Original Article

Quantitative evaluation of implemented interproximal enamel reduction during aligner therapy: *A prospective observational study*

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ABSTRACT

Objectives: To investigate the correspondence between programmed interproximal reduction (p-IPR) and implemented interproximal reduction (i-IPR) in an everyday-practice scenario. The secondary objective was to estimate factors that might influence i-IPR to make the process more efficient.

Materials and Methods: Fifty patients treated with aligner therapy by six orthodontists were included in this prospective observational study. Impressions were taken at the beginning of treatment and after the first set of aligners. Data on p-IPR, i-IPR and technical aspects of IPR were gathered for 464 teeth. Statistical analyses included the Wilcoxon signed-rank test, Kruskal-Wallis, and multilevel mixed regression.

Results: Mean difference between p-IPR and i-IPR was 0.15 mm (SD: 0.14 mm; $P = .0001$), with lower canines showing the highest discrepancy. Use of burs and measuring gauges resulted in a smaller difference (respectively: coeff.: 0.09, $P = .029$; coeff.: –0.06, $P = .013$). IPR was performed more accurately on the mesial surface of teeth than on the distal surface. Round tripping before IPR resulted in a slightly more precise i-IPR compared to the previous alignment (coeff.: –0.021, $P =$ .041).

Conclusions: Implemented IPR tends to be less than p-IPR, especially for lower canines and distal surfaces of teeth. Burs tend to provide more precise i-IPR, especially compared to manual strips; however, there is variation between the techniques. Using a measuring gauge tends to increase the precision of i-iPR. As several factors influence the implementation of IPR, particular attention must be paid during the procedure to maximize its precision. (*Angle Orthod.* 2021;91:61–66.)

KEY WORDS: Interproximal reduction; Interproximal enamel reduction; Enamel reduction; Stripping; Aligners; Invisalign

INTRODUCTION

With the increased popularity of aligner therapy and its improving effectiveness in contemporary orthodontics,[1,2] interest in enamel interproximal reduction (IPR) has grown, as it is being considered as one of the major space-gaining orthodontic procedures. The cortical bone represents the limit for orthodontic tooth movement, which should be considered especially during treatment of crowding with proclination and expansion.[3] Interproximal reduction increases the amount of space available. It also offers an attractive alternative to dental extractions as the quantity of enamel removed can be calculated to match the amount of space required for the resolution of dental crowding. This methodology is also helpful for decreasing Bolton disharmonies in both the anterior region and full arch length.[4] Enamel reduction in the premolar and molar area can provide up to 9.8 mm of additional space for the realignment of mandibular teeth.[5,6] It can also be used to improve occlusal relationships and functionality by preserving the intercanine distance, while leaving the inclination of the incisors unaltered.

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IPR also reduces black triangles and increases the extension of the contact area, especially in triangular-shaped, periodontally compromised teeth whose interdental papilla level needs improvement. Therefore, IPR in adult patients seems to have a positive effect on interradicular bone volume, particularly in the presence of periodontal bone loss.[7,8]

Long-term studies on IPR have demonstrated that careful IPR in the anterior region (the most common area of IPR), using an appropriate technique and with excellent hygiene control, can be performed safely with no negative consequences on the teeth.[9–11] Interproximal reduction is considered a safe procedure on the dental pulp for teeth with average dentin thickness.[12] A variety of techniques and products can be used for IPR, including handheld abrasive strips, burs, and contra angle mounted discs.

In aligner therapy, the precision of IPR is a crucial part of the whole treatment and is one of the factors that ensures good sequential aligner fit and success of the final result. The correct implementation of the technique is therefore fundamental for precise tooth movement as determined by virtual planning. The programmed IPR (p-IPR) should correspond to what is actually implemented (i-IPR) to achieve the desired alignment with the correct interproximal contacts. p-IPR and i-IPR can be compared using the calculation features included in digital programming software (Bolton function).

The primary objective of this study was to investigate the correspondence between p-IPR and i-IPR performed by clinicians in an everyday-practice scenario. The secondary objective was to determine the potential factors that might influence the difference between p-IPR and i-IPR and, thus, provide guidelines for clinicians in order to make IPR more efficient and the results of therapy more predictable.

MATERIALS AND METHODS

Study Design and Treatment Protocol

This was a prospective cohort study including 50 consecutive patients treated with aligner orthodontic therapy (Invisalign, Align Technology, California, USA) by six orthodontic specialists. All patients had to be undergoing a Lite (one or both dental arches) or Comprehensive treatment including IPR in the anterior or posterior region.

Inclusion criteria were: absence of active periodontal pathology, nonextraction cases, compliance with IPR and aligner therapy, and no prosthetic or conservative restorations during orthodontic therapy. Impressions were taken at the beginning of the treatment and after the first set of aligners, corresponding to the refinement and to the end of the therapy, respectively.

Detailed information on the treatment and IPR was provided to the patients for each case. All patients signed an informed consent prior to starting treatment. All procedures in the study were followed in accordance with the ethical standards of the revised Helsinki Declaration for biomedical research involving human subjects.[13] The ethical committee of the University of Insubria (Varese, Italy) ruled the study as exempt since no experimental treatment was being implemented.

Sample Size

The sample size was calculated based on a patient level, considering an expected effect (difference) of 0.15 mm between p-IPR and i-IPR (mean result of all measured teeth for the same patient) as clinically significant with a standard deviation (SD) of 0.35 mm. The calculation was performed using the "*-power*" command for paired data on Stata 13 (StataCorp, College Station, TX, USA).

A two-tailed alpha of 0.05 and power of 0.8, accounting for 10% of potential dropouts suggested a sample size of 50 patients. As patients were treated by six different practitioners, each practitioner recruited between five and 10 patients.

Clinical Procedures

Six doctors contributed to this study with five to 10 patients each. In terms of experience with Invisalign cases, four doctors had moderate experience, and two had extensive experience. Of the four doctors with moderate experience, one used interproximal manual reduction strips (Horico one-sided metal strips, Henry Schein, Melville, NY, USA) or burs (IPR burs, Dentsply Sirona, Charlotte, NC, USA), one used only burs, and the other two used only contra angle mounted strips (Space File Interproximal reduction kit, Dentsply Sirona). Three of the doctors with moderate experience always used an IPR measuring gauge, whereas the fourth reported its use occasionally. Of the two doctors with extensive experience, one used only burs followed by an IPR measuring gauge, and the other doctor used interproximal manual reduction strips or burs with no gauge measurement.

Outcomes and Measurements

Patients' initial and final records were measured on digital models generated by the ClinCheck (Align Technology) after digital or manual impressions taken before the start of treatment (t0) and at the end of the first set of aligners/end of therapy (t1).

Measurement of the mesiodistal dimension of each tooth, from second premolar to second premolar, were performed using the Bolton table of the ClinCheck program at both t0 and t1. Data on t0 dimension (t0-d), t1 dimension (t1-d), and p-IPR were recorded for each tooth and entered into a predetermined database. With the assumption that IPR resulted by equal amounts reduced on both adjacent teeth (50% on the mesial tooth and 50% on the distal tooth), mesial and distal p-IPR was calculated. Expected/programmed tooth dimension (p-d) after IPR was calculated for all teeth considering mesial and distal p-IPR. Information on any IPR procedure variation related to macrodontic teeth (receiving more than 50% of IPR) or prosthetic restoration (receiving different ratio/not receiving IPR) was required and recorded from clinicians. Tooth expected/planned dimension (p-d) based on p-IPR and tooth real dimension (t1-d) after i-IPR were recorded and the difference between these two dimensions was the outcome reporting the real value of i-IPR. Difference between p-IPR and i-IPR was computed for each tooth where IPR was implemented. Data on technique of IPR, use of gauge for clinical measurement of IPR, type of tooth, and IPR timing (before alignment or after alignment) were recorded as well. The clinician's experience was assessed through a brief questionnaire (age, orthodontic specialization, certification year, total number of cases treated) and coded from 1 to 3 (1 = low experience, 2 = moderate experience, 3 = extensive experience).

Statistical Analysis

The normality of the data distribution was assessed through the Shapiro-Wilk test. Descriptive analyses were performed to report data on the patient cohort in terms of age, sex, and initial features of the occlusion. Likewise, descriptive data about the clinician (level of experience with Invisalign cases, impression technique), teeth (incisors, canine, or premolars), treated arch (maxillary and mandibular), technique adopted for the IPR (manual, burs, rotary discs), and clinical measurement of the performed IPR (with or without gauge) were reported. The descriptive statistical analyses included the computation of means, medians, and standard deviations (SD) for p-IPR, i-IPR, and their difference. The discrepancy between i-IPR and p-IPR was analyzed using the Wilcoxon signed-rank test. Kruskal-Wallis test was used to compare the three IPR techniques. The association between this discrepancy and factors such as IPR technique, use of IPR measuring gauge, level of doctor's experience, impression technique, and teeth subjected to IPR was investigated by means of multilevel multiple regression analysis; this was due to the clustered nature of the data, as each patient contributed to the analysis through multiple teeth. The repeatability of the ClinCheck Bolton function was estimated by comparing p-d to t1-d in all teeth not subjected to IPR through an intraclass correlation coefficient.

All the statistical tests were two-tailed, with .05 levels of significance. Statistical analyses were performed using the Stata 13 software by an independent clinician with expertise on clinical data statistical analysis.

RESULTS

Measurements were performed on 50 patients with a total of 1000 teeth (20 teeth per patient).

The mean age of patients was 31.42 years (SD: 10.47 years, ranging from 16 to 63) of which 14 were male and 36 were female. All patients were treated in both arches, 27 with the Lite package and 23 with the Comprehensive package. Five patients were in their teens and 45 were adults.

IPR was programmed to be performed in the maxillary arch in 43 patients, corresponding to 227 teeth (mean p-IPR: 0.25 mm, SD: 0.12 mm), and in the mandibular arch in 38 patients, corresponding to 237 teeth (mean p-IPR: 0.28 mm, SD: 0.12 mm). In 33 patients, IPR was performed in both maxillary and mandibular arches. In 24 cases (231 teeth), IPR was programmed before the resolution of crowding, and in 26 cases (233 teeth) after the alignment had been performed (round tripping).

Out of 50 patients, impressions were taken with digital scanning in 38 cases. The repeatability of the ClinCheck Bolton function was estimated by measuring the difference between t0-d and t1-d on 525 teeth not subjected to IPR. The mean difference was −0.057 mm (SD: 0.0167 mm) and median was −0.02 mm, ranging from −0.075 mm to 0.068 mm. The intraclass correlation coefficient was 0.983, indicating good repeatability of the measurement system. The calculation of the intraclass correlation coefficient separately for digital and analogue impressions resulted in similar values.

For all teeth where IPR was performed, the mean difference between p-IPR and i-IPR was 0.15 mm (SD: 0.14 mm), ranging from −0.43 mm to 0.5 mm. Table 1 shows values of p-IPR, i-IPR, and respective differences for different groups of teeth. The signed-ranked test indicated a significant discrepancy between p-IPR and i-IPR (P = .0001). In terms of IPR technique, manual reduction strips were used on 37 teeth, burs on 318, and contra angle mounted discs on 106 teeth. Descriptive data on values for p-IPR, i-IPR, and differences are reported in Table 2.

The three-level nested regression model (accounting for dentist, patient, and tooth) indicated that mandibular canines were more subject to an increased difference between p-IPR and i-IPR, especially compared to the upper canines, upper premolars, and lower premolars. Table 3 presents the results of the regression analysis.

Table 1 Values of p-IPR, i-IPR and Respective Difference for All Groups of Teeth[a]

Group of Teeth	Number of Teeth	p-IPR (Mean, SD)	i-IPR (Mean, SD)	Difference (Mean, SD)	Min and Max of Difference (mm)
Maxillary premolars	50	0.29 (0.14)	0.14 (0.19)	0.15 (0.21)	−0.40; 0.50
Maxillary canines	59	0.24 (0.11)	0.10 (0.13)	0.14 (0.12)	−0.15; 0.38
Maxillary incisors	118	0.24 (0.11)	0.10 (0.15)	0.14 (0.14)	−0.43; 0.43
Mandibular premolars	49	0.22 (0.08)	0.09 (0.11)	0.13 (0.11)	−0.07; 0.39
Mandibular canines	59	0.27 (0.13)	0.08 (0.10)	0.19 (0.13)	−0.09; 0.50
Mandibular incisors	129	0.31 (0.11)	0.14 (0.16)	0.16 (0.16)	−0.31; 0.50

[a] p-IPR indicates programmed interproximal reduction; i-IPR, implemented interproximal reduction; SD, standard deviation.

Overall, no relevant difference was observed between the upper and lower jaw (coeff.: 0.012, $P = .374$).

The Kruskal-Wallis test indicated a significant difference between the three IPR techniques ($P = .004$). Use of burs resulted in a smaller difference between p-iPR and i-IPR, especially compared to manual strips (regression analysis coeff.: 0.09, $P = .029$). On the other hand, use of the measuring gauge showed a smaller difference (regression analysis coeff.: −0.06, $P = .013$). The doctor's experience did not seem to influence the discrepancy (regression analysis coeff.: 0.05, $P = .06$). Similarly, the impression technique showed no association with discrepancy (regression analysis coeff.: 0.09, $P = .14$). Where IPR was performed on the distal surface of teeth, the difference between p-IPR and i-IPR increased by 0.09 mm ($P = .001$), whereas in teeth where IPR was performed mesially, the difference increased by 0.05 ($P = .048$). Round tripping before IPR resulted in a slightly more precise i-IPR compared to when IPR was done before alignment (coeff.: −0.021, $P = .041$). No significant predictor effect was observed for age (coeff.: −0.001, $P = .09$) or gender (coeff.: 0.05, $P = .13$).

DISCUSSION

The aim of the present study was to examine the precision of implemented IPR in providing a predetermined amount of enamel reduction in a clinical everyday scenario. Data gathered from 464 teeth subject to IPR indicated that the average amount of i-IPR was smaller than intended, although there was wide variation.

The findings were in agreement with other studies reporting a reduced amount of IPR achieved compared to the prescribed amount.[14,15] Mandibular canines exhibited the highest discrepancy between p-IPR and i-IPR with a significant tendency toward insufficient i-IPR. This was likely due to the frequently encountered position of the mandibular canines, since they are often tipped forward, distorotated and in tight interproximal contact with adjacent teeth. Especially in adult patients, as the intercanine distance tends to decrease, the altered position of canines becomes more pronounced.[16–18] Interestingly, mandibular premolars exhibited a lower discrepancy, as they are also the teeth with the smallest p-IPR. This indicated a general tendency for clinicians to concentrate IPR on the anterior region of mandibular teeth, especially on the incisors, although posterior IPR has been highly recommended by several studies as the enamel thickness increases in this area.[5,6] This general trend is based on the aim to resolve anterior crowding without altering posterior occlusion.

Three different techniques of IPR were used in the present study. In most cases (47.2%), the use of burs was the technique of choice, which also resulted in a smaller discrepancy between p-IPR and i-IPR, especially compared to manual strips. However, large variations were observed regardless of the IPR method, in agreement with results reported in similar studies.[14,15] Implemented IPR tended to be insufficient especially when manual strips were used. As suggested by several authors, traditional handheld abrasive strips make the reduction of enamel laborious, especially on posterior teeth.[15,19] Furthermore, by forcing an abrasive strip into the contact area, teeth are displaced

Table 2 Values of p-IPR, i-IPR and Respective Difference for the Three Techniques of IPR[a]

Technique of IPR	Number of Teeth	p-IPR (Mean, SD)	i-IPR (Mean, SD)	Difference (Mean, SD)
Manual strips	139	0.26 (0.09)	0.08 (0.08)	0.18 (0.12)
Burs	219	0.28 (0.11)	0.16 (0.16)	0.12 (0.11)
Contra angle strips	106	0.24 (0.10)	0.09 (0.11)	0.15 (0.13)

[a] IPR indicates interproximal reduction; p-IPR, programmed interproximal reduction; i-IPR, implemented inter-proximal reduction; SD, standard deviation.

Table 3 Results of Regression Analysis Comparing All Groups of Teeth to Lower Canines

Comparison to Lower Canines	Coefficient	Standard Error	*P* Value	95% Confidence Interval
Maxillary premolars	−0.06	0.03	.023*	−0.11, −0.01
Maxillary canines	−0.05	0.02	.034*	−0.10, −0.01
Maxillary incisors	−0.03	0.02	.114	−0.08, 0.01
Mandibular premolars	−0.09	0.02	.001**	−0.14, −0.04
Mandibular incisors	−0.03	0.02	.177	−0.07, 0.01

* Statistically significant.
** Highly statistically significant.

into the periodontal space and the perceived reduction in enamel might be much more than the actual amount.

Another factor was the use of a reduction measuring gauge. This seemed to be a useful tool for controlling the amount of i-IPR and reducing discrepancies with p-IPR, thus improving the precision of IPR. Therefore, it is recommended that i-IPR be checked carefully with a gauge at each contact point.

Other findings of the present study suggested that the discrepancy between p-IPR and i-IPR tended to be higher for distal compared to mesial contact points. Particular attention should be paid to the distal surfaces of teeth requiring IPR, as these might be areas that are difficult to reach. Furthermore, in these areas, IPR needs advanced manual skills and good compliance of the patient.

Timing of IPR was one of the factors that was investigated as a potential predictor of IPR precision. Round tripping resulted in slightly more precise IPR compared to previous alignment, although the difference was not statistically significant. The increased precision might be explained by the more accessible contact areas that are created after tooth alignment. This is a desirable effect for preserving tooth structure but might have side effects, considering that teeth perform an overcorrection that is reduced in a second stage. Furthermore, such additional movement might be a risk factor for root resorption. Therefore, it is advisable to schedule round tripping, taking into consideration biological and treatment strategies, rather than solely for IPR precision.[20]

In this study, the clinical significance level was set at 0.15 mm, which corresponded to the mean value of the observed IPR imprecision. If a smaller amount had been considered as clinically significant, such imprecision might be higher. However, the predetermined amount of 0.15 mm for clinical relevance was smaller than that prescribed as the minimum IPR for each interproximal contact in the aligner technique, usually corresponding to 0.2 mm. In terms of the overall clinical significance, the amount of IPR imprecision observed in the present study was low and not influenced by the technique, the doctor's experience, or other patient-related factors.

The present investigation was designed as a prospective observational study, with inclusion criteria that generally apply to the majority of patients treated orthodontically. This conveys important external validity for application in everyday clinical practice. However, a wide variety of potential confounding factors was present due to the inclusion of several clinicians applying different treatment techniques. Another limitation of the present study was calculating outcome measurements with the digital tool of ClinCheck. Although the quantified imprecision of the system was reasonably low and clinically acceptable, the results may still not have been entirely accurate. However, as suggested by several research studies, all manual and digital measurement methods imply a margin of error.[21,22] As long as this imprecision did not significantly alter the estimated effect, the system was reliable.

CONCLUSIONS

- The results of this prospective observational study suggest that there is a discrepancy between implemented IPR and prescribed IPR, with a tendency to provide less enamel reduction than prescribed.
- Particular attention should be paid to IPR performed on lower canines and on distal surfaces of teeth, as these areas are more prone to imprecision.
- In terms of IPR techniques, burs tend to provide more IPR compared to manual and contra-angle strips; however, there are significant variations between the techniques.
- Further studies are needed to estimate the best conditions for precise and efficient IPR.

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