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ABSTRACT

AIM: To quantify deviations in slot size, tip and torque values of commercially available MBT-prescription metal brackets relative to the MBT standard.

METHODS: A literature review was performed. Electronic searches were conducted between March and May 2023 via PubMed, ResearchGate and Google Scholar. A total of 16,223 records were retrieved; 58 articles were assessed by full-text screening and 20 studies were included according to predefined inclusion and exclusion criteria.

RESULTS: The ideal tip value is 4 degrees; observed tip values ranged from 1.67 to 6 degrees. The ideal torque value is 17 degrees; observed torque values ranged from 7.67 to 17.81 degrees. Measured slot heights ranged from a minimum of 0.0209 inch at the base to a maximum of 0.0261 inch at the face, whereas the brackets claimed a 0.022 inch slot height.

CONCLUSION: A substantial proportion of measured brackets exhibit dimensional deviations from stated values. International standards for acceptable manufacturing tolerances and mandatory pre-market quality assessment are recommended. A consistent, repeatable measurement protocol should be established to reduce placement-related measurement error and to improve comparability across studies.

Keywords: Tip; Torque; Slot dimension accuracy; Precision orthodontic brackets; MBT

1. Introduction

The most important part of fixed-appliance therapy is the orthodontic bracket, as it connects the tooth to the arch wire. The ultimate aesthetic result of treatment is influenced by the tip and torque values integrated into the brackets, which are referred to as bracket prescriptions. Andrews was the first to introduce the straight-wire bracket system in orthodontics in the 1970s (Awasthi et al., 2015; Alavi & Tajmirriahi, 2016). Since no information had previously been integrated into the bracket slot or at the base of the bracket, Andrews provided the first bracket prescriptions by examining the optimal occlusion of 120 patients (Proffit et al., 2006). The straight-wire technique implies the insertion of a series of straight arch wires of increasing cross sections, terminating with a slot-filling wire, allowing the bracket information to be fully expressed. In contrast, in the conventional edgewise technique the favourable position of the tooth was achieved in the first and second orders by the orthodontist by creating in-and-out bends in the arch wire, and in the third order by twisting the arch wires using pliers to produce the desired torque (Graber et al., 2011).

Currently, the majority of brackets available on the market, particularly from Roth and from the author group McLaughlin, Bennett and Trevisi (MBT), are pre-adjusted and have torque and angulation incorporated into the bracket slot or base (Awasthi et al., 2015; Alavi & Tajmirriahi, 2016; Mendonça et al., 2014). Their prescriptions have been modified and the operational challenges of Andrews's appliance have been resolved (Proffit et al., 2006). The MBT version was introduced with the aim of promoting the final tooth positions at the end of patient treatment (McLaughlin & Bennett, 1990; McLaughlin & Bennett, 1995).

Edward H. Angle introduced the edgewise bracket with a 0.022-inch standard slot size for brackets (Cash et al., 2004). The gold wires employed either singly or in a twin arrangement were suitable for the 0.022-inch slot, which was the first to be developed. The 0.022-inch method provides greater flexibility in the choice of arch wire sizes. Smaller arch wires enable free sliding of the arch wire through the bracket slot, while the ability to use larger-diameter arch wires increases stiffness and helps to keep the teeth upright during space closure with different retraction mechanics. By contrast, the 0.018-inch system provides fewer choices in arch wire dimensions and fills the bracket slot more easily. The slot-dimension dichotomy remains unresolved because modern wires are likely to be equally effective in both 0.022- and 0.018-inch slots (Peck, 2001; Rubin, 2001).

The correctness of bracket slot dimensions and wire engagement is crucial for expressing the intended prescription, that is, the tip and torque (Bernés Martínez et al., 2021a). During orthodontic treatment, torque moments are most frequently achieved using a force couple created by the torsion of a rectangular arch wire in a rectangular bracket slot. Torsion magnitude, wire composition, torsional stiffness, wire diameter, slot dimension, wire/bracket slot play, tooth inclination, interbracket width (wire length) and bracket deformability are among the variables theorised to affect torque expression (Hixson et al., 1982). The required tip and torque values will not be expressed if there is any discrepancy between the ideal dimensions and the produced dimensions, which will affect treatment outcomes.

Because of the importance of bracket accuracy, quality standards have been established. In the European Union the European Committee for Normalization published ISO 27020:2019 as a reference standard for orthodontic brackets and tubes. This standardises the testing procedure for measuring dimensional accuracy and reports the difference in tolerance limits between manufacturers' declared and actual tolerance limits (Sernetz, 2005). To reduce tolerance in the bracket slots, several standards have been established globally for bracket manufacturers. These include ISO 27020:2010 (Joch et al., 2010; Sernetz, 2005), DIN S 13971-2 and ANSI/ADA Standard No. 100 (2012).

According to the standards, a tolerance of 0.001 inch is accepted in the bracket slot (Sernetz, 2005; Brown et al., 2015).

According to Proffit et al. (2006), in modern orthodontics the accuracy of orthodontic bracket manufacturing should produce slot-dimension accuracy of at least one millimetre to ensure appropriate expression of the prescription. Bennett and John (2010) cautioned that excessively large slots undermine the entire concept of preadjusted edgewise orthodontic brackets because they prevent full prescription expression. Currently, orthodontic brackets are made from a variety of substances with varied degrees of roughness, including metal, ceramic, plastic, titanium and composite (Radhakrishnan et al., 2017). Metal (stainless steel) is the most widely used material in the Middle Eastern market. There are several bracket prescriptions available commercially, but the orthodontist needs to be aware of the correctness of all measurements since these affect tooth position. Many commercially available brackets are advertised as prescribed, although it is often unclear whether the manufacturer has tested the brackets for dimensional correctness prior to marketing. In the literature there is a lack of standardised methods for the evaluation of bracket prescriptions. Several methods have been reported for bracket slot measurements, such as electron microscopy, profile-projector microscopy, leaf gauges and microhardness testing (Siatkowski, 1999; Major et al., 2010; Demling et al., 2009).

Different types of manufacturing processes also affect the resultant bracket slot dimensions and frictional forces. Compared to precision grinding and machining, injection moulding tends to produce more rounded corners (Kalpakjian & Schmid, 2001). Some brackets, despite being correctly machined, have an excess of brazing material that clogs the slot, making insertion of the arch wire impossible (Matasa, 1990).

Orthodontic brackets and slot dimension tolerances are rarely specified by manufacturers. However, deviations do exist in all production processes (**Figure 1**). Different imperfections might result from various machining processes. For instance, rounded corners are more common with injection moulding than with precise grinding and machining (Kalpakjian & Schmid, 2001).

The aim of this study is to systematically review studies of MBT prescription metal brackets with 0.022” slots and to assess whether tip, torque, slot-height measurements and measurement protocols, including base/face and mesial/distal comparisons, deviate from standard MBT values.

2. Methods

The search strategy was developed after formulating the PICO(S) questions to identify all available and relevant literature. The PICOS framework was specified as follows: Population and Intervention (Exposure) were considered irrelevant given the in vitro nature of the enquiry; Comparisons comprised (1) slot dimensions of other orthodontic bracket prescriptions and (2) slot dimensions of the MBT prescription across different manufacturers; Outcome measures included any observed variations in tip and torque values, slot height variations, and measurement parameters for slot dimensions (torque, slot height).

Electronic searches were conducted in PubMed, ResearchGate, Google Scholar and the Google search engine. PubMed was searched using the following terms with retrieved and selected counts reported in parentheses: "Slot dimensions Accuracy" (19; 4), "Failure MBT brackets" (5; 0), "Precision orthodontic brackets" (161; 4), "Self-ligating brackets" (589; 4), "MBT metal brackets" (24; 4) and "Invitro metal bracket study" (65; 1).

ResearchGate searches used the terms "Tip and Torque accuracy MBT brackets" (100; 9), "Slot dimensions accuracy MBT brackets" (100; 2) and "Orthodontic bracket slot height" (100; 2). Google

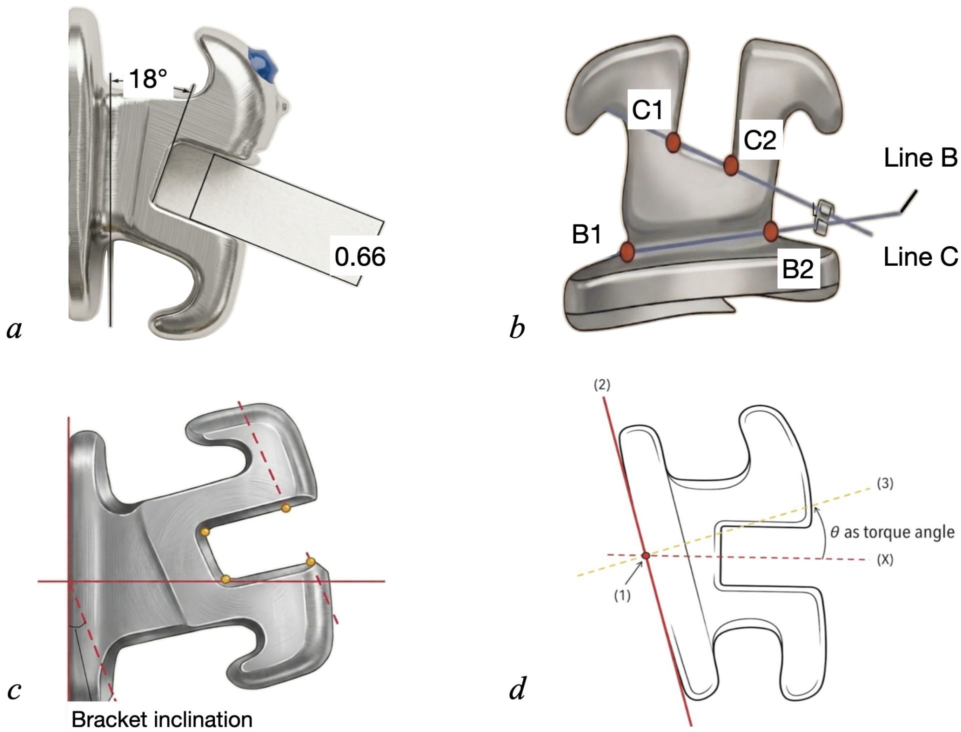

Figure 1. Orthodontic bracket torque measurement protocols. (a) Torque is measured as the angle between the long axis of the bracket base and the long axis of the slot base in central incisors, lateral incisors and canines (Awasthi et al., 2015). (b) A landmark-based point-to-line method is used to define torque by constructing two reference lines: Line B, formed by two points placed at the cervical and occlusal extremities of the bracket base, and Line C, formed by two points located at the internal slot-floor vertices. Torque is then determined as the angle between these two lines. Although the same geometric principle is applied across studies, it was used for maxillary and mandibular canines as well as for central incisors (Streva et al., 2011; Anjos et al., 2015; Mathiew et al., 2020). (c) In central incisors, torque is measured using a median line passing through the midpoints of the occlusal and gingival slot walls, and the angle is determined relative to a line drawn perpendicular to the tangent of the bracket base (Alavi & Tajmirriahi, 2016). (d) Following ISO 27020:2019, the slot is bisected by line X in the gingival–occlusal direction, while a tangent line is drawn on the tooth-side bracket base and an orthogonal reference line is projected through their intersection point; the torque angle is defined as the angle between the slot-bisecting line and this orthogonal reference line (Bernés Martínez et al., 2021b).

Scholar searches included "Slot size orthodontic brackets" (9,500; 10) and "Slot, self-ligating brackets" (5,560; 7).

The Google search engine was used to locate full texts that were not accessible via the databases above and to retrieve articles cited within identified papers that were otherwise unavailable (two articles located in this manner). Searches yielded repeated and overlapping records across platforms; identical records retrieved by multiple searches were treated as duplicates during screening.

Studies were included if they were in vitro investigations of bracket slot dimensions and involved MBT prescription brackets, encompassing conventional metal brackets and self-ligating brackets with MBT prescription; studies addressing manufacturing tolerances on brackets were also eligible. The search strategy was restricted by using quotation marks to ensure all search terms were present, and the most relevant results were taken from articles published in scientific journals in the last 15yrs. Only freely available articles that were repeatedly retrieved across the searched databases were considered, and a total of twenty articles was selected for the literature review (**Figure 2**).

Articles were excluded if they concerned aesthetic (ceramic or plastic) brackets, lingual bracket systems, metal brackets with other prescriptions (Roth, Ricketts, Andrews), or bracket slot dimensions after reconditioning. Such articles were therefore not considered for inclusion.

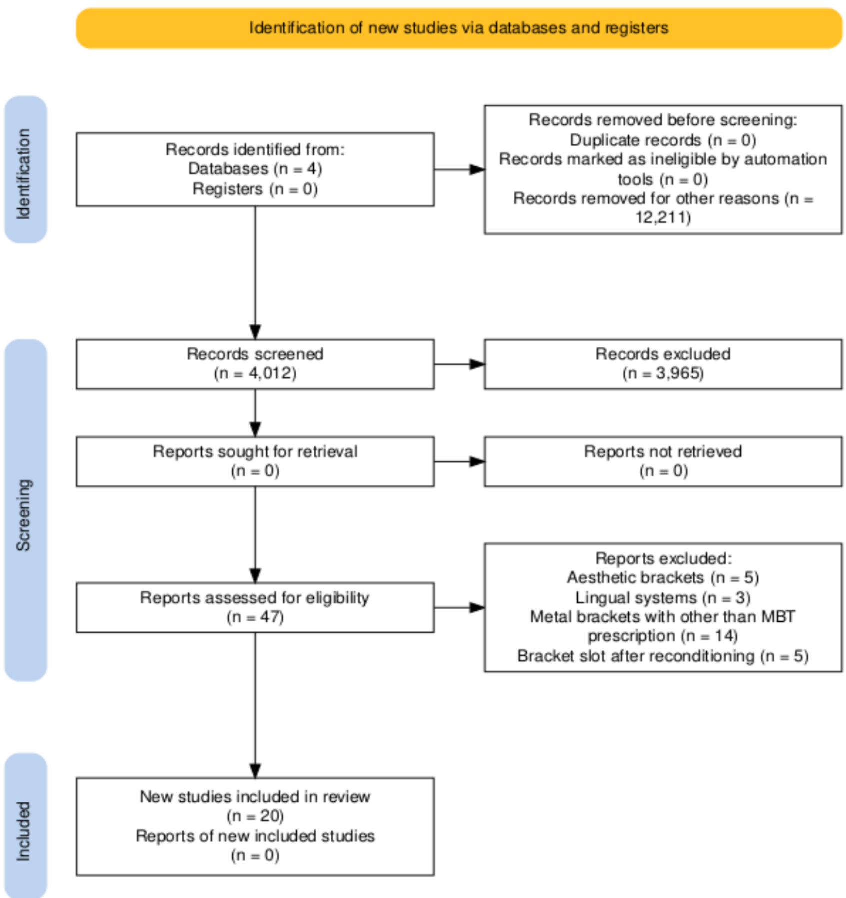

Figure 2. Prisma flow chart of selected articles.

2.1. Statistics

Descriptive statistics, frequency analysis, and content analysis were employed as part of the qualitative methodology to systematically analyze the textual content of the included studies. It is important to note that, given the narrative nature of this study, regression analysis and meta-analysis techniques were not deemed suitable for the analytical framework.

3. Results

Orthodontic bracket prescriptions are the angulations, inclinations and offset values used in a bracket system to treat a particular patient's malocclusion. Several bracket prescriptions are mentioned in the book Contemporary Orthodontics by Proffit et al. (2006), of which Andrews, Roth, and MBT are the most important. The prescription for central incisors given by these authors is as follows: Andrews: tip-5, torque-7; Roth: tip-5, torque-12; MBT: tip-4, torque-17. The MBT prescription has been most widely used due to its versatility.

The angulations and inclinations are described as the tip and torque of the bracket system. The tip is the mesio-distal angulation of the teeth, which can be incorporated into the bracket by angulating the bracket wing in the mesio-distal plane. Torque is the labio-lingual inclination of the tooth, which was incorporated into the bracket initially by angulating the base (torque in base) and later by angulating the face (torque in face) (Awasthi et al., 2015).

There are different methods of measuring tip and torque values reported in the literature. Some studies have used a stereomicroscope, scanning electron microscope, projector and leaf gauge to measure bracket slot height and depth. Generally, there are two types of bracket systems, namely conventional and self-ligating, based on the way the archwire is ligated to the bracket slot. Both varieties were selected for the study.

A comparison of mean tip values, torque values and slot dimensions from different manufacturers was undertaken to determine how accurately the manufacturers' stated (prescribed) values were. Twenty studies were selected for this purpose. All the bracket series used in this study were of 0.022-inch slots.

3.1. Central incisor bracket torque

Studies including only central incisor brackets (stainless steel) with an MBT prescription were selected, irrespective of whether they were conventional or self-ligating, for the comparison of tip and torque values.

Studies from six different authors were selected for the torque comparison because they involved similar manufacturers; studies whose manufacturers did not match other studies were excluded from this comparison.

The torque is produced by torsion in an "archwire" that creates a couple upon interacting with a "bracket slot" (Harzer et al., 2004). Complete torque expression can be achieved by using a full-sized archwire to fill the bracket slot. However, to insert such a wire a certain amount of play is required. This means that the dimension of the bracket slot must be greater than that of the archwire. If there is a large discrepancy between the archwire dimensions and the bracket slot, the torque expressed will be inconsistent (Joch et al., 2010).

The maxillary central incisor has the greatest built-in torque, and any manufacturing errors that alter this value may necessitate additional bends in the wire or compromise treatment outcomes. Hence, a comparison was undertaken to assess the precision of the built-in torque of the maxillary

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central incisor bracket, which influences the torque expressed on the incisors. **Table 1** compares the mean torque values of central incisor brackets from different manufacturers with the MBT prescription and a slot size of 0.022 inches, based on six studies. The ideal torque value is 17 degrees according to the MBT prescription.

Table 1. Mean torque values (degree) of central incisor brackets (MBT 0.022” slot).

MANUFACTURER	AWASTHI (2015)	KIM (2012)	ALAVI (2016)	DAGA (2017)	BERNES MARTINEZ (2021B)	MATHIEW (2020)
American Orthodontics	12.67	-	16.23	17.11	17.81	14.85
3M Unitek	17.67	16.15	-	16.35	17.05	14.71
Ortho Organisers	-	-	16.88	17.06	-	-
Orthox Organizers	7.67	-	12.01	-	10.75	-
Dentaurum	-	-	-	17.20	15.28	-
Forestadent	-	-	16.54	17.06	-	-
Modern	-	-	17.17	17.33	-	-
Normal Torque Value	17	17	17	17	17	17

Analysis of mean torque values for central incisor brackets revealed that Orthox Organizers were consistently below the prescribed torque value, whereas 3M Unitek’s values were broadly consistent. Only one study reported mean torque values close to the standard value; the other studies showed substantial variability, which could be attributable to manufacturing error.

Awasthi et al. (2015) reported mean torque values for American Orthodontics and Orthox Organizers of 12.67 degrees and 7.67 degrees, respectively; 3M Unitek was around the normal value (17.67 degrees). Kim et al. (2012) demonstrated that, because manufacturers’ standard torque values varied, the mean torque value of 3M Unitek was not considered significant. Alavi and Tajmirriahi (2016) reported a substantial disparity between the final torque of American Orthodontics brackets and the MBT reference value of 17 degrees. Alavi and Tajmirriahi (2016) also found a significant difference when comparing the final torque of American Orthodontics brackets with the MBT reference value of 17 degrees ($P < 0.001$); however, Ortho Organisers did not exhibit a significant difference at 17 degrees ($P = 0.0202$).

Daga et al. (2017) found the mean torque value of Forestadent (16.54 degrees) to be closest to the prescribed value, whereas Orthox Organizers (12.01 degrees) were far below. There was a significant difference in the average torque angle ($P < 0.001$).

Bernés Martínez et al. (2021a) found that the torque value declared by the manufacturer for the upper central incisor was 17 degrees; ISO 27020:2019 admits a tolerance of ± 1 degree (the permissible torque range is 16 to 18 degrees). All torque values of American Orthodontics, 3M Unitek, Dentaurum and Forestadent respected the tolerance limits, but the torque values of Modern Series were outside the declared value (min: 15.11 degrees, max: 19.32) despite the mean being 17.33 degrees. The study used about 360 brackets for torque analysis, and values fell into the nominal range for all manufacturers except Ortho Organisers and Orthox Organisers, as they were not used in the study.

Mathew et al. (2020) reported that American Orthodontics, 3M Unitek and Dentaurum showed no statistically significant difference compared with the ideal values; however, Orthox Organizers showed a highly significant difference ($P < 0.01$) relative to the reference values.

3.2. Central incisor bracket tip

Four studies were selected for tip analysis, as there were limited studies on tip accuracy and it was difficult to find common manufacturers focusing on MBT stainless steel brackets.

One of the most important aspects of the straight-wire method is tip information. According to Mendonça et al. (2014) and Castro et al. (2018), relative tooth size and the associated Bolton index are both significantly affected by tooth inclination in the mesiodistal plane. However, tip expression is one of the primary contributing causes of anchorage loss, and tip information often manifests early in the course of therapy (Plaza et al., 2010). It is notable that so few studies have addressed the issue of bracket tip manufacturing accuracy.

Table 2 compares the mean tip value of central incisor brackets from different manufacturers with the MBT prescription and a slot size of 0.022 inches (according to different studies). The ideal tip value is four degrees. Three of the four studies had mean tip values within the normal range, whereas one study showed considerable variability. The mean tip values for American Orthodontics and 3M Unitek appeared to be within the expected range according to these studies, while Orthox Organisers were inconsistent.

Table 2. Mean tip values (degree) of central incisor brackets (MBT 0.022” slot).

MANUFACTURER	AWASTHI (2015)	ALAVI (2016)	DAGA (2017)	BERNES MARTINEZ (2021B)
American Orthodontics	6	4.17	4.03	4.16
3M Unitek	4.33	N/A	3.55	4.11
Ortho Organisers	N/A	4.24	4.22	N/A
Dento Smile	5.67	N/A	N/A	N/A
Galaxy Orthodontics	5	N/A	N/A	N/A
Liberal Traders	4.66	N/A	N/A	N/A
Orthox Organizers	1.67	N/A	4.08	N/A
Modern	N/A	N/A	4.22	4.71
Forestadent	N/A	N/A	4.17	4.30
Ideal	4	4	4	4

Awasthi et al. (2015) reported that mean tip values were statistically significant for Orthox

Organisers (1.67 degrees; $P < 0.05$). Alavi & Tajmirriahi (2016) found no significant differences in the final tip between American Orthodontics and Ortho Organisers. Daga et al. (2017) reported no significant difference in the average tip angle value of the brackets. Bernés Martínez et al. (2021a) reported that the tip value declared by all manufacturers for the upper central incisor was four degrees; ISO 27020:2019 admits a tolerance of ±1 degree in relation to the declared value. The Modern Series showed a maximum tip of 5.50 degrees, which is 1.5 degrees (+37.5%) higher than the declared value, with a mean of 4.71 degrees reflecting greater data dispersion.

3.3. Central incisor bracket slot height

The slot dimensions of central incisor brackets from nine manufacturers, based on six studies for 0.022-inch slots, were compared; the slot dimension considered was the vertical slot height between the horizontal bracket wings. A few studies measured only at the face, whereas others measured at the base of the slot. As the bracket base had rounded corners, base height was measured 100 microns from the base to obtain more accurate measurements. Studies recorded either both sides (mesial and distal) or only one side for slot-height registration. Some studies also measured in the middle of the bracket slots; these measurements are not mentioned here to maintain uniformity. A few studies measured the bracket slot depth from the face to the base of the slot (horizontally); these were not considered relevant to the present analysis. As the studies used different units (such as millimetres), values were converted to inches for ease of comparison.

Table 3 compares the mean slot height of central incisor brackets from different manufacturers with the MBT prescription and a slot size of 0.022 inches (according to different studies). The mean slot values for central incisors vary between studies for the same manufacturers with MBT prescription and also vary across different regions of the same bracket (mesial, distal, facial/top, base), with standard deviations indicating differing dispersion. Despite selecting only central incisor brackets, there was no uniformity in slot dimensions among the same manufacturers; in contrast, the Modern Series group showed marked variability across studies. 3M Unitek and American Orthodontics were relatively consistent in their slot dimensions. Overall, the measurements appear to be slightly oversized.

Awasthi et al. (2015) reported mean slot values for 3M Unitek (0.0259") and Orthox Organizers (0.0236") that were statistically significant ($P < 0.05$). Tangri et al. (2012) reported slot sizes ranging from a minimum of 0.0201" on the distal base of the Modern bracket series to a maximum of 0.0248" on the distal face of the Ortho Organisers bracket. At the base there was a significant difference in the slot size of the Dentaurum brackets, while at the face the Modern brackets showed a significant difference. There was no significant difference in mesial and distal slot sizes in the 3M Unitek series or in the Ortho Organisers series, either at the base or at the face. Overall, all brackets presented divergent slots from base to face.

Based on Joch et al. (2010), Ormco brackets produced measurements closest to the maximum permissible mark allowed by DIN 13971–2, which is 0.023" (upper limit/maximum tolerance = 0.023" and lower limit/nominal size = 0.022"). The GAC series showed a significantly smaller deviation from nominal dimensions than other bracket series. Daga et al. (2017) reported no significant difference in mean bracket slot height at the entry, but a significant difference at the base of the slot ($P < 0.001$). The American Orthodontics series had slot dimensions much closer to standardised/prescribed values. All bracket series were divergent from base to face/entry of the bracket slot except for Orthox Organizers, which appeared to be more parallel.

Bernés Martínez et al. (2021a) stated that the nominal slot height declared by manufacturers is

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Table 3. Mean slot height values (inch) of central incisor brackets (MBT 0.022” slot).

MANUF.	AWASTHI (2015)	TANGRI (2012)	JOCH (2010)	DAGA (2017)	BERNES MARTINEZ (2021A)	MATHIEW (2020)
3M Unitek	0.0259	Db-0.0226+/-0.0002 Df-0.0232+/-0.0002 Mb-0.0226+/-0.0001 Mf-0.0232+/-0.0002	N/A	SHE=0.0240+/-0.0009 SHB=0.0228+/-0.0005	0.0220+/-0.0003	0.0224+/-0.00028
AO	0.0224	N/A	N/A	SHE=0.0236+/-0.0007 SHB=0.0216+/-0.0006	0.0215+/-0.0001	0.0223+/-0.00029
Ormco	N/A	N/A	0.0235+/-0.00003	N/A	0.0218+/-0.0001	N/A
Dentsply GAC	N/A	-	0.0230+/-0.00003	N/A	0.0220+/-0.0007	N/A
Dentaurum	N/A	Db-0.0219+/-0.0002 Df-0.0230+/-0.0003 Mb-0.0222+/-0.0003 Mf-0.0233+/-0.0002	N/A	N/A	0.0224+/-0.0003	0.0226+/-0.00021
Ortho Organisers	N/A	Db-0.0224+/-0.0006 Df-0.0234+/-0.0006 Mb-0.0225+/-0.0003 Mf-0.0236+/-0.0005	0.0234+/-0.00003	SHE=0.0240+/-0.0002 SHB=0.0220+/-0.0005	N/A	N/A
Forestadent	N/A	N/A	N/A	SHE=0.0240+/-0.0007 SHB=0.0236+/-0.0009	0.0223+/-0.0001	N/A
Modern	N/A	Db-0.0210+/-0.0005 Df-0.0229+/-0.0005 Mb-0.0209+/-0.0004 Mf-0.0232+/-0.0006	N/A	SHE=0.0240+/-0.0011 SHB=0.0220+/-0.0009	0.0215+/-0.0003	N/A
Orthox Organisers	0.0236	N/A	N/A	SHE=0.0236+/-0.0009 SHB=0.0232+/-0.0009	N/A	0.0229+/-0.00035
Ideal	0.022	0.022	0.022	0.022	0.022	0.022

Note: Db = Distal base, Df = Distal face, Mb = Mesial base, Mf = Mesial face, SHE = Slot Height Entry, SHB = Slot Height Base, AO = American Orthodontics

0.022 inches. According to ISO 27020:2019, the industrial tolerance for slot height is ±0.0003", the acceptable range being between 0.0216" and 0.0224". All bracket series showed highly statistically significant differences ($P < 0.001$); Dentsply GAC had a P value less than 0.01, which was still significant. Mathiew et al. (2020) reported that the slot sizes of American Orthodontics brackets were closest to the nominal value; however, mean values for all other manufacturers were higher than the nominal value. When compared with ideal values, 3M Unitek and American Orthodontics showed no statistically significant difference. The mean slot size for Dentaurum showed a significant difference ($P < 0.05$) from the standard value, while the mean slot size for the Orthox Organizers series showed a highly significant difference ($P < 0.01$) from the standard value.

3.4. Unspecified bracket prescriptions

Studies that did not specify the bracket prescription used or the tooth bracket measured were selected based on the aforementioned criteria. Furthermore, studies with different prescriptions and tooth brackets other than central incisors were also included, as the bracket slot height value remains the same (0.022-inch slots) regardless of the bracket prescription or tooth bracket. Nine studies were used for this purpose, and each study measured the bracket slot height at two points: at the base and at the face (termed differently across studies) or at the mesial and distal aspects (right and left). Some studies provided only the mean slot height without specifying whether it was measured at the top or the base of the slot. Additionally, some studies measured values of two or more bracket system series from the same manufacturer. Where studies reported measurements in millimetres, values were converted to inches for comparison.

Table 4 shows the comparison of mean values of slot measurements (unspecified prescription and unspecified brackets) with 0.022-inch slots. It can be inferred that mean values of slot dimensions of different tooth brackets (unspecified) and prescriptions vary considerably, generally being oversized. The GAC series showed consistency in its measurements and was closest to the standard value. The table also indicates that the slots were mostly divergent; as the mesial and distal heights differed, it is clear that the slots are not parallel, reflecting unstandardised slot dimensions, which may lead to insufficient contact between the wire and the bracket.

Table 4. Mean slot measurement values in unspecified prescriptions with 0.022" slots.

MANUF.	LEFEBVRE [2019] (C.I; N=730)	ANCONA [2015] (N.S; N=40)	SILVER [2018] (N.S; N=N.S)	PAI [2011] (N.S; N=40)	BROWN [2015] (N.S; N=100)	KHAN (2018A) (CN; N=140)	MAJOR [2010] (C.I; N=30) [MP.]	RADHAKRISHNAN [2017] (CN; N=60)	KHAN (2018B) (L.I; N=140)
3M Unitek	N/A	N/A	0.0233+/-0.0004	SPPb =0.0219 +/-0.005 SPPt=0.0221 +/-0.006	0.0229+/-0.0003	N/A	N/A	RVD=0.0229+/-0.0005 LVD=0.0221+/-0.0003	N/A
G A C	BSW=0.0229+/-0.0004 FSW=0.0232+/-0.0003	Int=0.02264+/-0.00032 Ext=0.02295+/-0.00032	0.0230+/-0.0004	N/A	0.0224+/-0.0001	N/A	BD= 0.0222 +/-0.00035 TD=0.0229+/-0.00027	N/A	N/A
G C Orth.	BSW=0.0227+/-0.0006 FSW=0.0231+/-0.0004	N/A	0.0239+/-0.0007	N/A	N/A	N/A	N/A	N/A	N/A
Ormco	BSW=0.0209+/-0.0004 FSW=0.0223+/-0.0002	D3; Int=0.02332+/-0.00030 Ext=0.02333+/-0.00038 D3MX; Int=0.02305+/-0.00040 Ext=0.02337+/-0.00044	DQ; 0.0231+/-0.0006 SMB; 0.0225+/-0.0008 DC; 0.0227+/-0.0004	SPPb=0.0210+/-0.004 SPPt=0.0215 +/-0.004	0.0229+/-0.0003 (n=78)	N/A	DQ; BD=0.0225 +/-0.00074 TD=0.0224 +/-0.00086	N/A	N/A
Class One	N/A	N/A	N/A	N/A	N/A	M=0.0240+/-0.0005 D=0.0241+/-0.0003	N/A	N/A	M=0.0239+/-0.0002 D=0.024+/-0.000
DB Orth.	N/A	N/A	N/A	N/A	N/A	M=0.0233+/-0.0006 D=0.0234+/-0.0005	N/A	N/A	M=0.0235+/-0.0005 D=0.0234+/-0.0005
Masel	N/A	N/A	N/A	N/A	N/A	M=0.0234+/-0.0012 D=0.0258+/-0.0015	N/A	N/A	M=0.0236+/-0.0009 D=0.0237+/-0.0008
Aria	N/A	N/A	N/A	N/A	N/A	M=0.0238+/-0.0007 D=0.0248+/-0.0013	N/A	N/A	M=0.0233+/-0.0008 D=0.0233+/-0.0008
Precise	N/A	N/A	N/A	N/A	N/A	M=0.0254+/-0.0017 D=0.0255+/-0.0017	N/A	N/A	M=0.0261+/-0.0016 D=0.0261+/-0.0016
Sia	N/A	N/A	N/A	N/A	N/A	M=0.0236+/-0.0012 D=0.0243+/-0.0018	N/A	N/A	M=0.0237+/-0.0010 D=0.0237+/-0.0009
Lancer	N/A	N/A	N/A	N/A	N/A	M=0.0238+/-0.0004 D=0.0238+/-0.0004	N/A	N/A	M=0.0238+/-0.0004 D=0.0238+/-0.0006

Note: C. I = Central Incisor, L. I = Lateral Incisor, Cn = Canine, N.S = Not Specified, N = Number of brackets, D3 = Damon 3, D3MX = Damon 3MX, DQ = Damon Q, DC=Damon Clear, SMB=Spirit MB, Int = Internal, Ext = External, M = Mesial, D=Distal ,BSW = Base Slot width/height,FSW = Face Slot width/height, SPPb = Starrette profile projector base, SPPt = Starrette profile projector top, RVD = Right Vertical Dimension, LVD = Left Vertical Dimension, DSR = Depth of the Slot Right, DSL = Depth of the Slot Left, BD = Bottom Distance, TD = Top Distance, M.P = Mesial Profile

Lefebvre et al. (2019) found that the base of the slot, measured at 78% distal to 79% mesial value, was noticeably wider. At the face, none of the bracket slots were narrower than predicted, whilst 97% were much wider. Significant divergence was observed from 84% distal to 85% mesial value. The mesial side measurement revealed no convergence in any conventional bracket. According to Lugo Ancona et al. (2015), the wall shape found in Ormco (Damon) brackets was parallel, whereas the GAC series were divergent. There were statistically significant differences in terms of internal and external dimensions of the slot between the two bracket series ($P < 0.05$). It appears that bracket slots were slightly divergent.

According to Silver et al. (2018), all of the bracket series measured had mean slot dimensions larger than the manufacturer's stated dimensions. 3M Unitek and GC Orthodontics had a slot size statistically 0.001 inches higher than their reported values ($p < 0.05$). Ormco Spirit MB had the highest standard deviation. According to Pai et al. (2011), the slot size of 3M Unitek brackets was greater than the standard. The Z value was greater than 2.58, indicating that the inaccuracy is statistically highly significant. The slot size for Ormco brackets was less than the standard

($Z > 2.58$, significant). The bracket measurements showed that they were parallel to divergent.

According to Brown et al. (2015), the GAC series were oversized but had the smallest standard deviation of any bracket in the sample. Khan et al. (2018a) reported that orthodontic brackets showed the most uniformity in mesial and distal slot height. DB orthodontic brackets reported the least tolerance in both mesial and distal slots; however, their tolerances were above acceptable limits of 0.001 inches or 4.5%. Precise, DB Orthodontics, Lancer, and Class One bracket series appeared to be parallel, whereas Masel, Aria, and Sia were not. Major et al. (2010) claimed that the GAC series slot size is 2.6 standard deviations larger at the top of the slot than at the bottom, meaning that over 99.5% of GAC series brackets are oversized as measured at the top. Whilst the Ormco series was marginally convergent, the GAC series was slightly divergent.

When the slot dimensions of the received brackets were analysed, it was discovered that the mean values of the right and left vertical dimensions showed no statistically significant difference, with a standard deviation of ± 0.0005 on the right compared to ± 0.0003 on the left. However, the right and left vertical dimensions were not identical, indicating that the slots are not parallel (Radhakrishnan et al., 2017). According to Khan et al. (2018a), the mean bracket slot height ranged from $0.0233'' \pm 0.0008''$ to $0.0261'' \pm 0.0016''$. The maximum range of 0.005 inches was exhibited by Precise brackets, whilst the minimum range was exhibited by Class One brackets. Additionally, the maximum slot height of 0.028 inches was reported in Precise brackets. A general uniformity in slot height was observed in both the mesial and distal slots. However, it was noted that all bracket series were oversized, with the Precise bracket series being significantly larger ($M = 0.0261$, $D = 0.0261$).

4. Discussion

This review evaluated and compared the efficacy of tip and torque incorporated into metal brackets with the MBT prescription by measuring the slot size and prescription specifications of 0.022” brackets. Twenty manufacturers were included in the study.

The pre-adjusted appliance system represented a major development in fixed appliance mechanics, and its most important feature is the torque incorporated into the brackets. Torque expression depends on many factors such as torsion magnitude, wire stiffness, wire composition, wire dimension, slot dimension, tooth inclination, interbracket width, and tooth inclination (Awasthi et al., 2015). It was noted that manufacturers differed in their bracket slot dimensions across studies. There was a wide range of standard deviations from the mean values, which could indicate that some measured bracket slot dimensions were far from the standard values. Bracket slots are designed to engage the archwire to create a connection and provide effective tooth movement. Manufacturers usually produce oversized bracket slots and undersized wires, but unfortunately these tolerance values are not provided to end users (Kancab Díaz et al., 2014; Meling et al., 1997). As advocated by Siatkowski (1999), orthodontists should keep leaf gauges in their clinics to measure bracket slot tolerance if torque expression does not occur as planned. These gauges are inexpensive and can easily be used to measure bracket slots even when they are bonded. Any additional play identified can be compensated for by manual torque application in specific brackets.

4.1. Tip

Regardless of the measurement method used, the most common tip values obtained were 4.17 degrees (American Orthodontics, Alavi & Tajmirriahi, 2016, Forestadent, Daga et al., 2017) and 4.22 degrees (Modern series and Ortho Organizers, Daga et al., 2017). Given that the ideal MBT tip value is 4 degrees, the most common values deviated from the ideal by 0.17 degrees and 0.22 degrees, respectively. The minimum and maximum tip values were 1.67 degrees (Orthox Organizers, Awasthi et al., 2015) and 6 degrees (American Orthodontics, Awasthi et al., 2015), respectively. A manufacturing error might explain the large variation in tip values of pre-adjusted orthodontic brackets. Two factors affect bracket tip, first the long axis, depicted by a vertical slot, and second a line connecting the lower border of the upper wings or the upper border of the lower wings. The built-in tip of the bracket is determined by the minor angulation of its wings relative to its long axis. This may be due to production processes including injection moulding, grinding, and machining methods (Awasthi et al., 2015). Insufficient studies were available for evaluating the tip values of different manufacturers. The studies selected for tip evaluation did not include enough common manufacturers for proper comparison. The most common manufacturers' tip values analysed were those of American Orthodontics and 3M Unitek.

4.2. Torque

The positioning and size of brackets, the distance between the bracket wire and bracket slot, tooth size, the morphology of the facial and root surfaces of the tooth, and the application of force outside the centre of resistance all affect torque (Proffit et al., 2006). When a clinician inserts a 0.028" wire into brackets with 0.022" slots, full torque expression as specified in the selected bracket series would be expected. However, the results of this systematic study did not support that expectation. Given that the ideal torque value for the MBT prescription is 17 degrees, most of the brackets analysed were below this value. The most common torque value obtained was 17.06 degrees, 12 brackets were below 17 degrees, and nine were above. Furthermore, the minimum and maximum recorded torque values were 7.67 degrees (Orthox Organizers, Awasthi et al., 2015) and 17.81 degrees (American Orthodontics, Bernés Martínez et al., 2021a), respectively. It should be highlighted that torque values were 9.33 degrees lower than the declared values (Supriadi et al., 2015).

Incisor torque values are regarded as crucial for achieving treatment goals. According to different treatment philosophies, torque ranges from 7 degrees in the original straight-wire appliance to 22 degrees in the bioprogressive prescription have been proposed (Archambault et al., 2010).

4.3. Slot dimension

Proffit stated that the internal bracket slot dimension should be accurate to within 0.001". This gives a bracket slot size range of 0.021" to 0.023" (Proffit et al., 2006). The acceptable variation specified by Deutsches Institut für Normung (DIN 13971-2) is 0.00157" from the nominal value. The lower limit corresponds to 0.022", and the upper limit corresponds to the maximum tolerance of 0.023" given by DIN 13971-2 (Deutsches Institut für Normierungen E.V., 2000). Although the nominal slot height declared by manufacturers is 0.022", according to ISO 27020:2019 the industrial tolerance for slot height is $\pm$ 0.0003", giving an acceptable range from 0.0216" to 0.0224". The vast majority of analysed bracket slot heights complied with the norms described by these criteria, as the accepted range is wide, that is 0.0216" according to ISO 27020:2019 to 0.023" according to Proffit and DIN 13971-2.

4.3.1. Slot Parallelism / Slot Convergence / Slot Divergence

The slot height was measured at two different points to determine bracket slot geometry. To avoid bias caused by the roundness of the slot angles, the internal height, that is the height at the base, was estimated 100 microns from the deepest point of the slot, and the external height, that is the height at the face, was estimated 100 microns from the outer border of the slot. Most studies used the shorter border as a reference when the upper and lower borders differed in length (Lefebvre et al., 2019).

Slot geometry was established by comparing the external and internal heights. If the difference was zero, the walls were considered parallel. If positive, they were considered divergent. If negative, they were considered convergent. Eight studies did not mention whether their reference points were external or internal (Awasthi et al., 2015, Joch et al., 2010, Bernés Martínez et al., 2021a, Mathew et al., 2020, Silver et al., 2018, Brown et al., 2015, Khan et al., 2018a). Therefore, it was difficult to determine slot geometry in these studies, and this may also have introduced bias, as slot parallelism is a critical contributor to vertical slot accuracy and precision. Since dimensional reproducibility varies greatly among bracket series, practitioners cannot rely on repeatability of treatment results. Measurements often tended towards slot wall divergence and slot wall expansion. These findings were consistent with those of Tangri et al. (2012), Brown et al. (2015), and Lefebvre et al. (2019). In the study by Cash et al. (2004), six different companies were included. They drew attention to the fact that every bracket slot was oversized by between 5% and 24%. It was also noted that some slots were divergent and some were convergent. Most observations in this evaluation showed that the walls appeared to deviate from the internal aspect towards the slot mouth, which may have been intentional to prevent undercuts in injection moulding moulds. The angular relationship of the slot walls has not been quantified in any published study to date.

From **Table 3**, bracket slots measured at the base were within the upper and lower tolerance limits, based on Proffit, DIN 13971-2, and ISO 27020:2019, that is between 0.0216” and 0.023”, except for Forestadent in one study (Daga et al., 2017). In addition, bracket slots were greater at the face than at the base, sometimes beyond the upper limit. From **Table 4**, bracket slots measured at the base were within the upper and lower tolerance limits, except for Ormco, whose base slot height was below the lower limit in one study (Lefebvre et al., 2019), although the height at the face remained within the upper limits.

4.3.2. Oversized / Undersized

Based on MBT prescription slots, the smallest 0.022” slot measured 0.0209”, almost 0.0011” too small (Tangri et al., 2012). The largest 0.022” slot measured 0.0259” and was almost 0.0039” oversized (Awasthi et al., 2015). Based on unspecified prescription slots, the smallest 0.022” slot measured 0.0209”, almost 0.0011” too small (Lefebvre et al., 2019), and the largest 0.022” slot measured 0.0261”, which was almost 0.0041” larger (Khan et al., 2018a). American manufacturers use the imperial system when standardising their brackets (Siatkowski, 1999). It was reported that European manufacturers use metric tools, and therefore their target value was 0.6 mm (0.0236”) for a 0.022” slot. Consequently, brackets from European manufacturers are oversized (Kusy & Whitley, 1999), which is consistent with these findings. According to Khan et al. (2018a), mesial slots show less tolerance than distal slots, with the exception of Lancer brackets. The maximum difference between mesial and distal height was noted in Masel, at 0.0024” (Khan et al., 2018a). Apart from the effect on torque loss, this tolerance loss will lead to poor rotational control of any tooth during retraction (Siatkowski, 1999). **Tables 3** and **4** show that the slot height of 59.01% of all analysed brackets was oversized according to the Proffit and DIN 13971-2 criteria, whereas 9.83% were undersized according to ISO 27020:2019 criteria. One study showed that the Modern series brackets had an undersized slot height at the base and an oversized slot height at the face (Tangri et al., 2012). In the European system, 0.022" slots are by default oversized up to 0.0236", which would imply that Db Orthodontics, (M=0.0233±0.0006, D=0.0234±0.0005), (M=0.0235±0.0005, D=0.0234±0.0005), and Aria (M=0.0233±0.0008, D=0.0233±0.0008) were made undersized by the manufacturer to maintain international standards (Khan et al., 2018a).

Results similar to those of this study were also reported by Cash et al. (2004). In 11 commercially available bracket systems, the slots of five upper left central incisor brackets with 0.022-inch dimensions were measured. Their findings also showed that every bracket slot was too wide in height.

Siatkowski (1999) illustrated how protraction of the buccal segments during space closure with the pre-adjusted edgewise appliance might result in unexpected torque loss in the maxillary and mandibular incisors, demonstrating the consequences of large brackets on anterior torque loss. These anterior teeth could lose 5 to 10 degrees of torque, which is equivalent to 1. During space-closing protraction, the incisal borders of the tongue protruded by 9 mm.

4.3.3. Bracket Symmetry

Based on **Table 4**, 26.66% of bracket slots were asymmetrical when slot height was measured on the mesial and distal sides. Three studies, Khan et al. (2018a) and Radhakrishnan et al. (2017), measured mesial and distal bracket slot heights and showed that they were not identical, and therefore were asymmetric, for example Masel, Aria, Sia, and 3M Unitek. Particularly for brackets with a significant mesiodistal width, such a mismatch between the mesial and distal sides would result in inadequate control of tooth tipping (Khan et al., 2018a).

It is possible that a bracket could have an irregularity at the same location on each bracket, which may or may not coincide with one or both investigated points, that is the upper and lower reference points, during measurement of slot height. This could make the slot appear divergent or asymmetric even though this might not be the case if the reference points were positioned slightly differently (Major et al., 2010).

One study stated that it evaluated the mesial profile (Major et al., 2010), but different results might have been obtained for the distal profile, as none of the other studies specified the exact profile and instead referred to the lateral profile, which was assumed to be mesial based on the pictorial depictions (**Figure 3**). These results support the view that manufacturers must improve adherence to dimensional restrictions. Practitioners must be aware that adjustments may be required during the final stages of treatment and that they cannot rely fully on the accuracy of the appliances currently available on the market.

4.3.4. Methods of measurement of slot dimensions

Most studies used a stereomicroscope at different magnifications to enlarge and capture a two-dimensional image and to calibrate it within software for data analysis (Awasthi et al., 2015, Tangri et al., 2012, Radhakrishnan et al., 2017, Bernés Martínez et al., 2021a, Lefebvre et al., 2019, Silver et al., 2018, Major et al., 2010, Brown et al., 2015, Lugo Ancona et al., 2015, Pai et al., 2011). A few studies used projectors, claiming an accuracy of 0.001 mm (Pai et al., 2011). Some used digital readouts with leaf gauges, as mentioned in **Figure 3**. As there are no standardised protocols for data collection, comparisons are difficult because of blurring effects at the margins under magnification, and manual methods depend on individual perception, although inter-operator and intra-operator reliability were tested. A few studies repeated measurements at least twice to verify the results, yet

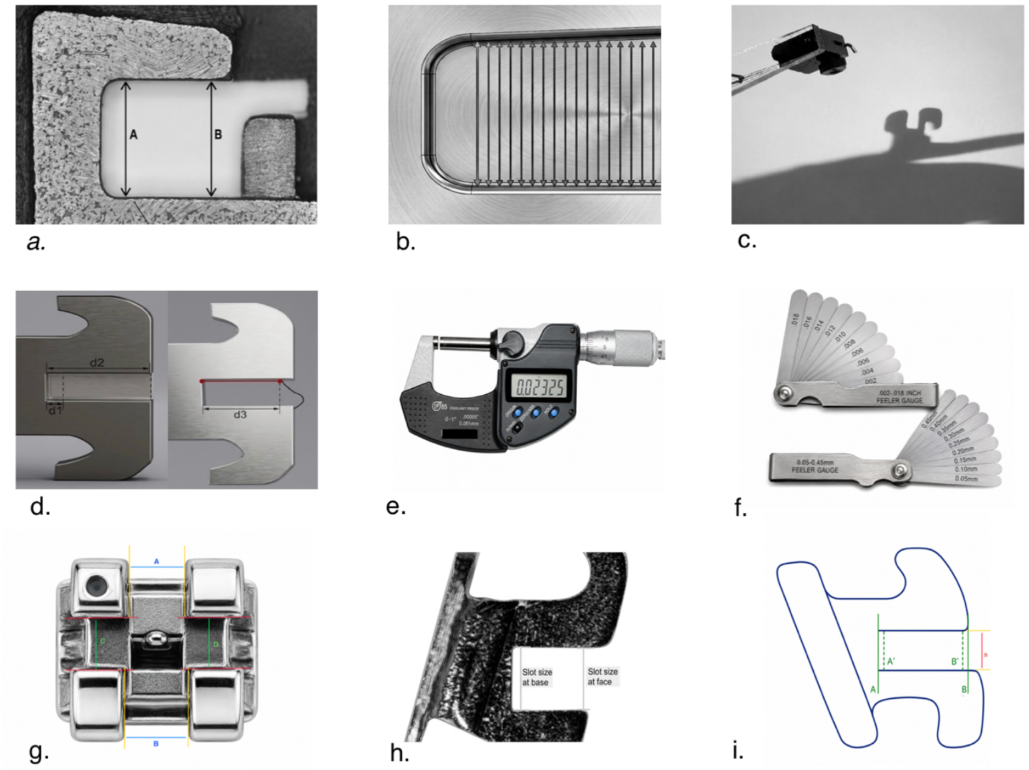

Figure 3. Measurement protocols for orthodontic bracket slot dimensions. (a) Internal measurement near the bracket base, external measurement near the bracket face (Lugo Ancona et al., 2015). (b) The microscope is autofocused on the slot walls. A reference line is automatically detected on one wall of the slot, and 40 measurement points are identified on the opposite wall. The mean distance between the line and these 40 points is calculated and recorded (Silver et al., 2018). (c) The image of the bracket appears on a projector screen. The measuring table is adjusted such that one of the walls of the slot coincides with the y-axis. The distance between the two walls can be read on a digital screen (Pai et al., 2011). (d) Conventional brackets: d1, distance between the slot base and the base measurement, 100 micrometres from the slot base, d2, distance between the slot base and the face measurement, 610 micrometres. Self-ligating brackets: d3, slot length measurement, as far as possible from the base (Lefebvre et al., 2019). (e) and (f) Mesial slot height and distal slot height were measured using leaf gauges. After measuring each slot, the combined thickness of the leaf gauges was measured with a micrometer, "Mitutoyo digimatic micrometer", having an accuracy of 0.00005" to obtain a digital readout (Khan et al., 2018a; Khan et al., 2018b). (g) A, internal tie-wing width, cervical, B, internal tie-wing width, occlusal, C, right vertical dimension, D, left vertical dimension (Radhakrishnan et al., 2017). (h) Mesiobuccal, mesiofacial, distobuccal, and distofacial dimensions were calibrated, but the exact measuring points were not specified (Tangri et al., 2012). (i) h is the maximum occlusogingival dimension of the hypothetical rectangle that completely fills the bracket slot. A, line tangent to the slot bottom, B, line parallel to line A and tangent to the outermost part of the slot. A', internal bracket slot height parallel to line A at a distance of 100 micrometres, B', external bracket slot height parallel to line B at a distance of 100 micrometres (Bernés Martínez et al., 2021a).

it cannot be confirmed whether measurement protocols are related to the results obtained, as this issue has not been discussed extensively in the selected literature.

4.4. Manufacturing defects

A possible reason for the wide range in torque values of pre-adjusted orthodontic brackets could be manufacturing error in the alignment of the slot base and bracket base (Awasthi et al., 2015). Another reason could be the type of manufacturing process, that is injection moulding, casting, or milling (Awasthi et al., 2015). Milling can produce a rough-grained surface, whereas moulding exposes the material to expansion or shrinkage (Awasthi et al., 2015). When sufficient feed material is not available to compensate for shrinkage during solidification of thick metal, shrinkage defects can arise during casting (Awasthi et al., 2015).

If injection moulding and casting are not carried out under sufficient compression, internal gaseous porosity may occur, weakening the metal microstructure and increasing susceptibility to deformation. Milling may also introduce imperfections and a rough-grained surface, whereas moulding exposes the material to expansion and contraction. When adequate feed material is unavailable to compensate for shrinkage as thick metal solidifies, shrinkage defects arise in casting (Awasthi et al., 2015). Injection moulding tends to produce more rounded corners than precision grinding and machining techniques (Kalpakjian & Schmid, 2001).

Anterior torque loss may occur when bracket deformation exists because of the material from which the bracket was manufactured and the manufacturing process itself. Torque loss may also occur when small rectangular wires are used or when the internal angles of the bracket slot are rounded, which prevents intimate contact between the archwire and slot angles (Siatkowski, 1999).

4.5. Clinical relevance

In an orthodontic setting where the aim is to achieve optimal final aesthetic, functional, and occlusal results, it is disappointing to find tolerance in orthodontic brackets beyond acceptable limits. Clinically, increased wire-slot play and loss of torque control are caused by larger slots and diverging slot walls. Practitioners should be aware that adjustments, such as corrective bends, may be required during the final stages of treatment because they cannot completely trust the position of the equipment used. Manufacturers must reduce tolerance in their brackets, and orthodontists should keep leaf gauges in their clinics to check bracket tolerance at random.

Depending on the orthodontic mechanism used, oversized brackets cause either torque loss or less than ideal torque expression. Tip and torque values depend on the interaction between the archwire and the slot, which in turn depends on geometry and size. Therefore, in addition to bracket geometry and dimensions, tip and torque values also depend on wire dimensions.

However, as the values reported for each prescription are mean favourable values identified by researchers, the ideal levels for each patient may vary. The ideal range of these values differs from patient to patient depending on facial features and tooth morphology. It is crucial that independent researchers conduct studies to evaluate the quality of products from different companies before they are marketed, in order to confirm dimensional accuracy and the acceptable range of manufacturing error for the relevant population. Careful bracket selection and positioning may help the treatment process.

5. Conclusion

This literature review showed that the majority of measured brackets displayed inaccurate slot dimensions when compared with the stated values. It demonstrated that most bracket slots were oversized, divergent, and not parallel.

In the present study, the most common tip values obtained were 4.17 and 4.22 degrees. The minimum and maximum tip values were 1.67 degrees and 6 degrees, respectively. The most common torque value recorded was 17.06 degrees, with minimum and maximum values of 7.67 degrees and 17.81 degrees, respectively.

The question is whether a maxillary central incisor bracket with a 6 degree tip is reasonable for the MBT prescription, since it is close to the values reported for the Roth and Andrews systems, both 5 degrees. Scientists have conducted experiments and established these unique prescription values for individual teeth, therefore their stated values should be respected when a particular treatment philosophy has been selected, because altering the tip and torque values from the stated values changes the appearance of the entire dentition. The same applies to slot dimensions.

If manufacturers do not fabricate precise slot dimensions, this leads to excess wire play, which means that the wire slides across the bracket and prevents the intended tooth movement. Therefore, in answer to the research questions, there are significant differences in the tip and torque values reported in the studies, and the slot height is not the same throughout the bracket slots.

It is essential that international measurement protocols should be established to define an acceptable level of manufacturing error, and that pre-market quality assessment of brackets should be undertaken. In order to assess the dimensional accuracy reported in studies, a common and repeatable technique is needed.

The ideal bracket for a patient's treatment can be selected with the greatest possible accuracy by the orthodontist once adequate understanding of the industry's leading suppliers has been gained. The orthodontist can also keep leaf gauges in the clinic to measure slot height chairside and make the necessary correction bends in the archwire to provide the best treatment outcome for the patient.

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