial site)

| Bracket system | Occlusal Mean | Occlusal SD | Gingival Mean | Gingival SD | Base Mean | Base SD | Face Mean | Face SD |
|----------------|---------------|-------------|---------------|-------------|-----------|---------|-----------|---------|
| 3M-Victory     | 23.66         | 1.01        | 32.16         | 1.23        | 24.81     | 0.28    | 24.81     | 0.28    |
| 3M-Clarity     | 27.90         | 0.90        | 28.35         | 0.70        | 23.13     | 0.33    | 26.87     | 0.34    |
| 3M-SmartClip   | 47.50         | 1.29        | 48.15         | 0.55        | 24.97     | 0.01    | 25.62     | 0.74    |
| 3M-Clarity SL  | 29.15         | 0.86        | 29.15         | 0.24        | 24.56     | 1.42    | 27.02     | 1.09    |
| ORM-Damon     | 31.74         | 1.30        | 33.05         | 0.67        | 25.36     | 0.39    | 25.97     | 0.19    |
| ORM-Damon Q   | 33.11         | 1.60        | 35.27         | 1.09        | 25.63     | 0.19    | 26.53     | 0.58    |
| ORM-Damon C   | 48.88         | 1.37        | 66.09         | 1.22        | 23.59     | 0.51    | 26.67     | 0.19    |
| GAC-Ovation    | 30.96         | 0.34        | 30.53         | 0.48        | 25.85     | 0.01    | 26.76     | 0.19    |
| GAC-Mystique  | 36.90         | 0.81        | 39.14         | 0.89        | 25.23     | 0.40    | 26.41     | 0.40    |
| GAC-In-Ova R  | 22.57         | 0.39        | 38.10         | 0.58        | 25.63     | 0.19    | 26.76     | 0.39    |
| GAC-In-Ova C  | 18.36         | 0.30        | 34.81         | 1.09        | 24.72     | 0.78    | 25.97     | 0.39    |

Table 3: Mean slot dimensions of the brackets in 1/1000\textsuperscript{th} inch (Distal site)

| Bracket system | Occlusal Mean | Occlusal SD | Gingival Mean | Gingival SD | Base Mean | Base SD | Face Mean | Face SD |
|----------------|---------------|-------------|---------------|-------------|-----------|---------|-----------|---------|
| 3M-Victory     | 24.97         | 0.49        | 33.30         | 0.49        | 24.81     | 0.28    | 25.79     | 0.74    |
| 3M-Clarity     | 28.24         | 0.90        | 28.92         | 0.90        | 23.59     | 0.51    | 26.69     | 0.70    |
| 3M-SmartClip   | 48.81         | 0.74        | 48.97         | 0.01        | 24.81     | 0.28    | 25.13     | 1.13    |
| 3M-Clarity SL  | 29.15         | 2.48        | 30.14         | 0.73        | 23.89     | 1.18    | 27.35     | 1.18    |
| ORM-Diamond    | 25.63         | 1.37        | 32.78         | 0.78        | 25.63     | 0.19    | 26.08     | 0.19    |
| ORM-Damon Q   | 32.43         | 2.46        | 41.05         | 9.82        | 25.40     | 0.19    | 28.46     | 3.94    |
| ORM-Damon C   | 49.90         | 3.30        | 67.25         | 1.87        | 26.42     | 0.19    | 32.89     | 0.19    |
| GAC-Ovation    | 27.56         | 0.90        | 32.32         | 0.68        | 26.31     | 0.19    | 26.65     | 0.19    |
| GAC-Mystique  | 37.02         | 1.94        | 39.38         | 1.94        | 24.87     | 0.20    | 26.53     | 0.35    |
| GAC-In-Ova R  | 21.43         | 1.18        | 37.65         | 0.19        | 26.76     | 0.78    | 26.87     | 0.01    |
| GAC-In-Ova C  | 18.60         | 0.52        | 34.36         | 0.89        | 25.40     | 0.39    | 25.29     | 2.18    |
Table 4: Comparison of the mean mesial and distal slot dimensions (in 1/1000th inch) of base and face surface of the brackets

| Bracket system          | Surface | Mean | SD  | Mean | SD  | p-value |
|-------------------------|---------|------|-----|------|-----|---------|
| 3M-Victory              | Base    | 24.812 | 0.284 | 24.812 | 0.284 | 1.00    |
|                         | Face    | 24.975 | 0.490 | 25.793 | 0.748 | 0.04*   |
| 3M-Clarity              | Base    | 24.976 | 0.000 | 24.812 | 0.284 | 0.42    |
|                         | Face    | 26.879 | 0.341 | 26.995 | 0.709 | 0.74    |
| 3M-SmartClip            | Base    | 23.138 | 0.339 | 23.591 | 0.519 | 0.42    |
|                         | Face    | 25.629 | 0.748 | 25.138 | 1.132 | 0.23    |
| 3M-Clarity SL           | Base    | 24.560 | 1.421 | 23.892 | 1.185 | 0.50    |
|                         | Face    | 27.028 | 1.009 | 27.357 | 1.182 | 0.18    |
| ORM-Diamond             | Base    | 25.404 | 0.393 | 25.633 | 0.195 | 0.53    |
|                         | Face    | 25.972 | 0.198 | 26.087 | 0.198 | 0.42    |
| ORM-Damon Q             | Base    | 25.633 | 0.195 | 25.406 | 0.198 | 0.42    |
|                         | Face    | 26.538 | 0.589 | 28.467 | 3.944 | 0.46    |
| ORM-Damon C             | Base    | 25.633 | 0.521 | 26.427 | 0.195 | 0.19    |
|                         | Face    | 33.004 | 0.000 | 32.891 | 0.195 | 0.42    |
| GAC-Ovation             | Base    | 25.858 | 0.000 | 26.314 | 0.195 | 0.06    |
|                         | Face    | 26.765 | 0.195 | 26.652 | 0.195 | 0.42    |
| GAC-Mystique            | Base    | 25.232 | 0.409 | 24.878 | 0.205 | 0.23    |
|                         | Face    | 26.413 | 0.409 | 26.532 | 0.354 | 0.74    |
| GAC-In-Ova R            | Base    | 25.633 | 0.195 | 26.766 | 0.786 | 0.18    |
|                         | Face    | 26.766 | 0.393 | 26.878 | 0.000 | 0.67    |
| GAC-In-Ova C            | Base    | 24.726 | 0.782 | 25.404 | 0.393 | 0.42    |
|                         | Face    | 25.974 | 0.393 | 25.293 | 2.186 | 0.58    |

*Statistically significant (student paired “t” test) 

0.028 to 0.066 inch and 0.028 to 0.067 inch at the mesial and distal sites, respectively.

Similarly, slot dimension at base of the bracket ranged from 0.023 to 0.025 inch and 0.023 to 0.026 inch at the mesial and distal sites, respectively. Similarly, the slot dimensions at face of the bracket ranged from 0.024 to 0.033 inch and 0.025 to 0.032 inch at the mesial and distal sites, respectively.

In evaluating the bracket symmetry, a comparison between mesial and distal sites was done using student paired “t”-test (Table 4). The data analysis revealed difference in measurements at mesial and distal sites for both base and face surfaces of the tested bracket systems. However, the difference in measurements was not significant (p > 0.05) except for 3M-Victory, which showed a significant difference in the face measurements from mesial to distal site (p = 0.04). On the contrary, the measurement of the base surface for the 3M-Victory bracket system at mesial and distal sites was accurate (p = 1.00). It was shown that 91% of the bracket slots were asymmetrical at their bases against 100% at their faces.

Table 5 presents the mean difference in the bracket slot height against the manufacturer stated height of 0.022 inch. The mean percentage difference in bracket slot height compared to the manufacturer stated dimension of 0.022 inch.

Table 5: Mean difference in the bracket slot height compared against the manufacturer stated height of 0.022 inch

| Bracket systems        | Mesial | Distal | Mean difference (1/1000th inch) |
|------------------------|--------|--------|---------------------------------|
| 3M-Victory             | 2.81   | 3.22   |
| 3M-Clarity             | 2.93   | 3.21   |
| 3M-SmartClip           | 3.22   | 2.90   |
| 3M-Clarity SL          | 3.71   | 3.54   |
| p-value                | 0.41   | 0.73   |
| ORM-Diamond            | 3.61   | 3.78   |
| ORM-Damon Q            | 4.01   | 4.86   |
| ORM-Damon C            | 7.24   | 7.58   |
| p-value                | <0.001*| 0.02*  |
| GAC-Ovation            | 4.23   | 4.40   |
| GAC-Mystique           | 3.74   | 3.62   |
| GAC-In-Ova R           | 4.12   | 4.74   |
| GAC-In-Ova C           | 3.27   | 3.27   |
| p-value                | 0.02*  | 0.03*  |

*Statistically significant (Tukey’s post-hoc analysis)

The outcome of the current study demonstrated that all the study brackets were significantly greater than the manufacturers’ stated dimension of 0.022 inch, and the walls of the bracket slot diverged from the base in all of the bracket systems. The study also demonstrated that discrepancies exist not only between different manufacturers but also in the bracket systems from the same manufacturer. Similar such outcome has been reported earlier by different authors evaluating the bracket slot measurements.
Precision of Orthodontic Bracket Slot

Kusy and Whitley\textsuperscript{12} analyzed 24 brackets using critical contact angle from eight manufacturers and found three smaller bracket slots, and another 20 wider than their manufacturers’ stated measurements. The slot of 0.018 inch bracket was 16% bigger and the slot of 0.022 inch brackets was 8% wider than manufacturer specification. Similarly, Cash et al.\textsuperscript{5} found a wider bracket slot ranging from 5 to 24% compared to manufacturer’s specification in all of the 11 commercially available bracket systems using Maxtascan 100 manual measuring device. Also, the study confirmed that the geometry of bracket slots variations, with some bracket systems, exhibits parallel, divergent, or convergent walls. Demling et al.\textsuperscript{9} using precision pin gauges compared the accuracy of slot dimensions of three lingual bracket systems, and they found that the brackets exhibited significant differences in slot dimension that could clinically result in torque play.

The electron microscopic measurements of upper central incisor self-ligating brackets from six manufacturers reported by Bhalla et al.\textsuperscript{7} were larger than the manufacturers’ stated dimension, and the walls of the slots diverged from the bracket bases. Moreover, Brown et al.\textsuperscript{14} used microhardness tester to evaluate the slot size of an entire series of metal orthodontic brackets. The authors found that the slot dimension differed greatly from series to series as well as within the series. Furthermore, Lee et al.\textsuperscript{3} evaluating the dimensional accuracies of ceramic self-ligation brackets using stereomicroscope found a significantly wider slot tops compared to slot bases thus creating a divergent slot profile.

Fig. 3: Mean percentage difference between the measured bracket slot heights of the tested bracket system against manufacturer’s stated height of 0.022 inch

Fig. 3: Mean bracket slot height at base and face of the tested bracket system. The number indicates the percentage of slot divergence from base to face
In the present study, the mesial and distal sites were compared to assess the symmetry of the brackets and surprisingly all of the bracket systems showed asymmetry. Although the dimensions varied from mesial to distal sites, the difference was not significant. All of the tested bracket system slots were asymmetrical at face from mesial to distal sites, whereas 91% of the brackets showed asymmetry at base from mesial to distal sites. This was in accordance with the findings of the previous study by Lefebvre et al.\textsuperscript{19} where the authors compared the mesial and distal sites and found a significantly asymmetrical bracket slots in 45% of the tested brackets. Contrary to the findings of our study, Khan et al.\textsuperscript{20} demonstrated uniformity of the bracket slot heights on both mesial and distal sites with all of the tested brackets using digital gauges. However, the authors reported an increased slot heights ranging from 6 to 19% in most of the commercially available bracket series.

While most manufactures may not specify their technical tolerances for bracket slot differences, manufacturing inaccuracies may occur as a consequence of any flaws or defects in manufacturing processes or material type.\textsuperscript{8,21} Orthodontic brackets cast from molds are affected by shrinkage and milling, which introduces various defects such as grooves and striations displaying porosity in the slot walls. To overcome such manufacturing defects and ensure that the defects do not interfere with the presence of archwire, manufacturers consciously increase the slot dimensions and bevel the edge of archwires.\textsuperscript{12}

Furthermore, it has been claimed that European orthodontic bracket manufacturers are using metric tooling and, as a result of the disparity between this and American imperial-based tooling, the 0.022-inch slots in European-made brackets are immediately over-sized by 4.22% even before any manufacturing variation is identified.\textsuperscript{13}

It is always necessary that orthodontist be aware that the pre-adjusted bracket and wire systems that are commonly used in clinical practice cannot provide the three-dimensional control throughout the study.

References

1. Kalpakjian S, Schmid S, Sekar V. Manufacturing engineering and technology/Serogpe Kalpakjian, Illinois Institute of Technology, Steven R Schmid, The University of Notre Dame. 7th edition; 2013.

2. Gioka C, Eliades T. Materials-induced variation in the torque expression of preadjusted appliances. Am J Orthod Dentofacial Orthop 2004;125(3):323–328. DOI: 10.1016/j.ajodo.2003.02.007.

3. Lee Y, Lee DY, Kim YJ. Dimensional accuracy of ceramic self-ligating brackets and estimates of theoretical torsional play. Angle Orthod 2016;86(5):804–809. DOI: 10.2319/092415-6471.

4. Urias D, Mustafa FIA. Anchorage control in bioprogressive vs straight-wire treatment. Angle Orthod 2005;75(6):987–992. DOI: 10.1043/0003-3219(2005)75[987:ACIBVS]2.0.CO;2.

5. Cash AC, Good SA, Curtis RV, et al. An evaluation of slot size in orthodontic brackets—are standards as expected? Angle Orthod 2004;74(4):450–453. DOI: 10.1043/0003-3219(2004)074[0450:ACIBVS]2.0.CO;2.

6. Fischer-Brandies H, Orthuber W, Es-Souni M, et al., Torque transmission between square wire and bracket as a function of measurement, form and hardness parameters. J Orofac Orthop 2000;61(4):258–265. DOI: 10.1006/s00560050011.

7. Bhalla NB, Good SA, McDonald F, et al. Assessment of slot sizes in self-ligating brackets using electron microscopy. Aust Orthod J 2010;26(1):38–41.

8. Major TW, Carey JP, Nobes DS, et al. Orthodontic bracket manufacturing tolerances and dimensional differences between select self-ligating brackets. J Dent Biomech 2010;2010:781321. DOI: 10.4061/2010/781321.

9. Demling A, Dittmer MP, Schwestka-Polly R. Comparative analysis of slot dimension in lingual bracket systems. Head Face Med 2009;5:27. DOI: 10.1186/1746-160X-5-27.

10. Meling TR, Odegaard J, Seqner D. On bracket slot height: a methodologic study. Am J Orthod Dentofacial Orthop 1998;113(4):387–393. DOI: 10.1016/s0003-3219(08)00009-7.

11. Siatkowski RE. Loss of anterior torque control due to variations in bracket slot and archwire dimensions. J Clin Orthod 1999;33(9):508–510.

12. Kusy RP, Whitley JQ. Assessment of second-order clearances between orthodontic archwires and bracket slots via the critical contact angle for binding. Angle Orthod 1999;69(1):71–80. DOI: 10.1043/0003-3219(1999)069[0071:AOASDB]2.0.CO;2.

13. Abdou J, Elsayouth M. Accuracy of intraoral scanners: a systematic review of influencing factors. Eur J Prosthodont Restor Dent 2018;26(3):101–121. DOI: 10.1922/EJPRD_01752Abduo21.

14. Brown P, Wagner W, Choi H. Orthodontic bracket slot dimensions as measured from entire bracket series. Angle Orthod 2015;85(4):678–682. DOI: 10.2319/042814-307.1.

15. Swain MV, Xue J. State of the art of Micro-CT applications in dental research. Int J Oral Sci 2009;4(4):177–188. DOI: 10.4248/IJOS09031.

16. Acar B, Kamburoglu K, Tatar I, et al. Comparison of micro-computed tomography and cone-beam computed tomography in the detection of accessory canals in primary molars. Imaging Sci Dent 2015;45(4):205–211. DOI: 10.5624/isd.2015.45.4.205.

17. Tamminen IS, Isaksson H, Aula AS, et al. Reproducibility and agreement of micro-CT and histomorphometry in human trabecular bone with different metabolic status. J Bone Miner Metab 2011;29(4):442–448. DOI: 10.1007/s00774-010-0236-6.

18. Dolci GS, Spoehr AM, Zimmer ER, et al. Assessment of the dimensions and surface characteristics of orthodontic wires and bracket slots. Dental Press J Orthod 2013;18(2):69–75. DOI: 10.1590/s2176-94512013000200016.

Conclusion

There was a considerable variation in the slot sizes between orthodontic bracket systems from different manufacturers and between different bracket systems from the same manufacturer. 3M-Victory were 11.99% larger (0.02509 inch) and the closest to the stated dimension and the ORM-Damon C were 24.07% larger (0.02948 inch) than the specified slot size of 0.022 inch. The walls of the bracket slots were divergent (1.96–26.58%) from the base for all of the tested bracket system.
19. Khan T, Khan H, Mohsin S, et al. Manufacturer tolerance in mesial and distal slot height of 0.022-inch maxillary lateral incisor brackets. Pak Orthod J 2018;10(1):41–45.
20. Lefebvre C, Saadaoui H, Olive J-M, et al. Variability of slot size in orthodontic brackets. Clin Exp Dent Res 2019;5(5):528–533. DOI: 10.1002/cre2.219.
21. Meling TR, Odegaard J. On the variability of cross-sectional dimensions and torsional properties of rectangular nickel-titanium arch wires. Am J Orthod Dentofacial Orthop 1998;113(5):546–557.
22. Morina E, Eliades T, Pandis N, et al. Torque expression of self-ligating brackets compared with conventional metallic, ceramic, and plastic brackets. Eur J Orthod 2008;30(3):233–238. DOI: 10.1093/ejo/cjn005.