Interproximal reduction in the refinement phase of Invisalign treatment: A quantitative analysis

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Introduction: Interproximal reduction (IPR) is a common adjunct to contemporary orthodontic treatment. This study aimed to carry out a quantitative analysis of IPR prescribed in the refinement phases of clear aligner therapy with the Invisalign appliance (Align Technology, San Jose, Calif). **Methods:** The digital treatment plans (DTPs) of a total of 330 patients treated by 11 orthodontists were evaluated. Relevant data regarding patient age, gender, and prescription of IPR in the initial and refined DTPs were obtained from Align Technology's digital interface, ClinCheck. Computational analyses included descriptive statistics, Mann-Whitney U, and Kruskal-Wallis tests. **Results:** Most (n = 182; 75.2%) of the 242 patients who satisfied inclusion criteria were females. The median (interquartile range [IQR]) age was 29.2 (22.1-40.2) years. More than 60% of the contact sites prescribed IPR related to the initial DTP (n = 1312; 60.4%), with 39.6% (n = 859) recorded in the refinement DTPs. A median (IQR) of 1.1 (0.6-2.1) mm of IPR was prescribed per patient in the initial DTP compared with a median (IQR) of 0.6 (0.3-1.3) mm in the refinement DTPs. The most common site for prescribed IPR in all DTPs was the mandibular anterior region. Almost half (n = 108; 44.6%) of the patients were prescribed IPR at the same contact point site more than once during treatment. **Conclusions:** Almost 40% of the contact points that were prescribed IPR were in the patients' refinement DTPs. Most IPR was prescribed for the anterior region of the mandible. Almost half of the patients had IPR repeatedly prescribed at the same sites during treatment. (Am J Orthod Dentofacial Orthop 2024;■:■-■)

Clear aligner therapy (CAT) has become an integral part of contemporary orthodontics, and its use has increased over the last 2 decades.[1,2] This is partly credited to a greater proportion of adult patients seeking orthodontic treatment and demanding more comfortable and esthetic alternatives to fixed appliances.[2,3] The popularity of CAT can also be attributed to the rise of digital dentistry, in which the increased use of extraoral and intraoral scanners has influenced the ease and efficiency by which patient data can be acquired and evaluated by the clinician.[4]

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The Invisalign appliance (Align Technology, San Jose, Calif) appears to be one of the most commonly prescribed CAT appliances globally.[5-8] Align Technology's proprietary software (ClinCheck Pro) is used by the clinician to formulate a digital treatment plan (DTP), which enables the manufacture of a series of aligners intended to address specific treatment objectives.[9]

ClinCheck Pro provides numerical data related to various dental, intraarch, and interarch characteristics, such as mesiodistal tooth widths. After treatment with the initial series of aligners, ≥1 additional or refinement phase may be needed. This involves the manufacture of ≥1 additional series of aligners from ≥1 new DTP to obtain the desired treatment outcomes. Several studies have shown that ≥1 refinement phases are routinely required during Invisalign CAT.[9-11]

Interproximal reduction (IPR) is an adjunctive technique commonly employed during CAT.[5,11,12] It involves the permanent removal of proximal enamel from the contact points between the teeth.[13] Purported reasons for its use include the need to gain space for the relief of crowding and tooth reshaping in addition to the management of open gingival embrasures and tooth size

discrepancies.[14-19] IPR has also been used as an adjunct to increase the stability of incisor alignment after orthodontic treatment.[20] Current evidence suggests that up to half of the enamel thickness may be removed without adverse side effects. This equates to approximately 0.3 mm for each single maxillary incisor interproximal contact point or surface, 0.2 mm for each single mandibular incisor interproximal contact point or surface, and 0.6 mm for a single contact surface of a posterior tooth.[21]

The ClinCheck Pro software can be used to identify relevant sites and time and quantify the amount of IPR required in the DTP.[11] The IPR recorded within the software is for each contact area and not for the individual teeth associated with each contact area. A 2022 study reported that IPR was prescribed in 71% of 500 patients in the initial DTP of Invisalign treatment.[14] Furthermore, respondents in a recent survey of orthodontists reported that they routinely prescribed IPR in a mean of 55% of their annual caseload in the initial accepted DTP and 31% of their annual caseload in the additional refinement plans.[5] However, the evidence also indicated that the quantity of IPR carried out is less than that prescribed in the initial DTP for treatment with the Invisalign appliance, with less than half of the planned amount of IPR being carried out.[14,16,17] This may be of clinical relevance, as shortfalls in this regard may have a deleterious impact on treatment efficacy and patient and clinician satisfaction.

To date, research regarding IPR in the refinement phases of CAT is limited. One recent prospective study evaluated the accuracy of IPR with the Invisalign appliance, but direct evaluation of the refinement phase was lacking.[18] This study aimed to quantitatively analyze the IPR prescribed in the refinement phases of CAT with the Invisalign appliance. A secondary aim was to compare the characteristics of IPR prescribed in the refinement phase with those in the initial phase.

MATERIAL AND METHODS

Institutional ethical approval was granted by the University of Adelaide Human Research Ethics Committee.

The study used data from the Australasian Aligner Research Database (AARD). As of October 2023, the AARD contained the relevant Invisalign treatment information related to approximately 17,000 patients treated by 17 orthodontists between 2013 and 2023. At the time of data acquisition, the database included patients from 11 orthodontists.

Before commencing their Invisalign treatment, all patients had provided consent for their records to be used for research purposes. The orthodontists are required to make the records of all patients treated with the Invisalign appliance available to AARD.

The last 30 consecutive patients treated to completion by each of the orthodontists with the appliance were selected. After selection, the patients were screened with reference to the selection criteria. The inclusion criteria entailed: (1) patients aged ≥18 years undergoing nonextraction, dual arch CAT with the Invisalign appliance; (2) patients who required ≥1 refinement phase; (3) the availability of ClinCheck Pro files after completing the initial phase, and the completion of the refinement phase; (4) IPR prescribed after the initial phase, to have been completed by the end of the refinement phase; (5) minimum 1-mm IPR in total per patient; and (6) minimum of 2 sites for IPR per patient.

Patients with missing teeth and IPR prescribed to the second and third molars only were excluded from the study.

The age, gender, and number of refinement phases of patients satisfying inclusion and exclusion criteria were recorded. The resultant patient files were opened with the ClinCheck Pro facility, and millimeter values for prescribed IPR between tooth contacts were recorded.

The prescribed IPR sites were recorded and grouped according to the following DTP categories: initial DTP (I), first refinement DTP (R1), second refinement DTP (R2), third refinement DTP (R3), fourth refinement DTP (R4), combined refinement DTPs (R1-4), and total (I + R1-4).

The categories were classified into the following subgroups: maxillary (anterior and posterior), mandibular (anterior and posterior), anterior (incisors and canines), posterior (premolars and first molars), maxillary anterior, maxillary posterior, mandibular anterior, and mandibular posterior.

The contact area between the first premolar and canine was classified as a posterior contact. Consequently, the anterior subgroup contained 5 contact points, and the posterior subgroup contained 6 contact points. All data were entered into a Microsoft Excel spreadsheet (Microsoft, Redmond, Wash).

Statistical analyses

Statistical analysis was conducted via SPSS software (version 29; IBM, Armonk, NY). The significance was set to $P < 0.05$. The Shapiro-Wilk test was performed to determine the normality of the distribution of the data. The test indicated that the results did not follow a normal distribution. Frequencies were presented in medians and percentages. The Mann-Whitney U test and the Kruskal-Wallis H test were carried out to

Table I. Location of IPR sites according to DTP (n = 242)

		DTP					
Group	*Total*	*Initial*	*R1*	*R2*	*R3*	*R4*	*R1-4*
Mx + *Md*	2171 (100)	1312 (60.4)	600 (27.6)	223 (10.3)	32 (1.5)	4 (0.2)	859 (39.6)
Mx	728 (100)	408 (56.1)	214 (29.4)	96 (13.2)	10 (1.4)	0 (0.0)	320 (44.0)
Md	1443 (100)	904 (62.7)	386 (26.8)	127 (8.8)	22 (1.5)	4 (0.3)	539 (37.4)
Mx + *Md* anterior	1608 (100)	941 (58.5)	471 (29.3)	170 (10.6)	22 (1.4)	4 (0.3)	667 (41.5)
Mx + *Md* posterior	563 (100)	371 (65.9)	129 (22.9)	53 (9.4)	10 (1.8)	0 (0.0)	192 (34.1)
Mx anterior	527 (100)	284 (5.0)	170 (32.3)	68 (12.9)	5 (1.0)	0 (0.0)	243 (46.1)
Mx posterior	201 (100)	124 (61.7)	44 (21.9)	28 (13.9)	5 (2.5)	0 (0.0)	77 (38.3)
Md anterior	1081 (100)	657 (60.8)	301 (27.9)	102 (9.4)	17 (1.6)	4 (0.3)	424 (39.2)
Md posterior	362 (100)	247 (68.2)	85 (23.5)	25 (6.9)	5 (1.4)	0 (0.0)	115 (31.8)

Note. Values are presented as n (%).
Md, mandibular; *Mx*, maxillary.

determine whether the differences between the medians of groups and subgroups were significant.

RESULTS

A total of 242 (73.3%) patients were evaluated after the exclusion of 88 patients who did not satisfy the selection criteria. The sample comprised 182 (75.2%) females and 60 (24.8%) males. The median (interquartile range [IQR]) age for the overall sample was 29.2 (22.1-40.2) years, with no significant differences in the median ages of males and females ($P > 0.05$).

More than 60% of the contact sites prescribed IPR related to the initial DTP (n = 1312; 60.4%), with 39.6% (n = 859) recorded in the refinement DTPs.

Table I outlines the location of IPR sites according to the DTP in which the IPR was prescribed. IPR was prescribed for a total of 2171 contact point sites. The maximum number of refinement DTPs requiring IPR was 4. Overall, 15 patients required 4 refinement DTPs, and 22 patients required 3 refinement DTPs.

Table II shows that IPR was prescribed at a median (IQR) of 4 (2-7) sites in each patient in the initial DTP compared with a median (IQR) of 3 (1-5) sites per patient in the refinement DTPs.

Figure 1 illustrates the number of prescribed IPR sites, according to location, in the initial DTP. The site related to the contact points between the central incisor and lateral incisor (n = 111 and 27.2% in the maxilla; n = 278 and 30.8% in the mandible) was the individual site at which IPR was prescribed most frequently. Figure 2 shows that the contact point between the central and lateral incisor was the individual site at which IPR was prescribed most commonly in the refinement of DTPs in the maxilla (n = 97; 30.3%). The contact point between the central incisors was the individual site in which IPR was prescribed most commonly in the mandible (n = 97; 30.3%) in the refinement DTPs.

Table II. Number of sites prescribed per patient in the initial and refinement DTPs

DTP	*Median (IQR)*
Initial	
Maxillary	3 (1-5)
Mandibular	5 (3-7)
Maxillary + mandibular	4 (2-7)
Refinement	
Maxillary	2 (1-4)
Mandibular	4 (2-7)
Maxillary + mandibular	3 (1-5)

Note. Values are presented as median (IQR).

The most common site for IPR across all phases of treatment was the mandibular anterior zone, with a prescription rate of 50.1% (n = 657) from the initial DTP and 49.36% (n = 424) from the refinement DTPs. Most of the IPR prescribed in the refinement DTPs was related to the R1 (n = 600; 27.6%) and the R2 DTPs (n = 223; 10.3%). Figure 3 shows that minimal amounts were performed in the R3 (n = 32; 1.5%) and R4 DTPs (n = 4; 0.2%).

Table III shows that there was a median (IQR) of 1.1 (0.6-2.1) mm of IPR prescribed per patient in the initial DTP compared with a median (IQR) of 0.6 (0.3-1.3) mm in the refinement DTPs.

Table IV shows that a median of 0.3 mm of IPR was prescribed per contact point in the initial DTP. The Kruskal-Wallis test indicated that there was significantly more IPR prescribed per contact point in the initial DTP compared with each of the refinement DTPs ($P < 0.001$).

Almost half (n = 108; 44.6%) of the patients were prescribed IPR at the same contact point site more than once.

Figure 4 shows that IPR was prescribed in 3 DTPs between the central incisors in the maxilla 9 times, whereas

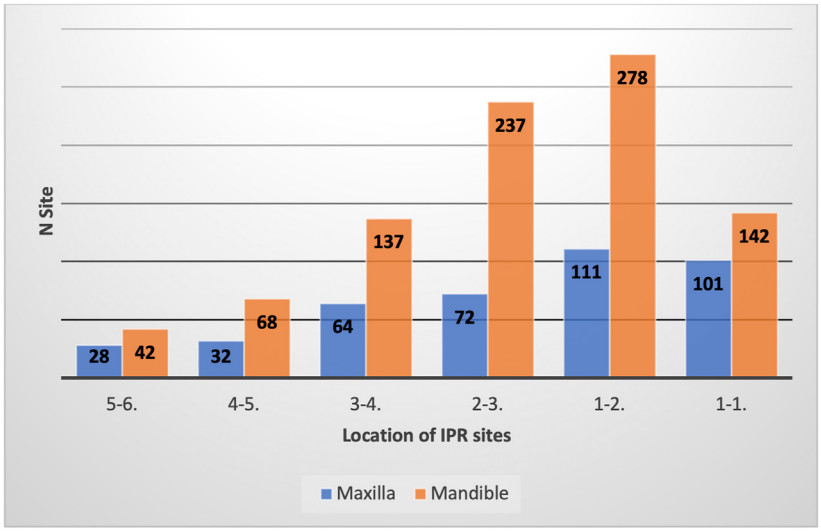

Fig 1. Number of prescribed IPR sites, according to location, in the initial DTP.

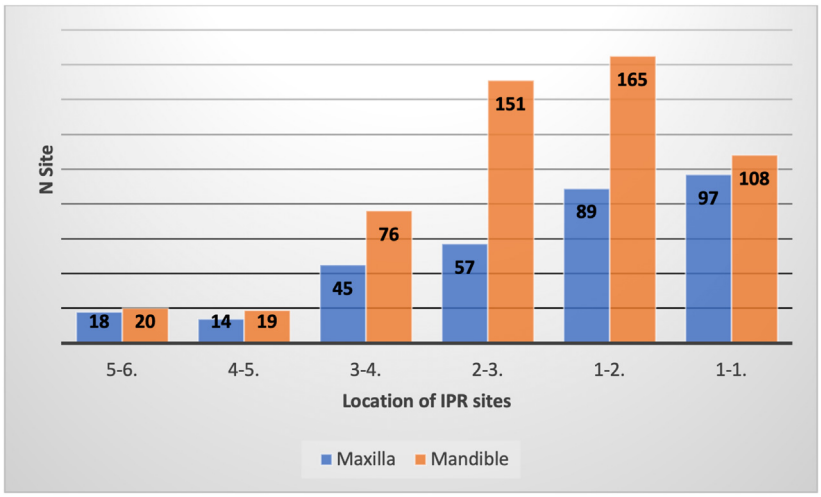

Fig 2. Number of prescribed IPR sites, according to location, in the refinement DTPs.

Figure 5 shows that 3 patients had IPR prescribed between the central incisors at the beginning of 4 accepted DTPs.

DISCUSSION

This study is the first to investigate IPR prescription in the refinement of DTPs of CAT with the Invisalign appliance. The findings indicated that almost 74% of the sample were prescribed IPR in the initial and refinement DTPs and that almost 40% of the sites prescribed IPR occurred in the refinement DTPs. In addition, the findings demonstrated that IPR was most frequently prescribed in the anterior region of the mandible in the initial and refinement DTPs and that almost half of the patients were prescribed IPR at the same contact site more than once.

The lack of research regarding IPR in the refinement phases of CAT limits direct comparison with other studies. Therefore, a large number of patients was chosen, as there was little relevant information to compute a number to power the investigation. However, analysis of our findings in relation to studies evaluating IPR in the initial phase of CAT is likely to provide valuable insight. The 300 patients initially evaluated in this study compared with 30-500 patients evaluated in similar

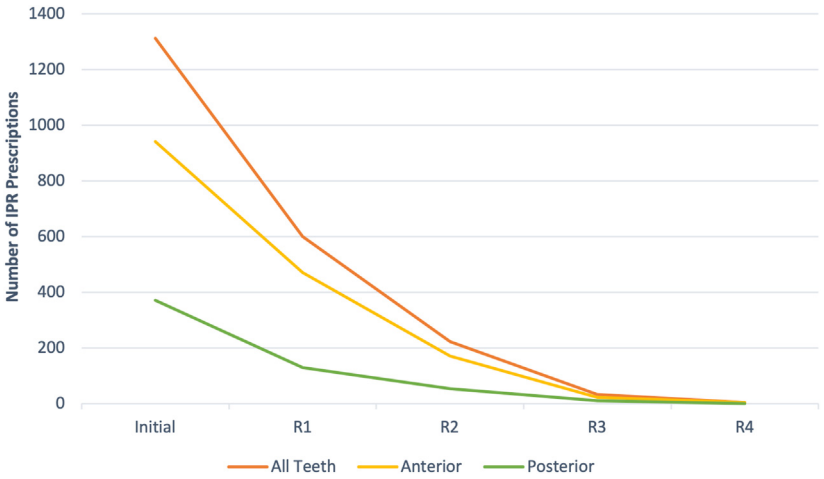

Fig 3. Frequency of IPR prescription according to DTP.

Table III. Prescribed IPR (mm) per patient in the initial and refinement DTPs

DTP	*Median (IQR)*
Initial	
Maxillary	0.8 (0.4-1.5)
Mandibular	1.5 (0.9-2.3)
Maxillary + mandibular	1.1 (0.6-2.1)
Refinement	
Maxillary	0.4 (0.3-1.0)
Mandibular	1.0 (0.4-1.6)
Maxillary + mandibular	0.6 (0.3-1.3)

Note. Values are presented as median (IQR).

Table IV. IPR (mm) prescribed per contact point according to DTP

DTP	*Median (IQR)*	*Maximum*	*Minimum*
Initial	0.3 (0.2-0.4)	0.1	1.1
R1	0.2 (0.2-0.3)	0.5	0.1
R2	0.2 (0.2-0.3)	0.5	0.1
R3	0.2 (0.2-0.4)	0.2	0.4
R4	0.2 (0.2-0.2)	0.2	0.2

investigations.[11,14,16-19] The median age of the patients was 29.2 years, which was similar to the 28.5-31.4 years recorded in corresponding studies.[9,11,18] In addition, this study investigated patients treated by 11 orthodontists, which compared with 1-10 in the other evaluations.[14,16,18,19]

More IPR was prescribed in the initial DTP than in the refinement DTPs. This was similar to the findings of a 2022 survey of orthodontists in which respondents reported that they prescribed IPR more frequently in the initial DTP compared with in the refinement DTPs.[5] In addition, virtually all of the prescribed IPR occurred by the third refinement DTP—the timepoint, according to a 2022 study, in CAT with the Invisalign appliance, at which no further improvement in treatment outcomes can be expected.[10]

IPR was prescribed at a median of 3 sites in the maxilla and mandible per patient in the refinement DTPs. This compared with a median of 4 sites in the initial DTP of the present study and 6.92 in the initial DTP reported in a study by Weir et al.[14] The median amount of prescribed IPR in the refinement DTPs of each patient was 0.6 mm, which was less than the median of 1.1 mm in the initial DTP of this study. It also compared with a mean of 0.28-2.16 mm of IPR prescribed in the initial DTPs in similar investigations.[14,17,19]

Prescribed IPR in the refinement DTPs was comparatively more common in the mandible than in the maxilla. This was similar to the findings related to the initial DTP of this study and other similar research.[14,16] Moreover, a greater amount of IPR was prescribed in the mandibular anterior zone, and this was in accordance with the findings from other investigations.[14,15,17] It also aligned with the findings from a survey of orthodontists in the Republic of Ireland, in which respondents reported that the lower labial segment was the area in which IPR was most commonly performed.[12] This might be due to the greater prevalence of tooth size discrepancies observed in the lower anterior region compared with in the corresponding teeth in the maxilla.[14,22] It might also have reflected the need to address the open gingival embrasures that may emerge as previously imbricated

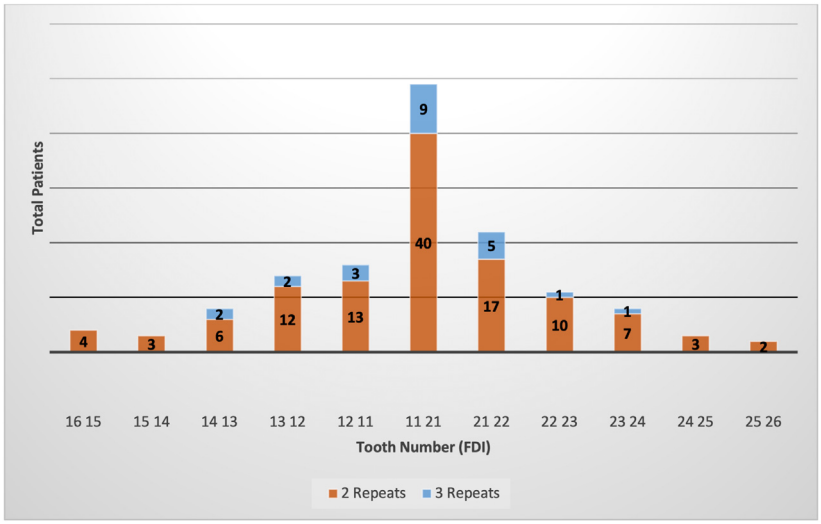

Fig 4. Distribution of frequency of repeated IPR prescriptions among patients in the maxilla.

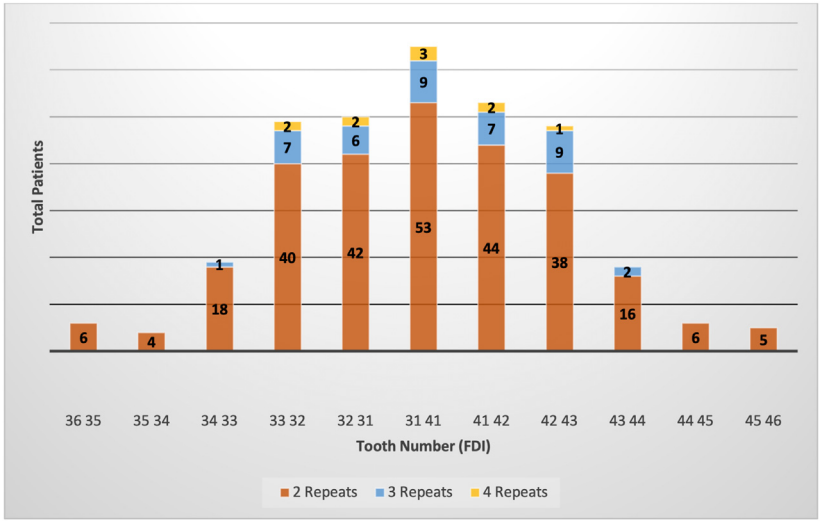

Fig 5. Distribution of frequency of repeated IPR prescriptions among patients in the mandible. *FDI*, Fédération Dentaire Internationale.

teeth gradually align during treatment. In addition, it might reflect an approach of waiting for greater alignment of the teeth before commencing IPR.[23]

Several studies have indicated that IPR routinely underperformed compared with that prescribed in the initial DTP.[14-18] This might have been a factor in this study. The amount of IPR performed by the clinicians might have been less than that prescribed by them in the initial DTP and in previous refinement DTPs. One of the purported reasons for the underperformance of IPR is the choice of instrument to carry out the procedure. Laganà et al[19] contended that it was the use of mechanical oscillation that enabled the amount of IPR performed to be matched by the actual amount carried out in their study. However, a 2013 in vitro study[24] indicated that mechanical oscillation was not superior. Recent surveys,[5,11,12] in any case, have suggested that mechanical oscillation is rarely used by orthodontists.

Further evidence that supports the hypothesis that underperformance of IPR prescribed in previous DTPs results in the requirement for further prescribed IPR is

apparent from the findings of this investigation. The procedure was prescribed more than once at the same site in almost half of the surveyed patients. If the cumulative amount of prescribed IPR was accurately performed in many of the patients in this study, it might have surpassed the suggested relatively small maximum amounts of IPR before the procedure results in irreversible iatrogenic harm.[23,25]

All retrospective investigations are at a high risk of selection bias. To minimize the risk in this study, the last 30 patients who had completed treatment by all orthodontists contributing to AARD were evaluated. In addition, it was not known what instrument was used by the treating clinician and the reason why IPR was prescribed. Furthermore, the prescribed amount of IPR was presented per contact point within the ClinCheck Pro interface. An assumption might be made that the IPR was equally divided between the 2 teeth adjoining the contact point. However, this cannot be concluded with certainty, as different methods for IPR can result in unequal pressures between the teeth, resulting in an unequal distribution of IPR. This might have contributed to the need for additional refinements, as the imbalance of IPR might predispose to the development of open gingival embrasures.

Future randomized and prospective research should include a detailed determination of whether the repeated prescribed IPR in this study is replicated more widely. Investigations should also aim to ascertain what factors influence orthodontists' decision-making processes regarding the use and timing of IPR.

The findings of this investigation are of clinical relevance. Although the quantities of prescribed enamel removal are often small, the treatment is not without risk. Careful consideration of the timing, quantity, and location of IPR is essential to optimize treatment efficacy and to ensure patient and clinician satisfaction with treatment outcomes. The findings provide valuable information to clinicians and patients regarding the use of IPR in CAT with the Invisalign appliance. In addition, this study contributed baseline information for further relevant investigations by researchers.

CONCLUSIONS

The present study was the first to quantitatively assess the IPR prescribed in the refinement phases of CAT with the Invisalign appliance. Almost 40% of the contact points that were prescribed IPR were in the patients' refinement DTPs. Most of the IPR was prescribed for the anterior region of the mandible. Almost half of the patients had IPR repeatedly prescribed at the same sites during treatment, with some having IPR prescribed at the site up to 4 times during treatment.

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AUTHOR CREDIT STATEMENT

Tarek Abasseri contributed to formal analysis, investigation, methodology, software, validation, visualization, original draft preparation, and manuscript review and editing; Tony Weir contributed to conceptualization, data acquisition, data curation, formal analysis, methodology, software, validation, visualization, original draft preparation, manuscript review and editing, and supervision; and Maurice J. Meade contributed to conceptualization, formal analysis, methodology, project administration, resources, software, validation, visualization, original draft preparation, manuscript review and editing, and supervision.

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