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Interproximal reduction in orthodontics: a survey of specialist orthodontists and patients

Thesis submitted to National University of Ireland, Cork in partial fulfilment of the requirements of the

Doctorate in Clinical Dentistry (Orthodontics)

by

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List of Abbreviations

Abbreviation	Meaning
ARS	Air-rotor stripping
BOS	British Orthodontic Society
CPP-ACP	Casein phosphopeptide-amorphous calcium phospate
CUDSH	Cork University Dental School and Hospital
HSE	Health Service Executive
IER	Interproximal enamel reduction
IPR	Interproximal reduction
mm	Millimetres
Mn	Mandibular
Mx	Maxillary
RoI	Republic of Ireland
SD	Standard deviation
SPSS	Statistical Package for the Social Sciences
TSD	Tooth size discrepancy
Tx	Treatment
UCC	University College Cork
UK	United Kingdom
USA	United States of America
VAS	Visual Analogue Scale

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Thank you.

Declaration

This is to certify that the work I am submitting is my own and has not been submitted for another degree, either at University College Cork or elsewhere. All external references and sources are clearly acknowledged and identified within the contents. I have read and understood the regulations of University College Cork concerning plagiarism.

_____

Joey Donovan

Abstract

AIMS:

[1] To assess interproximal reduction (IPR) practices of specialist orthodontists in the Republic of Ireland (RoI).

[2] To evaluate patient perceptions of IPR as part of orthodontic treatment.

SUBJECTS AND METHODS: Ethical approval was granted by the Cork Teaching Hospitals Clinical Research Ethics Committee. Orthodontists on the Irish Dental Council's specialist register and consecutive patients receiving IPR in Cork University Dental School and Hospital's Postgraduate Orthodontic Unit were surveyed. Two *de novo* questionnaires were developed, pre-tested, piloted and distributed either electronically or by post to orthodontists and completed in-person by patients. Data with respect to demographic details, IPR use and technique employed, as well as patient perception were collected in the orthodontist survey. The patient survey collected demographic details, knowledge and perceptions of IPR. Descriptive statistics, Chi-squared tests, two-sample test comparison of means and correlation coefficients were used in analyses, with significance set at $p \leq 0.05$. Thematic analysis was performed independently by two assessors for qualitative questions in the Patient Questionnaire.

RESULTS: Responses were received from 105 specialists (75%)**.** Nearly all (98%) performed IPR, 44% reported increased use in the past five years. Handheld strips were most popular (37%), followed by burs (17%). Instrument use in postgraduate training was associated with subsequent use in practice ($p<0.001$ for abrasive strips in a holder; $p=0.003$ for burs). Lower labial segment teeth were most frequently reduced. IPR was most often employed with aligners (59%), pre-adjusted edgewise (33%) and self-ligating appliances (30%). Adult patients, followed by adolescents in the permanent dentition were most likely to be prescribed IPR, for the purposes of reshaping triangular teeth or restorations, resolving mild crowding and addressing tooth-size discrepancies or black triangles. Enamel removal, typically 0.3mm per

surface anteriorly and 0.4mm per surface posteriorly, created 2-4mm of space in each arch (60%) and was done in <5 minutes (45%) over multiple visits (82%) without routinely recontouring, polishing or treating the teeth afterwards. Written information was not given (90%) and only 12% reported prior patient awareness of IPR. Pain was the most common risk discussed, although reported patient perception of pain (9%) was less than for discomfort (48%) with 71% indicating patient preference of IPR over extractions.

Thirty patients (13 males and 17 females, mean age 16.2 ± 1.75 years) completed the questionnaire. Few (17%) had heard of IPR, but all reported understanding after explanation. Most (93%) 'did not mind' having IPR, 37% regarded it as 'uncomfortable' and 13% 'painful' (mean 2.3/10 on a visual analogue scale) and all would prefer IPR to extraction. Themes patients would tell a friend or family member about IPR were: pain, discomfort, comparison to extraction, speed, benefits, bleeding and side effects but would reassure and recommend the procedure.

CONCLUSIONS:

[1] Specialist orthodontists in RoI routinely performed IPR using handheld strips, mostly in the lower labial segment of the adult or adolescent permanent dentition, as part of aligner or fixed appliance treatment to reshape triangular teeth or restorations, resolve mild crowding and address tooth-size discrepancies or black triangles.

[2] Conservative enamel reduction of <0.5mm per surface, creating 2-4mm of space per arch, in <5 minutes over multiple visits without subsequently polishing, recontouring or treating enamel was most commonly adopted.

[3] Patients were rarely given written information on IPR, were perceived by orthodontists to be unfamiliar with IPR prior to treatment, found the procedure uncomfortable rather than painful and preferable to extractions.

[4] Patients themselves were unfamiliar with IPR but found it easy to understand, did not mind having IPR done, found it uncomfortable rather than painful, expressed a preference for IPR over extraction and would provide mostly positive feedback on the procedure to others.

Chapter 1. Introduction

Interproximal reduction or IPR is an integral part of orthodontic treatment. Aside from being used to create space for relief of crowding, it also has a role as an adjunctive procedure to address tooth size discrepancies and in conjunction with retention planning (Livas et al., 2013). With the reported decline in routine premolar extractions for orthodontic reasons (Fleming et al., 2018) and the increase in demand for adult orthodontic treatment in conjunction with clear aligner therapy (Tamer et al., 2019), its use is likely to increase.

To date, no data exists on the use of IPR by specialist orthodontists in the Republic of Ireland (RoI). Furthermore, what the patient thinks in relation to any treatment procedure is becoming of greater importance than the outcome of the procedure itself (Weldring & Smith, 2013). Minimal data are available on patient perceptions of IPR.

The project seeks to address these deficiencies in the orthodontic literature.

Chapter 2. Literature Review

Search strategies

This narrative literature review was conducted using University College Cork's OneSearch engine, Pub Med, Medline, Science Direct, and Google Scholar to search for relevant publications in the English language only. The search strategies used to identify articles for inclusion are outlined in **Table 1** and **Table 2.** Searches were not confined to full text articles. The searches identified 291 papers which were screened for inclusion in this review. Bibliographies of key papers were reviewed to identify further relevant content.

Table 1: Search strategy 1 to identify studies for inclusion in this review

Number	Search	Results
1	Orthodontics	740673
2	Dentistry	4272571
3	1 OR 2	4708733
4	"interproximal reduction" OR "inter-proximal reduction"	1066
5	"air rotor stripping" OR "air-rotor stripping"	175
6	Orthodontic AND "slenderiz*"	195
7	Orthodontic AND "reproximation"	115
8	4 OR 5 OR 6 OR 7	1420
9	3 AND 8	1292
10	9 with language restriction: English	772
11	10 with filter: human	257

Table 2: Search strategy 2 to identify studies for inclusion in this review

Number	Search	Results
1	Orthodontics	740673
2	"patient perception" OR "patient reported outcome measures"	68410
3	Title: “Questionnaire" OR "Survey”	123995
4	1 AND 2 AND 3	34

2.1 Overview of Literature Review

The literature review is laid out in five sections as follows:

- Section 2.2 defines IPR and outlines its history and rationale.
- Section 2.3 summarises the indications, contraindication, benefits and risks of IPR.
- Section 2.4 focusses on clinical considerations from treatment planning, methods of undertaking IPR to aftercare and record keeping.
- Section 2.5 addresses alternatives to IPR and appraises studies comparing its treatment outcomes to those of other methods of space creation.
- Section 2.6 summarises quantitative and qualitative surveys of specialist orthodontists and patients with specific reference to those undertaken in RoI and in relation to IPR. Surveys of orthodontic patient perceptions of specific/adjunctive procedures are also considered.

2.2 Interproximal Reduction

2.2.1 Definition

Interproximal reduction (IPR) is a clinical procedure involving an intentional reduction in the mesio-distal dimensions of the teeth by mechanical removal of the interproximal enamel surface (Zachrisson et al., 2007; Livas et al., 2013; Lapenaite & Lopatiene, 2014). Synonymous terms that are used in the literature include interproximal enamel reduction, air-rotor stripping (ARS), reproximation, interdental polishing, slicing, selective grinding and slenderizing (Sheridan, 1985; Zachrisson et al., 2007; Jadhav et al., 2011; Baumgartner et al., 2015).

2.2.2 History

IPR as part of orthodontic treatment was advocated by Ballard (1944) in cases lacking balance in the mesio-distal dimensions of maxillary and mandibular teeth. While this paper is often cited as the first article on the use of IPR in orthodontics, Ballard noted that IPR had been practiced and described in the past by orthodontists such as Linn (1943). Peck and Peck (1972) found that those with ideal incisal alignment had incisors with smaller mesio-distal dimensions than those with crowded incisors, which supported and quantified the use of IPR in the anterior segment for discrepancies in tooth size.

After several decades of IPR being primarily focused on addressing tooth size discrepancies in the anterior segment, the scope of IPR began to broaden with authors like Boese (1980) proposing its judicious use to enhance the stability of the mandibular anterior segment in the post-treatment phase. With the advent of full-arch bonding

instead of banding resulting in the liberation of proximal surfaces, IPR could be utilised as an effective means of space creation for relief of crowding. Sheridan introduced the technique of ARS, which is a turbine-assisted method of IPR, as an efficient and viable alternative to traditional means of space creation such as extractions or arch expansion for mild to moderate crowding (Sheridan, 1985, 1987). Aside from space creation, IPR may also improve aesthetics. Zachrisson (2004) advocated reshaping the interproximal surfaces of anterior teeth to modify contact points, thus eliminating or reducing the appearance of 'black triangles', which are a common consequence of aligning previously crowded anterior teeth.

Recent trends such as increasing numbers of adult orthodontic patients (McMorrow & Millett, 2017; Keim et al., 2020) and popularity of commercialised clear aligner systems have made IPR more relevant than ever before (Weir, 2017; Tamer et al., 2019). The difficulty associated with closure of large spaces after extraction in adult orthodontic patients has created a demand for alternative methods of localised space creation such as IPR (Pindoria et al., 2016).

With an increasing number of indications, instruments and techniques available to clinicians, IPR is today a universally-recognised adjunctive procedure in orthodontics, and its use appears to be on the rise (Keim et al., 2008; Fleming et al., 2018; Keim et al., 2020).

2.2.3 Rationale

Dental crowding is one of the most common problems among orthodontic patients. Crowding can be relieved in one of two ways; increasing the dimensions of the arch or

reducing the amount of tooth substance within an arch. Arch expansion, proclination of anterior teeth and distalisation of buccal segments are possibilities when considering the former, while the latter involves removal of teeth by extraction or selective reduction of individual teeth by IPR (Rossouw & Tortorella, 2003).

From an anthropological perspective, studies have indicated that historically, diets were more abrasive and up to 15mm of interproximal tooth tissue could have been expected to be lost throughout a lifetime (Jarabak, 1973; Kaidonis et al., 2012). With a modern refined diet, this natural attrition does not occur. Where crowding is present and due to a relative excess of tooth substance, there may be a need to compensate for the lack of this natural slenderisation, which provides justification for the use of IPR. Eminent orthodontists such as Begg and Kesling have gone as far as to state that attritional occlusion was very beneficial, and that IPR simulates this benefit if carried out regularly throughout life (Jarabak, 1973).

As well as generalised crowding, localised excesses or deficiencies in the amount of tooth structure can also limit the success of orthodontic treatment (Bolton, 1958). These variances are common, affecting anterior teeth in 20-30% of the population (Othman & Harradine, 2006). If a discrepancy prevents the goals of orthodontic treatment being met, then measures to compensate for a significant variation in tooth size between maxillary and mandibular arches are needed. As well as composite resin bonding, prostheses, extraction of teeth, leaving residual spacing and accepting a discrepant overjet or overbite, the option of selective removal of tooth substance by IPR should be considered.

2.3. Efficacy of Interproximal Reduction

This section addresses four key factors related to IPR: indications, contraindications, benefits and risks.

2.3.1 Indications

IPR is indicated for six reasons: management of tooth size discrepancies, space creation, modification of dental anatomy, reduction of interdental spaces, to facilitate spontaneous tooth movement and enhance stability during retention.

2.3.1.1 Management of tooth size discrepancies

Discrepancies in the size of corresponding teeth on opposite sides of the same arch or occluding teeth in opposing arches can affect aesthetics and the establishment of a stable occlusion (Ballard, 1944). Where a discrepancy exists, IPR may be indicated.

2.3.1.2 Space creation

Mild to moderate crowding may be resolved by IPR alone or in combination with other methods of gaining space within the arch (Jadhav et al., 2011; Lapenaite & Lopatiene, 2014). Space creation using IPR usually relates to the permanent dentition, although relief of crowding using IPR in the primary dentition has been described (Van Der Linden, 1975). IPR may also facilitate the levelling of the Curve of Spee or contribute to the space required to camouflage mild to moderate inter-arch discrepancies (Jadhav et al., 2011). The amount of space that can be created using IPR is dealt with in detail in Section 2.4.7.

2.3.1.3 Modification of dental anatomy

IPR may be used to recontour or camouflage teeth, for example where canines are moved into the position of a missing lateral incisor (Thordarson et al., 1991). Restorations may be similarly reshaped with IPR to improve dental aesthetics or interproximal contacts.

2.3.1.4 Reduction of interdental spaces

Triangular teeth, when aligned, often display unaesthetic 'black triangles' below the interdental contact points. IPR may be indicated to reshape triangular teeth and reduce or eliminate the resultant triangular spaces, normalising gingival contour and improving the aesthetic outcome of treatment (Zachrisson, 2004; Jadhav et al., 2011).

2.3.1.5 Facilitate spontaneous tooth movement

IPR in younger patients has been advocated to allow spontaneous bodily movement of first permanent molars, where second premolars are developmentally absent, which occurs in approximately 1.5-3.1% of Europeans (Polder et al., 2004). Sequential controlled IPR of primary second molars at eight to nine years of age was found to improve clinical outcomes, allowing bodily space closure by mesial movement of first permanent molars, without rotation or midline loss. Good outcomes were achieved in 90% of cases where sequential IPR was performed, whereas average or poor outcomes were found in 75% of cases where second primary molars were extracted early (Valencia et al., 2004).

2.3.1.6 Enhancing stability during retention

The use of IPR of mandibular incisors has been advocated by some to enhance stability and reduce orthodontic relapse, by creating broader areas of contact between incisors.

(Boese, 1980; Germeç-Cakan et al., 2010). IPR may be indicated for this purpose as an adjunct to retention appliances, or IPR can be performed as the sole method of retention (Aasen & Espeland, 2005; Tynelius et al., 2014).

2.3.2 Contraindications

There are four contraindications to use of IPR: severe crowding, microdontia, dental hypersensitivity, and unfavourably shaped teeth.

2.3.2.1 Severe crowding

Although Sarig et al (2015) suggest that it is theoretically possible to gain space of over 13mm in the maxilla and over 12mm in the mandible in some individuals, it is generally agreed that a reduction of 50% of the available interproximal enamel is possible in the average patient (Sheridan, 1985; Pinheiro, 2002). This would yield 8-10mm of space with IPR alone. For crowding in excess of this amount, other methods of gaining space need to be considered with or without concomitant IPR.

2.3.2.2 Small tooth size

The rationale for reducing the size of already diminutive teeth is questionable, and the amount of enamel present must be carefully evaluated (Ricketts, 1982).

2.3.2.3 Dental hypersensitivity

Long-term studies on the effects of IPR appear unequivocal that controlled IPR does not cause dentinal sensitivity (Thordarson et al., 1991; Zachrisson et al., 2007). When patients report pre-existing hypersensitivity, it has been claimed that the risk of

worsening this symptom may outweigh the potential benefits of performing IPR in some patients (Jadhav et al., 2011).

2.3.2.4 Unfavourably shaped teeth

According to McLaughlin et al. (2001), there are three main dental shapes; rectangular, triangular and barrel-shaped. While triangular or barrel-shaped teeth will often benefit aesthetically from IPR, this procedure should not be performed on teeth with parallel proximal surfaces (rectangular teeth) as it produces very broad contact areas which may exacerbate food impaction and interseptal bone loss (Jadhav et al., 2011). By virtue of its shape, significantly more enamel would have to be removed from a rectangular tooth than from a triangular tooth to create space in the arch (Florman et al., 2007). This is depicted in **Fig. 1**.

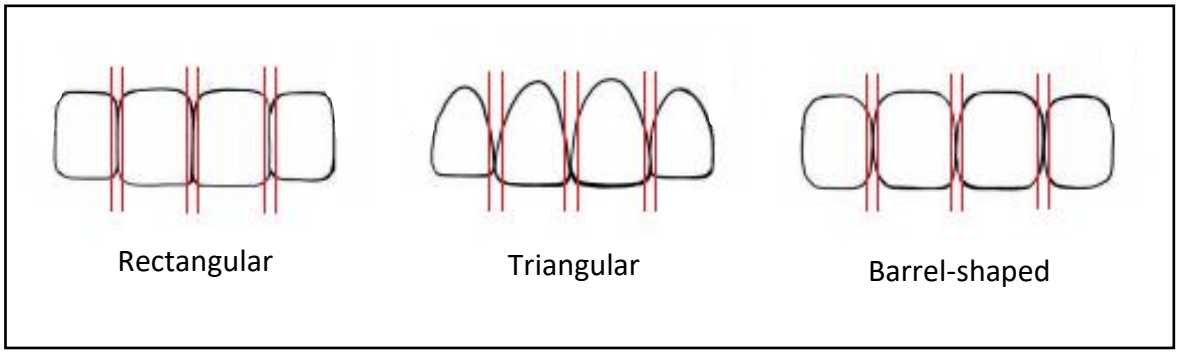


Fig. 1: Tooth shapes showing amount and pattern of enamel reduction for each

2.3.3 Benefits of interproximal reduction

Three potential benefits are linked with the use of IPR during orthodontic treatment: space gain without extractions, improved aesthetics and improved stability.

2.3.3.1 Space gain without extractions

A significant benefit of IPR is the creation of space, while minimising the potential negative outcomes of extractions. When extractions are used to create space, the clinician can face difficulties in achieving complete space closure and achieving parallel roots; the space has a tendency to reopen after active treatment and undesirable soft tissue or profile changes may occur (Florman et al., 2007; Pindoria et al., 2016). These difficulties are minimised through the use of IPR. In addition, the risks inherent in large tooth movements and the potential for loss of bone and root cementum are considered less with IPR than with extraction (Jadhav et al., 2011). The use of IPR also tends to reduce overall treatment time compared to extraction-based treatment plans (Germeç & Taner, 2008).

2.3.3.2 Improved aesthetics

2.3.3.2.1 Dental aesthetics

IPR can be employed to improve crown size and shape, or amend over-contoured restorations. This is particularly useful in the labial segment to create symmetry, correct centrelines and proportion the teeth for optimal aesthetics. Where tooth shape contributes to visible incisal spaces and interdental black triangles, these can be reduced or eliminated with IPR (Florman et al., 2007).

2.3.3.2.2 Soft tissue aesthetics

Adaptation of the soft tissue in areas where space has been created by IPR is superior to soft tissue adaptation in extraction sites (Florman et al., 2007; Jadhav et al., 2011). In non-extraction cases, final soft tissue aesthetics may be improved by the elimination of interdental black triangles.

2.3.3.3 Improved stability

Good stability of lower incisors was found after a follow-up period of three years in a study which used IPR as the sole means of retention after orthodontic treatment (Aasen & Espeland, 2005). The mean change in Little's Irregularity Index (Little, 1990) was 0.6mm in that study, after a mean amount of 1.9mm IPR was performed during the retention period (Aasen & Espeland, 2005).

Although the generalisability of the result is questionable given the retention protocols used, a long-term randomised controlled trial on retention found judicious IPR during the retention phase to be as effective at maintaining anterior alignment as bonded retainers, thermoformed retainers or positioners (Tynelius et al., 2014). The logic for improved retention when this adjunctive procedure is performed is through the creation of broader contact areas, stabilising the teeth and reducing slippage of contact points, particularly in the mandibular labial segment (Boese, 1980).

2.3.4 Risks of interproximal reduction

There are six potential risks of IPR: hypersensitivity, thermal damage to the pulp, caries, periodontal disease, iatrogenic damage and bacteraemia.

2.3.4.1 Hypersensitivity

Hypersensitivity can be a consequence of removing tooth structure, as is done during IPR. This may expose dentinal tubules to the environment, which can communicate with the pulp either directly or by the hydrodynamic flow of fluid (Davari et al., 2013). Reported prevalence of hypersensitivity after IPR varies, with 59 out of 61 subjects in one study reporting no increase in thermal sensitivity after IPR (Zachrisson et al.,

2007). Similarly, a ten-to-fifteen-year follow-up of patients who had undergone IPR to camouflage canines as lateral incisors found no significant difference in thermal sensitivity between teeth which had undergone IPR and those which had not (Thordarson et al., 1991). Conversely, 54% of Indian orthodontists reported that patients experienced this side-effect (Srivastava et al., 2012).

2.3.4.2 Thermal damage to pulp

Temperature increase can lead to necrosis of the pulp. The critical threshold for harm is typically considered to be a temperature increase of 5.5°C. This rise led to necrosis of the pulp in a substantial number of teeth in the classic study by Zach and Cohen (1965). As the mechanisms for performing IPR generate frictional heat, there is a risk of thermal damage to the pulp during this procedure. Factors which may increase heat include bur design, bur material, bur speed and the type of coolant used during IPR (Baysal et al., 2007). Both Sheridan (1985) and Zachrisson (2007) advocated the use of coolant during IPR procedures to offset this risk, even prior to any published scientific evaluation of pulpal temperature rise during this procedure.

A number of *in vitro* studies have looked at the temperature rise in the pulp chamber with various methods of performing IPR. Studies by Periera Jr (2014) and Sehgal (2019) found that the temperature increase during IPR was within safe limits, with none of the methods tested reaching the critical threshold value of 5.5°C. This is in contrast to prior work which found that tungsten carbide burs used on mandibular incisors caused a mean increase in pulp temperature which was greater than 5.5°C (Baysal et al., 2007). Individual instances of temperature increases above the threshold were also

reached in several of the other test groups, regardless of tooth type or method of IPR. The results of these studies are summarised in **Table 3**.

The greatest temperature increases occur when tungsten carbide or diamond burs are used in high speed handpieces without coolant, while the use of handheld metal strips results in smaller temperature variations, which are within safe limits. The recommendation to use water coolant during this procedure would seem prudent if IPR is to be carried out using a motorised system (Sheridan, 1985; Zachrisson et al., 2007).

As all of the aforementioned studies were carried out on extracted teeth, they do not consider the potential for dissipation of heat within the pulp chamber due to blood circulation or dentinal fluid movement (Raab, 1992). As such, these results are likely to overestimate the increase in heat caused by IPR, and need to be interpreted with care. A more recent *in vivo* study examined the temperature changes in the pulp of premolars during IPR carried out using ARS, an oscillating system and handheld strips; none of the methods reached the critical threshold (Kiran et al., 2020). The temperature rise in the pulp of vital teeth was greatest when ARS was performed, followed by the oscillating system and lowest for handheld strips. The mean temperature change for each of the methods as outlined in the order above was 2.09°C, 1.22°C and 0.53°C, with a narrow range between lowest and highest recorded temperatures within each group (Kiran et al., 2020).

Table 3: Changes in pulp temperature during IPR

Author/Year	Study Design	Method of IPR	Coolant used	Tooth type	Sample size	Time (seconds)	Amount of reduction (mm)	Mean Temperature Increase (°C) (SD)
Baysal et al., 2007	*In vitro*	Handheld strip	No	Incisor	10	10s	-	1.21 (1.48)
				Canine	10	10s	-	1.03 (1.3)
				Premolar	10	10s	-	-0.18 (0.97)
		Perforated disk	No	Incisor	10	10s	-	2.37 (1.31)
				Canine	10	10s	-	2.51 (1.25)
				Premolar	10	10s	-	3.84 (2.21)
		Tungsten carbide bur	No	Incisor	10	10s	-	5.63 (1.73)
				Canine	10	10s	-	3.22 (1.7)
				Premolar	10	10s	-	3.65 (1.67)
d'Ornellas Pereira et al., 2014	*In vitro*	Handheld strip	No	Incisor	13	-	0.5	1.24 (0.3)
				Premolar	13	-	0.5	0.96 (0.39)
				Molar	13	-	0.5	0.92 (0.18)
		Perforated disk	No	Premolar	13	-	0.5	2.64 (0.29)
				Incisor	13	-	0.5	2.58 (0.27)
				Molar	13	-	0.5	2.48 (0.38)
Sehgal et al., 2019	*In vitro*	Handheld Strip	No	Premolar	20	-	0.5	2.8 (0.41)
		Diamond bur, air rotor	Yes	Premolar	20	-	0.5	1.9 (1.07)
		Diamond bur, micromotor	No	Premolar	20	-	0.5	3.5 (0.95)
		Diamond bur, micromotor	Yes	Premolar	20	-	0.5	1.65 (0.81)
Kiran et al., 2020	*In vivo*	Carbide bur, air rotor	Unclear	Premolar	17	-	-	2.09 (0.52)
		Oscillating metal strip	No	Premolar	17	-	-	0.53 (0.18)
		Handheld Strip	No	Premolar	17	-	-	1.22 (0.19)

2.3.4.3 Caries

The theoretical increased risk of caries following IPR relates to an increase in surface roughness and the creation of plaque-retentive furrows on interdental enamel, a reduction in the thickness of protective enamel and the removal of the highly-mineralised outer enamel layer (Lapenaite & Lopatiene, 2014). The significance of increased surface roughness and demineralisation from IPR, and its influence on the development of caries will be considered in turn.

2.3.4.3.1 Surface roughness

As IPR involves adjustment of interproximal enamel surfaces, it is widely accepted that the surface characteristics of treated enamel differ before and after (Danesh et al., 2007; Zachrisson et al., 2007). Increased surface roughness has the potential to accentuate microflora accumulation at sites where IPR has been performed. The results of several *in vivo* experiments suggested that demineralisation is greater at sites where IPR is performed, and thus the process of IPR places those sites at increased risk of caries development (Twesme et al., 1994). Instruments used for gross reduction of enamel invariably produce a rougher surface than untreated enamel (Zingler et al., 2016). It is reported that the increased surface roughness created during IPR with some types of instruments, such as coarse diamond strips, coarse diamond burs or 16-bladed tungsten carbide burs, cannot be removed even after polishing (Piacentini & Sfondrini, 1996; Danesh et al., 2007). The grit size of the final instrument used to reduce the enamel surface is a critical factor in the final surface outcome, with finer grits reducing, or in some instances even eliminating the need for subsequent polishing (Zingler et al., 2016).

Other studies have reported techniques of performing IPR which result in surfaces which are equivalent or even smoother than untreated enamel. A comparison of a number of methods of performing IPR found enamel reduction with a diamond-coated metal strip followed by polishing with a fine Sof-lex disc to produce the smoothest surface, even smoother than in the untreated group (Bhambri et al., 2017), confirming the findings of other workers (Mikulewicz et al., 2007; Meredith et al., 2017).

Studies evaluating surface roughness are difficult to compare given the variety of methods and armamentarium used to perform IPR and the methods of assessing surface roughness. These issues with the existing evidence are highlighted in a systematic review of enamel roughness following IPR, which was unable to statistically combine the data from the included studies (Koretsi et al., 2014).

2.3.4.3.2 Demineralisation

Many *in vitro* studies have demonstrated that stripped surfaces are more susceptible to demineralisation than untreated surfaces, and this may lead to an increased caries incidence (Twesme et al., 1994; Kim, 2001; Hellak et al., 2015). The method and instruments used to perform IPR have been implicated as a factor, with Hellak *et al* (2015) reporting that the greatest amount of demineralisation occurred following IPR with Sheridan's ARS technique. The same study found that subsequent polishing does not have an influence over the susceptibility of the surface to demineralisation.

2.3.4.3.3 Influence of IPR on caries development

Meta-analysis of the results of *in vivo* trials has not found that caries incidence increased either in patients who had received IPR or indeed at specific sites where IPR had been

performed (Koretsi et al., 2014). It is now acknowledged that caries is a complex multifactorial process; increased presence of microflora or short-term reduction in resistance to demineralisation are not necessarily predisposing factors. As such, no proven correlation exists between IPR and caries incidence.

2.3.4.4 Periodontal disease

IPR poses potential risks to the periodontium, either from direct trauma during the procedure or through creation of plaque-retentive furrows. Mild gingival trauma has been reported after IPR, which was of no long-term consequence (Zhong et al., 2000). Several authors describe ways to minimise such damage to soft tissues, including the periodontium, during this procedure (Sheridan, 1987, Florman et al., 2007).

The creation of furrows in enamel may increase localised plaque accumulation, an important risk factor in the development of periodontal disease (Radlanski et al., 1988). Crain and Sheridan (1990) reported that patients were no more susceptible to periodontal disease following reduction of interproximal enamel than those who did not have IPR performed. Their conclusion was supported by a long-term follow up study of 61 patients who had undergone IPR at least ten years previously, which found no signs of gingival recession on the labial surface of mandibular incisors; wider mesio-distal bone dimensions were identified between the roots of incisors as compared to patients treated without IPR (Zachrisson et al., 2007). Furthermore, Hellak et al (2018) found no significant difference in bone volumes between mandibular incisor roots in patients treated with or without IPR, but noted the potential advantages of IPR in this area of the dentition, reducing the amount of labial expansion of mandibular incisors and allowing spacing of previously crowded incisors roots.

2.3.4.5 Iatrogenic damage

In order to increase the efficiency of IPR, turbine-assisted methods have been introduced (Sheridan, 1985). These confer a risk of operator error resulting in soft tissue damage, over-reduction, excessive space creation and loss of tooth contour (Florman et al., 2007).

2.3.4.6 Bacteraemia

As with any procedure that involves the manipulation of gingival tissues, there is the potential for bacteraemia as a result of IPR. This can hypothetically be caused either by the use of separators before or during the procedure, or trauma to the gingival tissues from the instruments used to perform IPR (Lucas et al., 2002).

One study has investigated bacteraemia in patients who have undergone IPR. One out of 29 subjects developed bacteraemia postoperatively (Yagci et al., 2013). *Streptococcus sanguinis* was the bacterial strain identified, which has been linked to endocarditis in patients with predisposing cardiac conditions.

Preventing trauma to soft tissues and an evaluation of the patient's medical history, including consultation with a relevant medical professional if the patient is at high risk of infective endocarditis, would seem prudent until more research is available on this topic.

2.4 Interproximal Reduction: Clinical Considerations

As the questionnaire to orthodontic specialists employed in this project recorded information relating to various clinical parameters, these will be considered here. Treatment planning, where, when and how to perform IPR including the need for separation, aftercare and record keeping, will now be presented.

2.4.1 Treatment planning

The importance of a formal space analysis before performing IPR is stressed in the literature (Pindoria et al., 2016). Study models will be required to analyse the amount of space required at specific sites to correct tooth size discrepancies, or to evaluate space requirements and plan IPR or alternative methods of space creation. Additional diagnostic information such as the use of calibrated radiographs to measure the exact amount of enamel at each proximal surface, or a diagnostic set-up of the finalised position and morphology of the teeth have also been recommended (Hall et al., 2007; Otsuka et al., 2010). Others have questioned the accuracy of these methods, as well as their practicality in routine clinical practice (Grine et al., 2001; Livas et al., 2013).

The amount of planned reduction of each individual proximal surface should be recorded, and the total should match the amount of space required to achieve the aims of treatment (Jadhav et al., 2011).

2.4.2 Where to perform IPR

IPR is generally performed on adult teeth, but reduction of primary teeth has been described for the purposes of: improving occlusion, encouraging mesial movement of first permanent molars where second premolars are absent, or relieving crowding of the mixed dentition (Van Der Linden, 1975). In these cases, the reduction is typically performed in the buccal segments only. If IPR is being carried out to correct a specific tooth size discrepancy, the process of selecting where to perform IPR is self-explanatory.

Where IPR is being used to create space, the Bolton Index is a valuable tool for determining the best site in which to perform IPR (Bolton, 1962). For example, if the total upper arch Bolton excess is 2mm, and the anterior Bolton ratio is normal, then reduction should be considered in the upper buccal segments. Other considerations when selecting which teeth to slenderise include whether the patient had any prior interproximal reduction performed or whether over-dimensioned restorations are present (Florman et al., 2007).

2.4.3 When to perform IPR

It has been advocated that initial alignment of teeth should be completed with fixed appliances prior to IPR being done, so that the contact points are established before being reproximated (Pinheiro, 2002). This may increase the accuracy of the amount of tooth reduction performed, at the expense of a degree of 'round tripping' the teeth (Kalemaj & Levrini, 2021). IPR can still be carried out prior to alignment if teeth are rotated, but care is required to reduce the anatomical proximal surface, rather the contact area of the rotated tooth (Jadhav et al., 2011).

2.4.4 Separation of teeth prior to IPR

There is potential for improved visibility and access to contact points by using separators, wooden wedges or coil springs to open the contact areas before performing IPR (Sheridan, 1987; Livas et al., 2013).

Separation of teeth, however, is not essential prior to IPR. The use of separators has been criticised for adding visits to treatment and making the true amount of space gained by IPR difficult to measure (Florman et al., 2007).

2.4.5 Protection of soft tissues

Chudasama and Sheridan (2007) recommend protection of gingival tissues with a steel or brass wire placed gingival to the contact point. Cheek retractors, tongue retractors, wedges, rubber dam, disc guards and the adoption of a four-handed approach to aid soft tissue retraction have all been sporadically recommended. In the only study to report on soft tissue trauma *in vivo*, only minor trauma to the gingival papillae was observed without the use of soft tissue protection (Zhong et al., 2000). This was not described as painful by patients and considered inconsequential.

2.4.6 Reduction of teeth

2.4.6.1 Method

Reduction of the interproximal enamel should be performed keeping the vertex of the dental papilla and the interdental contact point on the same tangent perpendicular to the occlusal plane; this avoids the appearance of aberrant tooth inclination. The interdental

contact point should be re-established at a distance of between 4.5mm and 5mm from the alveolar crest to ensure optimal soft tissue infill and contour (Tarnow et al., 1992).

2.4.6.2 Armamentarium

Various instruments and systems are available to perform IPR. These can be classified as either manual or mechanical.

2.4.6.2.1 Manual

These instruments are strips or discs made from stainless steel, with abrasive diamond coatings. Strip holders are available to aid manual reduction of enamel. The strips or discs are offered by a variety of manufacturers in fine, medium and coarse grits. A number of thicknesses of strips exist, which can be either single or double-sided (Florman et al., 2007).

The use of manual reduction instruments is considered laborious by some (Sheridan, 1987). It has been suggested that strips be reserved for the following situations:

- To perform enamel reduction where teeth are so rotated that a mechanical instrument is unsuitable;
- To allow easier subsequent access for mechanical instruments in areas of tight contacts;
- To recontour teeth after reduction with a mechanical system;
- To treat nervous patients who may experience less anxiety with a manual instrument (Florman et al., 2007; Livas et al., 2013).

2.4.6.2.2 Mechanical

2.4.6.2.2.1 Air rotor stripping

The concept of ARS was introduced by Sheridan in 1985, then expanded and refined in subsequent publications (Sheridan, 1985, 1987; Chudasama & Sheridan, 2007). It involves the use of tungsten carbide burs, diamond burs or diamond discs in a high-speed air-turbine handpiece, with subsequent finishing using fine diamond or carbide burs or manual strips. A number of bur designs have been developed for use with the ARS system, typically with non-cutting safety ends to avoid the creation of ledges (Livas et al., 2013). The proposed advantage of this technique is its efficiency, with a large amount of reduction possible in a short space of time. The technique has received some criticism, centred on a lack of control during the procedure. A high number of revolutions-per-minute are required to keep the bur spinning fast enough to cut enamel using an air-rotor which allegedly decreases the operator's ability to be conservative during the procedure (Florman et al., 2007).

2.4.6.2.2.2 Mechanical stripping

High-torque, low speed motors have been adopted for use to perform IPR, to overcome the potential lack of control when using higher speed cutting instruments (Florman et al., 2007). While the principles remain the same as for ARS, it has been reported that these motors can deliver the torque required to cut at speeds as low as 100 revolutions per minute, reducing the risk of iatrogenic damage to hard and soft tissues (Florman et al., 2007).

2.4.6.2.2.3 Oscillating systems

Metallic strips or segment discs are available for use with oscillating systems. Owing to the oscillating rather than rotating movement of the cutting surface, these systems have been reported to provide efficient enamel reduction with less risk of trauma to soft tissues without the need for lip and cheek retraction (Zhong et al., 2000; Johner et al., 2013). One study advised caution with these systems, as significantly more enamel was removed than that planned *in vitro* (Danesh et al., 2007).

2.4.7 How much IPR to perform

2.4.7.1 Amount of space that can be created

Various authors have quoted different figures for the amount of tooth reduction and consequent space gain that can be safely achieved with IPR. Sheridan (1985) asserts that a space gain of 2.5mm in the anterior region and 6.4mm posteriorly is achievable. Fillion (1995) recommended that reduction not exceed 0.3mm for maxillary incisors, 0.2mm for mandibular incisors and 0.6mm for molars and premolars. This is less reduction than the figures quoted by Stroud and co-workers (1998), who claimed that reducing 50 percent of the proximal enamel should yield 9.8mm of space in the posterior region alone in the average patient. Those individuals with the thinnest enamel should still be expected to achieve a space gain of over 7mm with 50% of their buccal segment enamel being reduced, while those in the 95th percentile of enamel thickness could achieve 11.7mm or more space posteriorly. A similar study by Sarig et al (2015) suggested that 3.2mm and 2.5mm of space is attainable in the maxillary and mandibular anterior regions, while posteriorly space of 10.2mm and 9.8mm may be gained respectively, giving a total maximum space gain of over

13mm in the maxilla and 12mm in the mandible. This would provide comparable space gain to the extraction of premolars bilaterally. Without accurate information on the thickness of enamel in an individual, more modest amounts of reduction are advised.

2.4.7.2 Enamel thickness

While absolute values differ on the potential for space gain with IPR, there is a consensus in the literature that 50 percent of the proximal enamel can be safely removed (Hudson, 1956; Sheridan, 1985; Pinheiro, 2002). Therefore, an evaluation of the thickness of enamel, or at least reference data, is needed to quantify the amount of enamel that may be removed. Enamel thickness has been explored in a number of studies, but these are difficult to compare or combine given the heterogeneity of study design, ethnicity of subjects, methods of measurement of enamel thickness and data reporting.

One such study of the proximal enamel thickness of 109 sectioned extracted teeth in Israel found that the thickness of enamel of anterior teeth did not exceed 1mm, while posterior teeth had thicknesses ranging from 1.1mm to 1.5mm (Sarig et al., 2015). Combining interproximal enamel thicknesses from the distal of the right first molar to the distal of the left first molar yielded measurements of 26.86mm in the maxilla and 24.52mm in the mandible.

Another investigation into enamel thickness using bitewing radiographs of 98 Caucasian adults in North America found a mean measurement of 0.98mm on the mesial side and 1.07mm on the distal side of first premolars. The corresponding measurements were 1.18mm and 1.22mm for the second premolars, 1.28mm and 1.41mm for the first permanent molars and 1.29mm and 1.48mm for the second permanent molars (Stroud et al., 1998). Differences in enamel thickness between men and women were not significant,

which supported the conclusions previously reached in other studies (Shillingburg & Grace, 1973; Stroud et al., 1994). With the exception of second premolars, teeth had significantly more enamel on their distal surface than mesial surface, which was again in agreement with other sources (Shillingburg & Grace, 1973; Akli et al., 2020). Molar enamel was significantly thicker than premolar enamel.

A separate North American study, which used periapical radiography, looked at enamel thickness of mandibular incisors in both Caucasian and African-American subjects (Hall et al., 2007). They noted a difference between the two ethnic groups. Enamel thickness in the mandibular anterior segment ranged from 0.44mm to 1.12mm in Caucasian subjects and 0.58 to 1.28mm in African-American subjects, with mean additional thickness of 0.1mm and 0.15 mm of enamel on the mesial and distal proximal surfaces of incisors respectively in the latter group (Hall et al., 2007). This suggests a racial variation, with slightly greater enamel reduction possible in African-American patients.

More recently, the enamel thickness of 32 extracted canines was analysed using micro-computed tomography scans, which highlighted the potential variation in thickness of enamel at various vertical positions of the crown (Akli et al., 2020). Enamel on both mesial and distal sides of the canines in this study tended to be thickest towards the incisal edge, and thinnest towards the gingival margin.

Due to the substantial individual variations evident from the ranges in enamel thickness quoted above, some authors have recommended the use of radiography before performing IPR to measure the thickness of interproximal enamel. An *in vitro* Japanese study suggested that this method gave accurate measurements (Otsuka et al., 2010), while

another cautioned that radiographs may overestimate the true enamel thickness (Grine et al., 2001).

Estimating the thickness of enamel based on tooth width has yielded positive but weak associations (Hall et al., 2007). A substantial variation in enamel thickness is not explained by tooth width differences alone (Peck & Peck, 1972; Hall et al., 2007).

2.4.8 Measuring the amount of tooth tissue removed

The amount of enamel reduction performed can be quantifed by leaf gauges of designated thicknesses which are commercially available (Livas et al., 2013). Disks used for IPR are also now being manufactured with a specified thickness, to eliminate the need for an additional measuring instrument (Johner et al., 2013). Orthodontic wires, a readily-available commodity in orthodontic practice, are of known dimensions and so may also be used to measure space created by IPR. **Table 4** shows a conversion chart which may be used.

Table 4: Conversion of orthodontic wire diameter to metric measurement

Wire diameter	Metric conversion
0.012”	0.3mm
0.016”	0.4mm
0.020”	0.5mm

It is worth noting that studies have regularly found all methods of performing IPR to deliver less enamel removal than intended (Johner et al., 2013; De Felice et al., 2020; Kalemaj & Levrini, 2021). In one study, for intended reductions of 0.1mm and 0.4mm, hand-held strips

removed significantly less enamel on average than planned, while motor-driven strips delivered less reduction when 0.4mm was planned, as did oscillating strips for 0.2mm, 0.3mm, and 0.4mm planned reduction (Johner et al., 2013). Another study examined the amount of reduction performed by ten orthodontists using handheld strips in 40 clear aligner patients, and found an average of 0.55mm discrepancy in the upper and 0.82mm discrepancy in the lower arch between the planned and actual tooth reduction, giving an accuracy of 45% and 37% in the respective arches (De Felice et al., 2020). A possible explanation for this is that forcing an instrument into a contact point or pressure applied against the surface being reduced can push the tooth laterally into the periodontal space (Johner et al., 2013). This can give the misleading impression of greater available space, highlighting the need to measure space created only after allowing sufficient time for the periodontal ligament to recover after IPR. Aligning the teeth prior to performing IPR, measuring the space created using a gauge and performing IPR with a bur rather than handheld strips was found to reduce the discrepancy between the amount of IPR planned and performed (Kalemaj & Levrini, 2021). That study also found IPR to be performed more accurately on the mesial than the distal surface of teeth.

The only study that found the amount of IPR to closely match the planned tooth reduction was that of Lagana (2021). This study had one experienced operator performing the IPR using an oscillating abrasive strip and found no difference between planned and actual IPR in the upper arch and a discrepancy of just 0.01mm in the lower arch. The accuracy of their findings was postulated by the authors to be due to the combination of operator experience and the mechanical method of tooth reduction (Laganà et al., 2021).

2.4.9 Recontouring and polishing

Gross reduction of interproximal enamel can create proximal corners which need to be recontoured to resemble the tooth's natural morphology. According to a review by Livas et al (2013); finishing burs, discs or handheld metal strips are all considered appropriate instruments to round proximal edges and reshape teeth. A subsequent study suggested that the use of handheld strips was the optimal technique for preserving the shape of the proximal surface (Nassif et al., 2017). The more abrasive the instrument used for gross reduction, the more polishing is required to remove surface irregularities (Lombardo et al., 2014). For final polishing, Sof-lex discs are endorsed by several authors, as these consistently produce the smoothest surface, which in some cases is smoother than untouched enamel (Piacentini & Sfondrini, 1996; Bhambri et al., 2017; Meredith et al., 2017). Chemo-mechanical polishing has also been advocated, with the addition of a 37% phosphoric acid gel to the polishing procedure to create a smoother surface than mechanical means alone (Joseph et al., 1992). Disappointing results have been achieved by other researchers who have tested this method and the technque is rarely given consideration in more recent studies (Rossouw & Tortorella, 2003; Zachrisson et al., 2011).

2.4.10 Surface treatments

The effect of surface treatments has been studied to reduce post-operative demineralisation and prevent caries. The rationale for surface treatment is based on the outcomes of *in vitro* research which indicated that by removing the highly mineralised outer layer of enamel, teeth which have been reduced are more susceptible to demineralisation and caries (Twesme et al., 1994; Hellak et al., 2015).

Application of a fluoride varnish to aid remineralisation of the reduced surface is a common theme, with several authors recommending its use based on the results of *in vitro* studies (Mikulewicz et al., 2007; Peng et al., 2016; Vicente et al., 2017). A retrospective study of patients up to six years after receiving ARS questioned the value of applying topical fluoride to reduced surfaces, however, as it was found to have limited value in reducing demineralisation and caries risk in patients receiving fluoride from other sources such as toothpaste or fluoridated water (Jarjoura et al., 2006).

The potential of Casein phosphopeptide-amorphous calcium phosphate (CPP-ACP) compounds to enhance remineralisation has also been assessed (Giulio et al., 2008). An *in vivo* trial found that the reduced microhardness of enamel after IPR could be rectified by remineralising agents such as fluoride and CPP-ACP, while another found no significant differences in surface mineral content of teeth which had undergone IPR or control teeth, regardless of whether CPP-ACP was applied (Paganelli et al., 2015).

Brushing with zinc-carbonate hydroxyapatite-containing toothpaste (Alessandri Bonetti et al., 2014) and resin infiltration have also been explored (Peng et al., 2016). The latter is claimed to have the dual potential to fill in residual furrows and flaws in the enamel surface created by IPR, as well as creating a diffusion barrier, but more high-quality evidence is required to substantiate these claims.

The aforementioned *in vitro* studies did not accurately replicate the oral environment, or account for the remineralising potential of saliva. The results of two *in vivo* studies on demineralisation after IPR suggest that saliva alone may emulate the effect of remineralising agents in a short period of time (Paganelli et al., 2015; Bayram et al., 2017).

2.4.11 Time taken to perform IPR

Zhong et al (2000) was the only study to measure the time required to perform this procedure. They reported the average time taken to reduce one interproximal surface was 29.8 seconds with an additional 51.5 seconds required for polishing, including the time taken to change the disc in the handpiece during polishing (Zhong et al., 2000).

Other authors have noted the difficulty in quantifying the time that this procedure requires due to the number of variables involved. These include the type of instrument used, the grain size of the instrument surface, how many times and for how long the instrument has been previously used, the amount of reduction to be carried out, enamel hardness of the surface to be reduced and operator influence (Lombardo et al., 2014; Lione et al., 2017). Some sources consider traditional hand-held abrasive strips to be time-consuming and laborious, and advocate the use of ARS or other motorised systems to reduce interproximal surfaces (Florman et al., 2007; Sheridan, 2008; Laganà et al., 2021).

Larger grain size results in less time being taken to grossly reduce the interproximal surface but a rougher surface is produced than with finer grit instruments. The operator may need to spend additional time subsequently polishing the surface (Lombardo et al., 2014). The more an instrument is used, the less efficient it is at reducing the enamel surface. After five minutes, or approximately 300 metres of use, the abrasive power of a strip is reduced by 60%, but this is considered an underestimation of the likely reduction in clinical efficiency due to the additional pressure placed on the strip by the operator. This is especially so where the strip is initially forced through a contact point (Lione et al., 2017). *In vivo* tests showed that the surface roughness of an instrument reduced with use, accounting for the reduction in efficiency (Livas et al., 2020). This finding was echoed by Lombardo et al

(2014), who concluded that any instrument tested took longer to reduce a surface after 10 uses than a new instrument. This study also confirmed the logical principle that the more enamel to be reduced, the longer the time needed to perform the procedure (Lombardo et al., 2014). An interesting finding was that more time was required to perform the initial 0.1mm of reduction of a surface than the subsequent 0.1mm, which was attributed to the difficulty in breaking the initial contact point, while the third reduction of 0.1mm took a longer time due to decreasing efficiency of the abrasive surface.

The general consensus in the literature is that although IPR requires chairside time, it is not considered time-consuming. Efficiency is optimised by regularly replacing the abrasive instrument used as well as employing motorised systems for reduction.

2.4.12 Record keeping

The use of an interproximal reduction chart, similar to a periodontal chart, has been recommended to aid in the recording of reductions done on each proximal surface (Florman et al., 2007). A *de novo* example of an IPR chart which could be used is shown in **Fig 2**.

7		6		5		4		3		2		1		1		2		3		4		5		6		7	
D	M	D	M	D	M	D	M	D	M	D	M	D	M	M	D	M	D	M	D	M	D	M	D	M	D	M	D
D	M	D	M	D	M	D	M	D	M	D	M	D	M	M	D	M	D	M	D	M	D	M	D	M	D	M	D
7		6		5		4		3		2		1		1		2		3		4		5		6		7	

Fig. 2: Example of chart used to record interproximal reduction

2.5. Alternatives to Interproximal Reduction

Both of the questionnaires used in this research project enquired regarding use of and attitudes to alternatives to IPR in orthodontic clinical practice. In this section management of tooth size discrepancies, methods of gaining space and comparisons to IPR are addressed.

2.5.1 Tooth size discrepancies

Where a discrepancy in tooth size exists, the options available to the patient include composite resin bonding to increase the mesio-distal width, prostheses, extraction of teeth, leaving residual spacing and accepting a discrepant overjet or overbite (McSwiney et al., 2014). Composite resin, ceramic restorations and prostheses can be highly aesthetic, but are liable to failure and require long-term maintenance (Schmidseder, 2000). Depending on the type of restoration, cost may also be a significant factor.

A systematic review described the extent of the Bolton discrepancy as a decisive issue when a mandibular incisor extraction is being considered for a tooth size discrepancy. It reported that patients potentially benefit more from extraction of an incisor where a discrepancy of greater than or equal to 4mm exists, while cases without such significant mandibular dental excess may be treated successfully with IPR (Almeida et al., 2015).

The option of leaving residual spaces or accepting a discrepant overjet or overbite equates to accepting a compromised result, and should be done only with the full understanding and agreement of the patient (Chate, 2013). The clinician should ensure

that accepting these discrepancies does not compromise function or stability, and that the patient has a realistic expectation of what the aesthetic outcome of treatment will be (Fleming et al., 2015).

2.5.2 Gaining space

The clinician has several options for space creation, which fall into two categories; increasing the perimeter of the arch or reducing the amount of tooth structure within the arch. Transverse expansions, anterior advancement and posterior movement of the buccal segments lengthen the arch to provide more space, while extraction of teeth and IPR reduce the amount of tooth structure.

2.5.2.1 Increasing arch perimeter

2.5.2.1.1 Transverse expansion

Approximately 0.5mm of space is created for every 1mm of lateral posterior arch expansion (Kirschen et al., 2000). The indications for transverse expansion to create space are essentially limited to cases where a crossbite exists, or where teeth are lingually tipped, constricting the arch. Transverse expansion where these conditions are not present is considered unstable and prone to relapse, particularly if expansion of the lower intercanine width is attempted (Lee, 1999). Excessive transverse expansion runs the risks of perforation of the buccal plate, and tipping of upper teeth can result in an increase in the maxillary-mandibular plane angle and lower face height, undesirable in high angle or anterior open bite cases (Orton & Noble, 1990).

2.5.2.1.2 Incisor advancement

Each millimetre of incisor advancement creates approximately 2mm of space within the arch (Kirschen et al., 2000). The indications for this type of movement include: cases with very mild crowding, Class III incisal relationship, Class II division 2 cases with retroclined mandibular incisors or Class II division 1 cases with overerupted mandibular incisors. This type of movement is prone to relapse and only small amount of expansion in an anteroposterior direction is usually appropriate (Little, 1990).

2.5.2.1.3 Distal movement of upper buccal segments

Distal movement of the upper buccal segment teeth is possible either through the use of extra-oral traction with headgear or intraoral appliances connected to mini-implants. Generally 2-3mm of distalisation is achievable per side, giving 4-6mm space in total, but distal movement of up to 5.7mm per side has also been reported (Atherton et al., 2002).

Possible indications for distalisation include: Class I cases with mild crowding, cases where the molar relationship is a half unit Class II and non-extraction treatment is being undertaken, Class II Division 1 cases with minimally increased overjet and a molar relationship of half unit Class II or less, cases where extraction of first premolars or other methods of space gain are insufficient or where unilateral loss of a primary molar has resulted in mesial drift.

This method of gaining space is highly conservative of tooth structure and can be used to supplement other forms of space creation. Distalisation is only realistic in the upper arch and places a significant burden on patient compliance if headgear is used (Al-Moghrabi et al., 2018).

2.5.2.2 Extractions

Extractions have been a topic of debate in orthodontics for a long time and their popularity as a method of gaining space waxes and wanes (Proffit, 1994). The space available after extractions for relief of crowding depends on which tooth is extracted and the method of anchorage reinforcement. With bilateral premolar extractions and maximum anchorage, up to 14mm of space gain can be expected. Without anchorage reinforcement, approximately half of this space is expected to be available for anterior alignment or overjet correction (Haque et al., 2017).

A multitude of factors affect whether extractions are the treatment of choice and if so, which tooth/teeth are to be extracted. These include: the aims of treatment, patient profile, prognosis and position of individual teeth, amount of space required and where, incisor relationship, anchorage reinforcement and appliances to be used

For space creation, first or second premolars are the most common extraction choice, although patterns of premolar extraction vary with time and their removal appears to be on the decline (Jackson et al., 2016; Fleming et al., 2018). Extraction of a mandibular incisor may also be an attractive choice when an incisor has poor prognosis or compromised periodontal support, the buccal segments are Class I but there is lower incisor crowding, or the patient is an adult with a mild Class III skeletal pattern and well-aligned buccal segments.

Where teeth have a poor long-term prognosis or where a significant amount of space is required to resolve localised moderate crowding or generalised severe crowding, extractions provide an attractive solution. Extractions can, however, be a painful and traumatic procedure for patients (Fagade & Oginni, 2005). Other downsides include

poor gingival adaptation at the extraction site, difficulties in space closure or space reopening, bone loss, a reduction in arch width. An increase of treatment time of up to eight additional months was reported in one study comparing space gain with IPR and premolar extractions (Germeç & Taner, 2008).

2.5.3 Studies comparing treatment outcomes of IPR with other methods of space creation

Studies comparing the effects and treatment results of IPR versus other forms of gaining space are scarce, with just one prospective randomised controlled trial found in the literature (Germeç & Taner, 2008). Details of this trial and other relevant studies are summarised in **Table 5**. Overall, IPR compared to premolar extractions had less effect on profile, maintained incisor positions, shortened treatment time and had similar effects on arch width.

Table 5: Studies comparing treatment with IPR versus other methods of space creation

Author/Year	Study Type Malocclusion	Treatments (n)	Findings
Germeç & Taner (2008)	Prospective, randomised Class I patients with moderate crowding	4 premolars extracted, minimum anchorage (n=13) vs ARS (n=13)	• IPR shorter treatment time by 8 months • Extraction group: incisors retracted; molars moved mesially; upper/lower lips 1-1.5mm retruded • ARS group: upper incisor position maintained; slight protrusion of lower incisors and lips; decreased nasolabial angle
Germeç-Cakan et al. (2010)	Retrospective Class I patients with moderate crowding	4 premolars extracted, minimum anchorage (n=13) vs ARS (n=13)	• ARS preserved arch width and arch perimeter • Extraction group arch width maintained, arch perimeter reduced • NS difference in intercanine widths with extraction or ARS
Jung (2013)	Prospective, non-randomised <6mm crowding	Extraction of second premolars (n=32) vs Distalisation with mini-implants plus IPR (n=34)	• NS difference in the treatment results between groups

n = number per group NS= Non significant

2.6. Qualitative and Quantitative Surveys of Specialist Orthodontists and Patients

Two qualitative and quantitative surveys were used in this research project to assess the opinion of specialist orthodontists and patients. In this section, previous surveys of specialist orthodontists in RoI are considered as well as those that have evaluated patient perceptions in relation to aspects of orthodontic practice. Surveys of dental professionals and patients in relation to IPR are also evaluated.

2.6.1 Surveys of specialist orthodontists in the Republic of Ireland

Previous studies have used questionnaires distributed to specialist orthodontists in the RoI. These are summarised in **Table 6.** The response rate from this group has been consistently high; ranging from 71 – 85%. There has been no survey of this group on the topic of IPR.

Table 6: Surveys of specialist orthodontists in the Republic of Ireland

Author/Year	Topic	Method	No. of responses	Response rate
McGuinness & Collins (2007)	The orthodontic workforce in Ireland	Postal questionnaire	95	85%
Murray et al. (2012)	Bonded molar tubes	Postal questionnaire	70	74%
Meade & Millett (2013)	Retention	Postal/electronic questionnaire	101	82%
McMorrow & Millett (2017)	Adult orthodontics	Postal/electronic questionnaire	101	83%
Higgins et al. (2019)	Provision of orthodontics in Ireland in 2018	Postal/electronic questionnaire	101	71%

2.6.2 Surveys of dental professionals on interproximal reduction

Despite being a common procedure performed during orthodontic treatment, only three surveys explicitly on the topic of IPR were found in the literature (Sheridan, 2006; Srivastava et al., 2012; Barcoma et al., 2015). These surveys show almost ubiquitous use of IPR with reported prevalence in the range of 89-100%. They report more frequent use anteriorly, using handheld strips, for the relief of crowding, addressing TSDs and reducing relapse potential. Varied opinions are reported regarding the risk of caries and use of fluoride postoperatively.

A further four surveys had secondary findings related to IPR. A recent cross-sectional survey of members of the British Orthodontic Society (BOS) aimed to determine if the frequency of extraction of premolars for orthodontic reasons was declining, and included a question examining whether the use of IPR was a factor in this change (Fleming et al., 2018). Another study by Evrard (2019) had questions on methods of space creation used by orthodontists in non-extraction cases. A third survey looked at treatment management techniques of orthodontists and general dentists treating patients with clear aligners; one of these was IPR (Best et al., 2017). Finally, the Journal of Clinical Orthodontics periodically run a cross-sectional study of orthodontists' diagnosis and treatment procedures, the most recent of which was published in 2020. That survey included questions on frequency of use of IPR in general as well as the frequency of use of specific instruments to perform IPR anteriorly and posteriorly in the dental arches (Keim et al., 2020).

Details of these studies and their findings are summarised in **Table 7**.

Table 7: Surveys of dental professionals on IPR

Author/ Year/Country	Topic	Questionnaire used	Method	Sample	Response	Findings
Sheridan (2006) International	IPR in orthodontic treatment	*De novo* questionnaire	Postal questionnaire	Random sample of Subscribers to the Journal of Clinical Orthodontics	Unclear	• All respondents performed IPR, in ≈20% of cases (range <5% to >50%) most commonly in anterior segments after initial alignment. • Indications: TSDs, relief of anterior crowding, aesthetics, borderline extraction cases and to reduce relapse. • Contraindications: poor OH, thin enamel, pre-existing sensitivity, inadequate access and unfavourable tooth morphology. • Handheld strips most popular followed by discs and burs. • Fluoride treatment prescribed by 40% after IPR. • Minimal reported patient concerns: some related to potential caries, sensitivity and residual spacing.
Srivastava et al. (2012) India	IPR in orthodontic treatment	*De novo* questionnaire – 10 questions related to IPR	Interviewed directly/ postal/ electronic questionnaire	Orthodontists in clinical practice or working in a teaching hospital	66% (200/300)	• Used by 95% of orthodontists. • Valuable tool in treating relapse (55%) and used by 67% for this purpose in the mandibular labial segment. • Tooth shaped deformed after IPR (81%). • Tooth more susceptible to caries (91%) and observed by 14%; topical fluoride reduced susceptibility (87%). • Post-operative sensitivity (55%) and observed by 54%
Barcoma et al. (2015) USA	Differences in perspective between orthodontists and dentists on IPR	*De novo* questionnaire – 3 sections; (i) Indications for IPR and alternatives, (ii) Polishing and surface treatment after IPR, (iii) Clinicians' subjective opinions on IPR	Electronic questionnaire	All members of American Association of Orthodontists, Virginia, Maryland and South Carolina Dental Associations	132 general dentists, 873 orthodontists	• Performed by 89% of orthodontists; used routinely by 66%. • IPR easier to perform anteriorly (50%); used posteriorly for aesthetic reasons (13%). • Effects on dental health researched (81%); little caries risk posed (95%); reluctant to perform IPR (7%) due to dental health impact. • Not imperative to polish surfaces of teeth (54%); topical fluoride applied (27%).

Best et al., (2017) USA	Treatment management differences between orthodontists and general dentists with clear aligners	*De novo* questionnaire – 3 sections; case selection, treatment management and background information	Postal questionnaire	Non-random sample of 1000 orthodontists and 1000 general dentists listed as Invisalign providers	374 orthodontists (37%) and 229 general dentists (23%)	• IPR performed with same frequency by orthodontists and general dentists in conjunction with clear aligners
Fleming et al. (2018) UK	Extraction of premolars for orthodontic reasons	*De novo* questionnaire – included questions on IPR	Interviewed directly/ postal/ electronic questionnaire	Pilot on non-random sample of 8 orthodontists/trainees. Study group – all members of BOS	16% (208/1250)	• Extraction frequency reduced over past decade (95%); increased use of IPR a factor (87%) and a moderate/major factor (49%) • In Class I crowding cases, IPR more likely use than 5-10 years ago in adolescents (63%) and adults (75%) • In combination with arch lengthening, IPR more likely use than 5-10 years ago in adolescents (53%) and adults (61%).
Evrard et al. (2019) Belgium	Factors influencing orthodontists in their decision to extract	*De novo* questionnaire – 14 cases: questions on methods of space creation	Unclear from published paper how questionnaire was conducted	30 randomly selected alumni orthdontists from the Université Catholique de Louvain, Belgium	28/30 (93%)	• IPR used in non-extraction cases (45%). • After dental expansion, IPR most common method of space creation.
Keim et al. (2020) USA	Diagnosis and treatment procedures used by orthodontists		Electronic questionnaire	16,686	153/16686 (0.92%)	• Anteriorly: “routinely” (35%), “occasionally” (54%); hand instruments routinely (56%), handpiece (50%) air turbine (17%) • Posteriorly: “routinely” (6%), “occasionally” (43%); handpiece routinely (25%) air turbine (19%) • Increased use compared to 1986, 2002, 2014 surveys

2.6.3 Surveys of orthodontic patient perceptions of specific/adjunctive procedures

Patient perception of various aspects of orthodontic treatment, including specific adjunctive procedures has been evaluated using questionnaires. Extractions (Rousseau et al., 2002; Fagade & Oginni, 2005), mini-implants (Gündüz et al., 2004; Lamberton et al., 2016), removable appliances (Čirgić et al., 2017; Lena et al., 2017), wear-time trackers (Schott & Göz, 2010; Schott et al., 2013), orthodontic elastics (Veeroo et al., 2014), elastomeric separators (Al-Melh & Andersson, 2017), impression techniques (Sfondrini et al., 2018), premolar transplantation (Shargill et al., 2014), corticotomy (Zawawi, 2015) and distraction osteogenesis (Garreau et al., 2016) have been evaluated.

Patients reported different levels of discomfort and pain with various adjunctive procedures (Rousseau et al., 2002; Fagade & Oginni, 2005; Shargill et al., 2014; Lamberton et al., 2016). Extractions were found to be more painful than other procedures (Rousseau et al., 2002); patient perception of pain was found to be influenced by factors such as duration of the procedure and occupation (Fagade & Oginni, 2005). Patients have low prior awareness of certain adjunctive procedures, but this did not affect the acceptance rate (Zawawi, 2015).

Questionnaire studies that evaluated patient perception of outcomes relevant to the present study, for example perception of discomfort related to the procedure, are summarised in **Table 8**.

Table 8: Surveys of orthodontic patient perceptions

Author/Year /Country	Topic	Questionnaire used	Method	Sample	Response	Findings
Rousseau et al. (2002) USA	Patient discomfort experienced during extractions in comparison to restorations and root canal treatment	*De novo* questionnaire with VAS	In clinic	250 patients, 150 root treatment, 50 single tooth extraction and 50 direct restoration	250	• Mean pain level: extraction (23.98/100), root canal therapy (7.73/100), and restoration (4.22/100). • Patients reported pain during extraction: ○ 'A lot less than expected' (52%) ○ 'Less than expected' (12%) ○ 'Expected' (22%) ○ 'Worse than expected' (8%) ○ 'A lot worse than expected' (6%)
Gündüz et al. (2004) Austria	Patient acceptance of palatal implants (PI) during orthodontic treatment	*De novo* questionnaire	Unclear	85 patients	85	• More information prior to and talk to others with PIs (75%). • Minimal discomfort with speaking/eating. • Appliance connected to PI less comfortable than PI. • 95% satisfied PI and 86% would recommend.
Fagade & Oginni (2005) Nigeria	Pain experience during extractions	VAS	In clinic	122 patients	122	• Mean pain level experienced during extraction 3.4 ± 2.5/10 (males) and (2.9 ± 2.9/10) females. • Pain level influenced by patient occupation and duration of surgery.
Shargill et al. (2014) UK	Premolar transplantation	*De novo* questionnaire using Likert scales	Mailed Response 20/41	41 patients	20/41 (49%)	• Mean discomfort level 6/10.

Zawawi (2015) Saudi Arabia	Patients acceptance of corticotomy-assisted orthodontics	*De novo* questionnaire	In clinic	129 patients	129	• Previously aware of corticotomy (3.1%). • 7.8% expressed preference for corticotomy over extraction, with fear of surgery (53.2%) and pain (36.9%) most common reasons to avoid corticotomy. • Acceptance of corticotomy similar for males and females and prior knowledge not a factor in acceptance.
Lamberton et al. (2016) USA	Pain during miniscrew placement	VAS	In clinic	24 patients	24	• Mean pain score: 9.3 ± 12.1/100 (needle-injected anaesthetic) and 33.9 ± 26.6/100 (compound topical anaesthetic).
Al-Melh & Andersson (2017) Kuwait	The effect of topical anaethetic on pain experience with elastomeric separators	De novo questionnaire with VAS	In clinic	50 patients	50	• More satisfied and mean pain sensation lower after separator placement with topical LA. • If they were to receive separators again in the future, all 50 patients would like to receive topical anaesthetic. • Discomfort and pain reduced over the ten minutes after placement of separators.
Čirgić et al. (2017) Sweden	Patient experience with AA and PFA	*De novo* questionnaire	In clinic or at home, at 1 month and 6 months	97 patients	67 (69%) at 1 month 44 (45%) at 6 months	• More pain reported with AA than PFA after 1 month. • Dentist had greatest impact on decision to initiate treatment.
Sfondrini et al. (2018) Italy	CI and DI techniques	VAS	In clinic	14 patients	14	• DI more comfortable than CI overall and specifically for comfort, time, size and gag reflex.

AA=Andresen Activator, CI=Conventional alginate impression, DI=Digital Impression LA=Local anaesthetic, PFA=Preformed functional appliance, PI=Palatal Implant, VAS=Visual Analogue Scale.

2.6.4. Surveys of patients on interproximal reduction

No studies were found which focussed exclusively on patients' perceptions or patient-reported outcomes of IPR. One study which evaluated an oscillating IPR instrument gathered patient feedback on the procedure but did not use a written questionnaire. Low levels of pain were reported during IPR, with no patient reporting a preference for receiving local anaesthetic if they were to undergo the procedure again (Zhong et al., 2000). The details of this study are presented in **Table 9**.

Table 9: Studies of patient perceptions of IPR

Author/Year/Country	Topic	Method	Sample	Findings
Zhong et al. (2000) Germany	Patient discomfort experienced during IPR with a mechanical oscillating system	Questioned verbally In clinic after IPR performed	32 patients	• Mean patient-reported discomfort 2.22-2.34 out of 10 • Preference reported for not receiving local anaesthetic if IPR repeated.

Chapter 3. Aims

This project is divided into two parts with the following aims:

Aim 1

To assess interproximal reduction practices of specialist orthodontists in the Republic of Ireland.

Aim 2

To evaluate patient perceptions of interproximal reduction as part of orthodontic treatment.

Chapter 4. Materials and Methods

4.1 Ethical Approval

Ethical approval to carry out this survey was granted from the Clinical Research Ethics Committee of the Cork Teaching Hospitals (**Appendix 1 – Ethical Approval**).

4.2 Development of Questionnaires

Two *de novo* questionnaires were developed: **Appendix 2 – Orthodontist Questionnaire**; **Appendix 3 – Patient Questionnaire**. The questionnaire for specialist orthodontists was developed with reference to previous questionnaires which included questions on IPR, as outlined in **Table 7** (Sheridan, 2006; Srivastava et al., 2012; Barcoma et al., 2015; Best et al., 2017; Fleming et al., 2018; Keim et al., 2020). There were no pre-existing questionnaires on patient perceptions of IPR to which to refer, with the exception of one question in a previous study by Zhong (2000).

Initial drafts of both questionnaires were developed by the research team (J.D. and D.M.). Questions were formulated following the guidance of Williams (2003) and Dillman (2014): simple language was used; questions were kept short and specific; double-barrelled questions, double negatives and questions involving assumptions were avoided; closed and open questions were used, with open questions carefully worded to encourage responses; an opportunity was given for further comments at the end of the questionnaire. The readability of the patient questionnaire was checked using Flesch Reading Ease and Flesch-Kincaid Grade Level scales within Microsoft

Word© to ensure the reading age of the questionnaire was appropriate for the study population (Flesch, 1948, Thomas et al., 1975).

The layout of the questionnaire also followed the recommendations of Williams (2003). The questionnaire was divided into distinctly numbered sections, with ample space given to each question and questions clearly separated from one another. Questions were ordered with general questions preceding specific questions. Large, clear fonts were used throughout. The questionnaire was printed on good-quality paper, with a coloured front page and clear instructions at the beginning and throughout the questionnaire. To reduce coverage error and non-response bias, the orthodontist survey was to be a mixed-mode survey as recommended by Dillman (2014); an electronic version of the orthodontist questionnaire, identical to the hard copy, was therefore created using LimeSurvey© software.

The questionnaires were pre-piloted with the research team (D.M. and M.H.) and postgraduate orthodontic students in Cork University Dental School and Hospital (CUDSH) to identify any issues with the questions and layout. Respondents were asked to complete the questionnaires and provide general feedback, as well as specific feedback on the clarity, order, layout and options given for each question and whether any additional questions should be asked (**Appendix 4-6**).

The time taken to complete the questionnaire at each pre-pilot stage was also recorded. Each questionnaire went through two cycles of pre-piloting, at which stage the author was confident that the questionnaire could be navigated correctly, questions were appropriate and unambiguous, and could be completed in a

reasonable length of time. The changes made to both questionnaires during the pre-pilot stage are summarised in **Table 10** and **Table 11**.

Table 10: Changes made to Orthodontist Questionnaire during pre-pilot stage

Feedback	Change to Orthodontist Questionnaire
Question B5 should be before B3.	Order of questions changed.
Answer boxes not in line with questions for some.	Re-formatted to ensure answer boxes in line with corresponding text.
Highlight which arch in question QB10.	"Upper arch" capitalised and bold font to highlight, same change made to "Lower arch" in QB11.

Table 11: Changes made to Patient Questionnaire during pre-pilot stage

Feedback	Change to Patient Questionnaire
QB10. Too much jargon – simplify for patients.	Language changed to simplify descriptions of instruments.
QC3. (xii) and (xiii) both say upper teeth.	QC3. (xiii) corrected to say "lower teeth".

At this stage, the questionnaires were piloted on a sample of the populations to be studied. Seventeen orthodontists, approximately 10% of the total sample size, were randomly selected to receive the pilot questionnaire using a random sequence generator (www.random.org/sequences). Five consecutive patients who were prospectively undergoing IPR in the Postgraduate Orthodontic Unit of CUDSH completed the pilot patient questionnaire after informed consent was given to participate in the study. Both pilot studies were carried out using an identical data

collection process to that of the final study, described in Section 4.4. Neither sample was informed that they were participating in a pilot or that their responses would not be included in the final data, to avoid any potential influence on the data provided.

After piloting both questionnaires, slight modifications were made to resolve minor issues related to the presentation, formatting and coding of the questionnaires. These changes are summarised in **Table 12** and **Table 13**. At this stage, both questionnaires were finalised.

Table 12: Changes made to Orthodontist Questionnaire during pilot stage

Finding	Change to Orthodontist Questionnaire
Some questionnaires were returned with two opposing pages of unanswered questions, as pages were getting stuck together due to the wet ink after printing.	Switched from double-sided to single-sided printing. Added page numbers to bottom right hand corner of each page**.**
QB13. and QD3. Contained duplicated item numbers.	Numbering corrected to allow coding of responses.

Table 13: Changes made to Patient Questionnaire during pilot stage

Finding	Change to Patient Questionnaire
Some questions requiring one answer per row were only getting an answer on the first row.	Highlighted the instructions for each question in capital letters and bold text.

4.3 Participants

4.3.1 Specialist orthodontists

Specialist orthodontists in RoI were invited to participate in the survey. The Dental Council of Ireland's Dental Specialist Register, Division of Orthodontics (as of May 2019) and the Orthodontic Society of Ireland membership list (as of July 2019) were used to generate a database of names and contact details of participants. Orthodontists who were known to live abroad or had ceased to practice were excluded.

4.3.2 Patients

A convenience sample of 30 consecutive patients who were to receive IPR as part of their orthodontic treatment at the Orthodontic Unit of CUDSH were invited to complete the questionnaire. The patients were receiving care either by postgraduate students, specialist orthodontists or hospital consultants.

4.4 Dissemination of the Questionnaires

4.4.1 Specialist orthodontists

Specialist orthodontists were contacted by telephone in February 2020 to give them a brief overview of the research project and to invite them to participate. After agreeing to participate, they were given the option of receiving the postal version or the electronic version of the questionnaire. If an orthodontist was not contactable by telephone after a minimum of three attempts, they were sent the postal version of the questionnaire with a personalised cover letter inviting them to take part.

The questionnaires were distributed in February 2020. A number of measures were employed to increase the response rate: the dissemination of the questionnaire was strategically timed to avoid the Christmas holiday period; questionnaires were sent out a maximum of one week after the pre-notice telephone call; all contacts and mailers were personalised; the anonymity of responses was assured; an entry form for a prize draw for a financial incentive was included; reminders were sent with an additional copy of the questionnaire included (Williams, 2003; Dillman, 2014). Additionally for the postal version: pre-paid addressed envelopes were included; official headed paper was used for cover letters; the personalised cover letter was signed in blue ink; a brightly-coloured front cover with a logo was used for the questionnaire; all items in the mailing were arranged in the order they would be required by the respondent (Williams, 2003; Dillman, 2014).

Responses to all surveys were anonymised. The unique numbering of the questionnaire booklets allowed non-responders to be identified and sent reminders, while allowing responses to be anonymised. By creating unique single-use digital

tokens for completion of the electronic version of the questionnaire, the software allowed responses to be anonymised and for non-responders to be selectively sent reminders.

Non-responders to both postal and electronic questionnaires were sent one reminder with a second copy of the questionnaire or link to the questionnaire respectively, four weeks after the initial questionnaire was sent. Although a second reminder is recommended to increase response rate by both Williams (2003) and Dillman (2014), the scheduled timing of this reminder occurred during the first lockdown the Covid-19 pandemic. It was deemed inappropriate to remind clinicians about a research survey during this time due to the widespread closure of orthodontic practices, the disruption to nationwide orthodontic services, and the potential stress and hardship the pandemic was causing for those due to be contacted. This impact of the Covid-19 pandemic on this project is further explored in Section 6.5.

4.4.2 Patients

Informed consent for participation in the survey was given by the patient, parent, or both depending on the age of the patient. After receiving instructions, patients completed the questionnaires by themselves in a quiet area of the clinic at the end of their appointment.

To ensure anonymity, the questionnaire booklet did not collect any information which could be used to identify the patient.

4.5 Data Entry

Data from the postal and electronic questionnaires of specialist orthodontists were combined into a single spreadsheet in Statistical Package for the Social Sciences (SPSS) (IBM Corporation, Version 26.0. Armonk, New York) by the author (J.D.) prior to statistical analyses. Data from the patient questionnaires were coded and entered by J.D. into an SPSS spreadsheet for analyses. Orthodontist Questionnaires (n=20) and Patient Questionnaires (n=20) were selected at random one month after the last data entry and re-entered by J.D. to check for errors in data input.

4.6 Data Analyses

Results from both questionnaires were analysed descriptively and presented in graphical and tabular form with accompanying descriptive analyses.

A thematic analysis of responses to two qualitative questions in the Patient Questionnaire was done independently and in duplicate by two researchers (D.M. and J.D.) with any disagreements resolved through consensus.

Associations between variables in both questionnaires with regard to instruments used, training in IPR, type of practice setting, years of operator experience, reported discomfort, patient age and gender were explored using Chi squared tests, two-sample test comparison of means and correlation coefficients as appropriate. The associations that were explored and the corresponding statistical test used are outlined in **Table 14**.

Table 14: Associations explored between variables

Statistical Test	Question
Chi squared	Did the instruments specialists used during training influence which instruments they used in practice?
	Did having training or not influence how much IPR they were willing to do?
	Did the location of training influence whether someone received training in IPR?
	Did the setting of practice influence how much IPR is being done?
Two-sample test comparison of means	Did those with more experience tend to use more or less IPR?
	Instruments used and reported discomfort from patients?
	Age/gender and level of discomfort from IPR?
	Whether pain was advised as a risk and level of pain reported
Correlation coefficients	The effect of age/gender and level of discomfort from IPR

Chapter 5. Results

5.1 Survey of Specialist Orthodontists

5.1.1 Response rate

Responses were received from 105 specialist orthodontists, representing a response rate of 75% to the survey. Not all questions were answered by all respondents; the number of responses to each question is indicated in the relevant Figure or Table. The response rate to both sampling frames throughout the pilot and implementation phases is summarised in **Fig. 3**. The timing of responses during the implementation phase is summarised in **Fig. 4** and **Fig. 5**

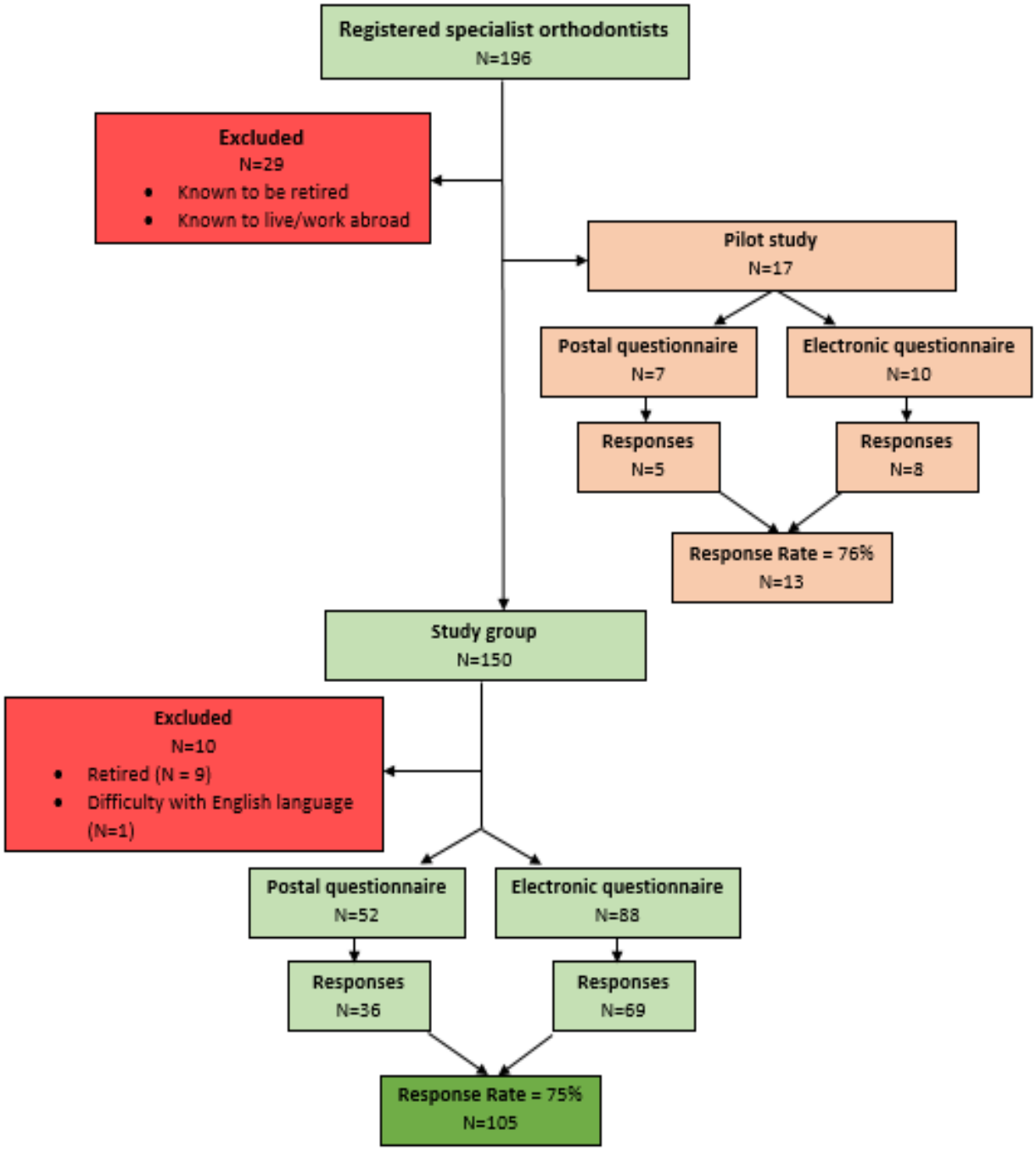


Fig. 3: Responses to survey of specialist orthodontists

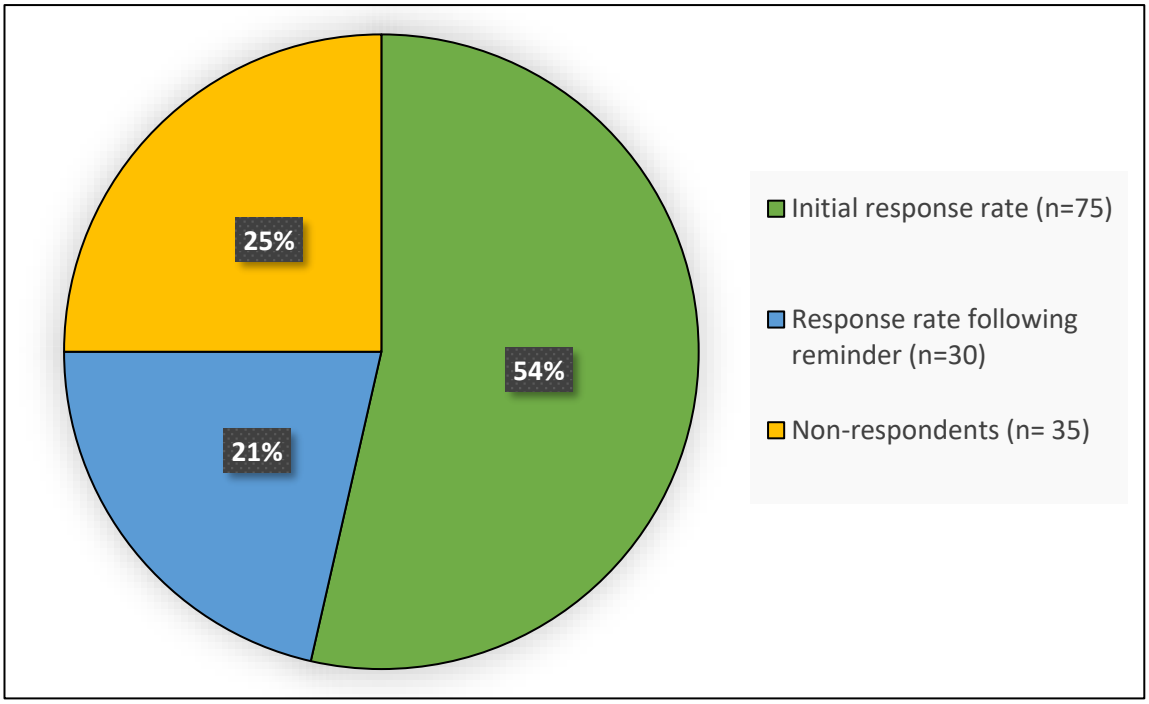


Fig. 4: Overall response to survey of specialist orthodontists (n=140)

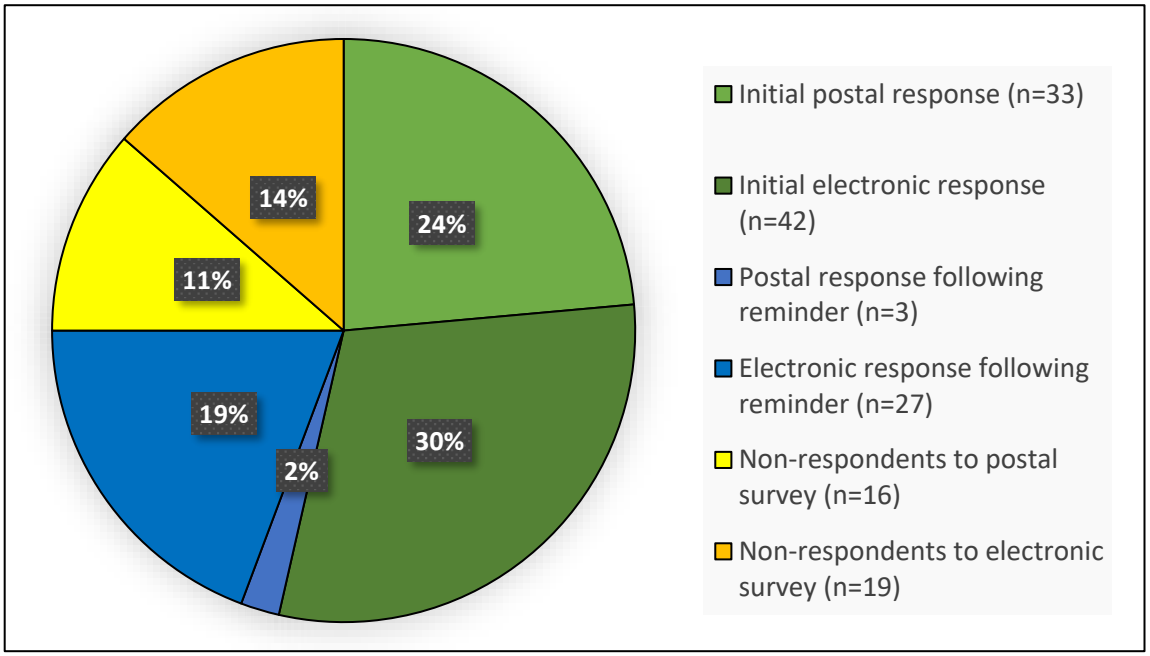


Fig. 5: Postal and electronic response to survey of specialist orthodontists (n=140)

5.1.2 Data entry

No errors were detected in the data entry for the twenty questionnaires chosen at random for re-entry one month after the initial data entry date.

5.1.3 Section A: General information about respondents

An almost equal number of male (54%) and female (46%) orthodontists responded to the survey. Over half (53%) of the respondents undertook their orthodontic training in the United Kingdom (UK), with a further 27% trained in Ireland (**Fig. 6**). Respondents had between one and 45 years of orthodontic experience, with a mean of 15.5 years (**Fig. 7**). Dublin was the most common location of practice (41%) (**Fig. 8**). A majority of respondents worked in private practice (59%) and/or a Health Service Executive (HSE) orthodontic clinic (32%) (**Fig. 9**). The majority of respondents (77%) reported that they received some formal instruction in IPR during their orthodontic postgraduate training (**Fig. 10**), mostly using handheld strips (63%) or strips in a holder device (50%) (**Fig. 11**).

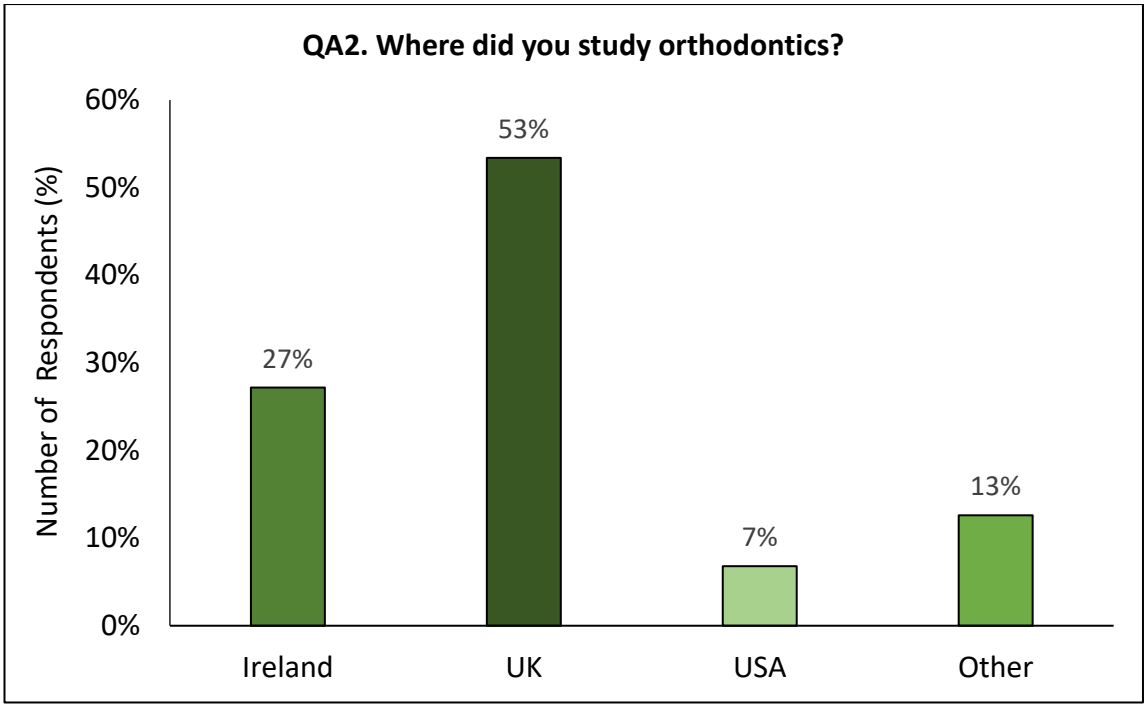


Fig. 6: Locations where orthodontists in ROI did their specialist training (n=103)

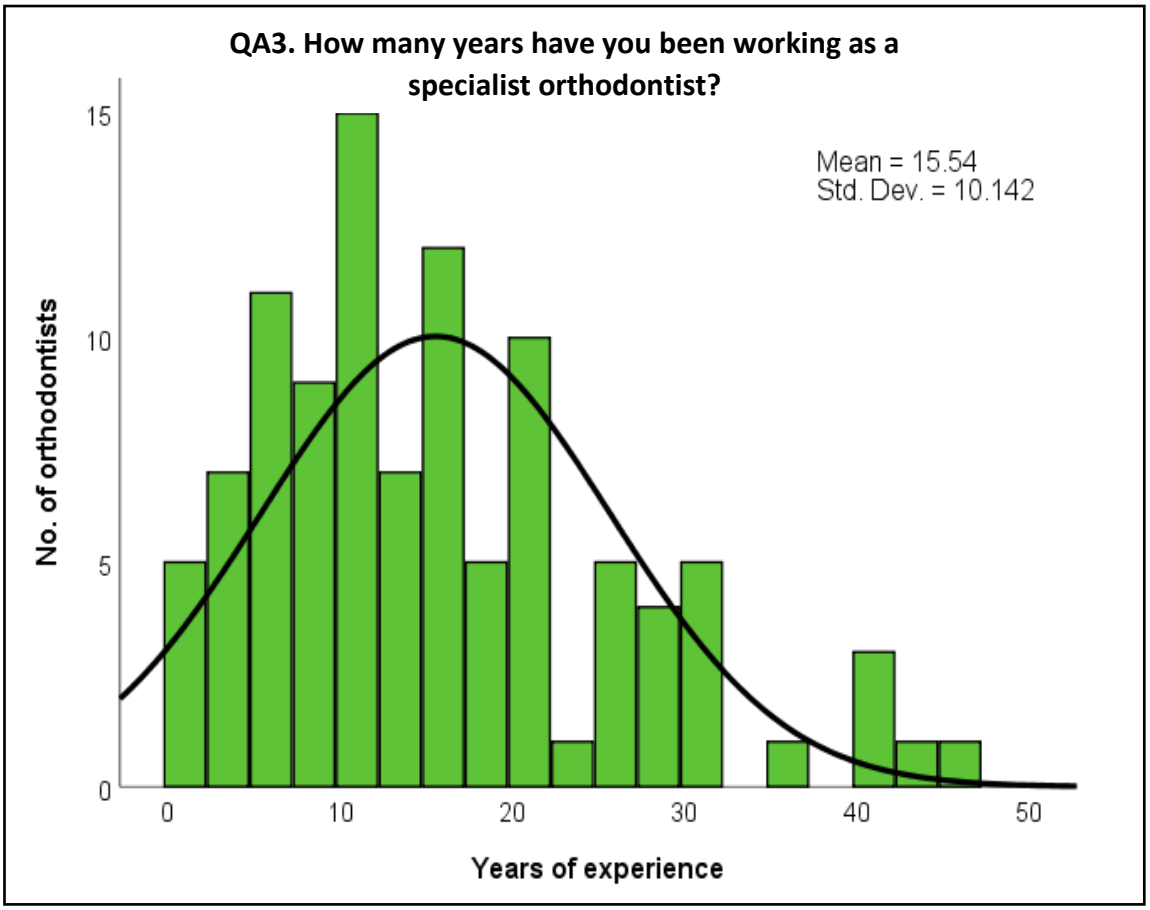


Fig. 7: Number of years of specialist experience of respondents (n=102)

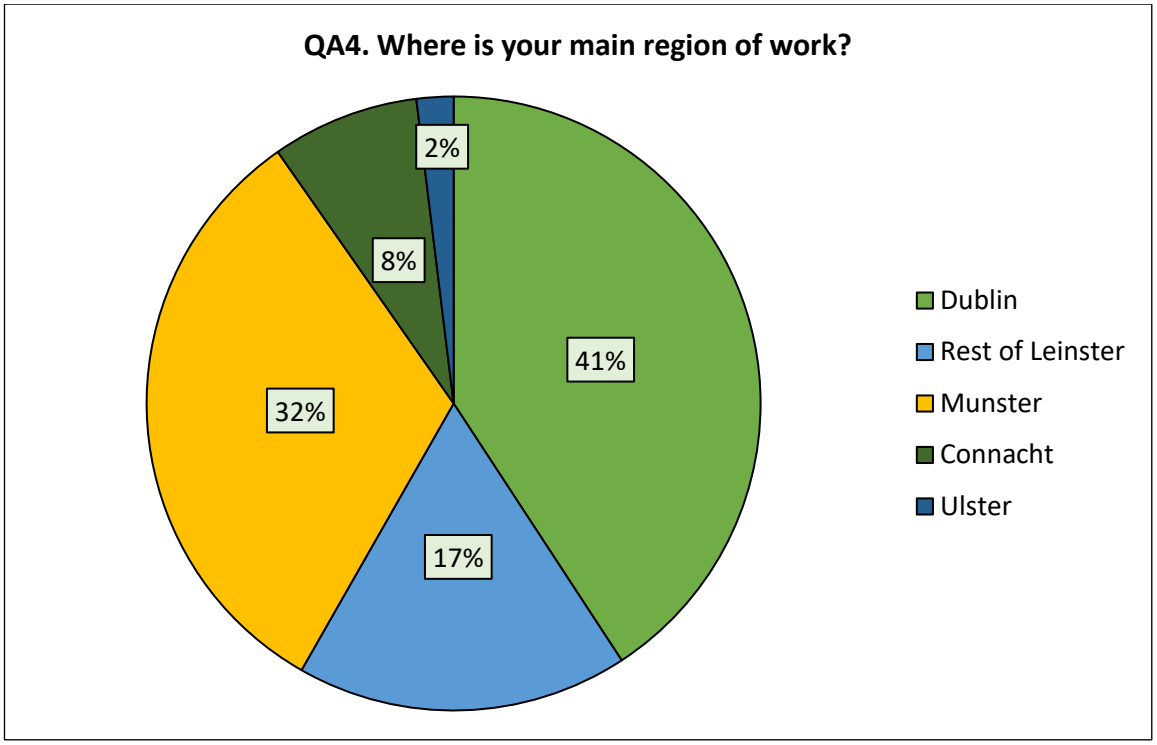


Fig. 8: Main practicing location of specialist orthodontists (n=103)

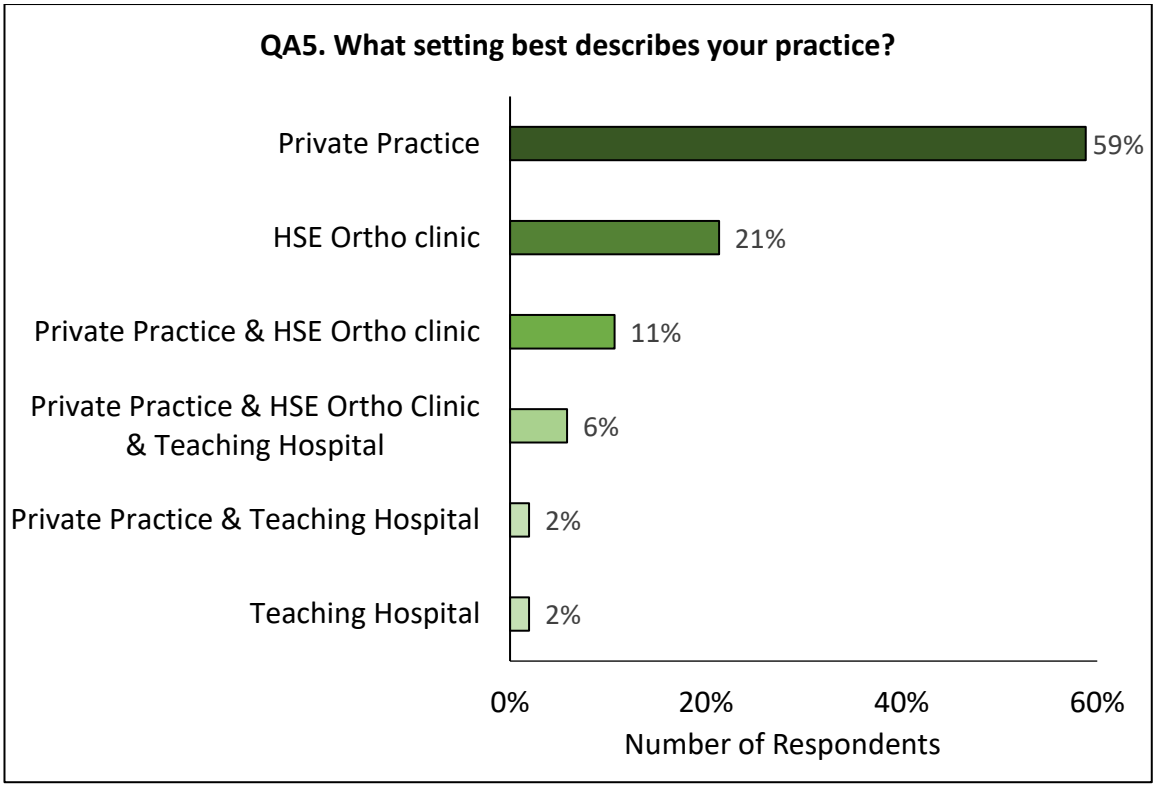


Fig. 9: Practice settings of specialist orthodontists (n=103)

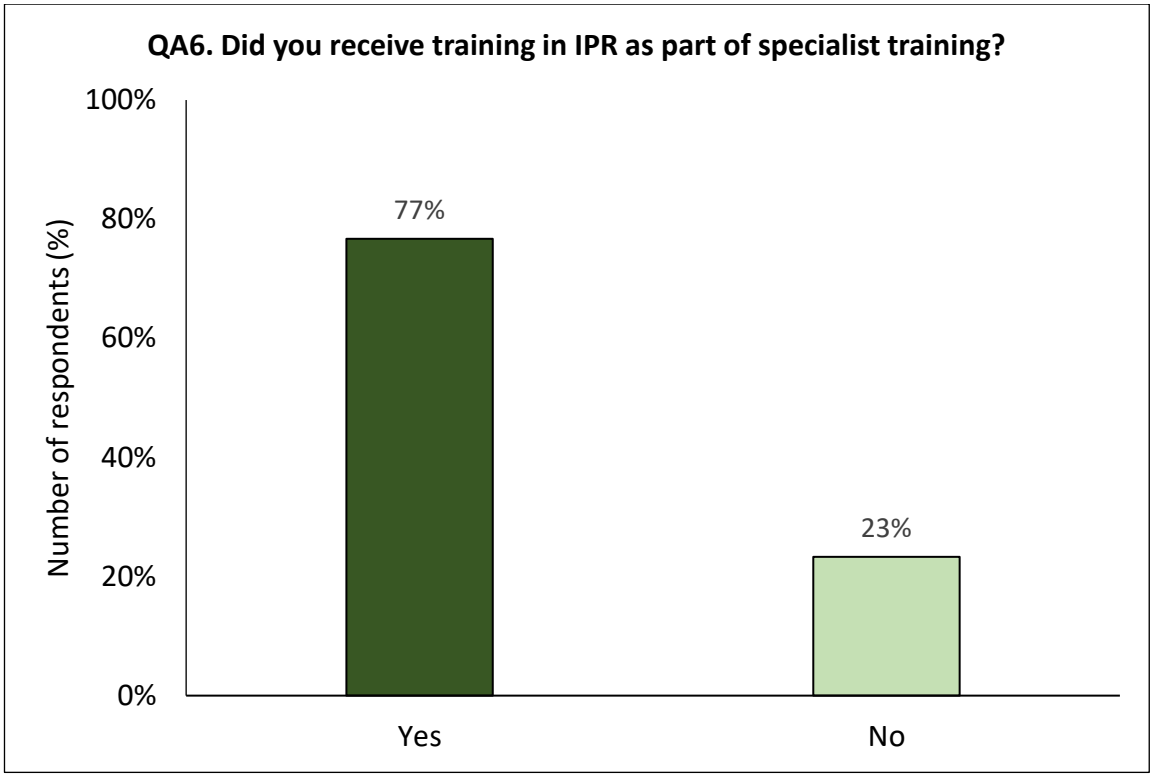


Fig. 10: Prevalence of IPR training as part of specialist training (n=103)

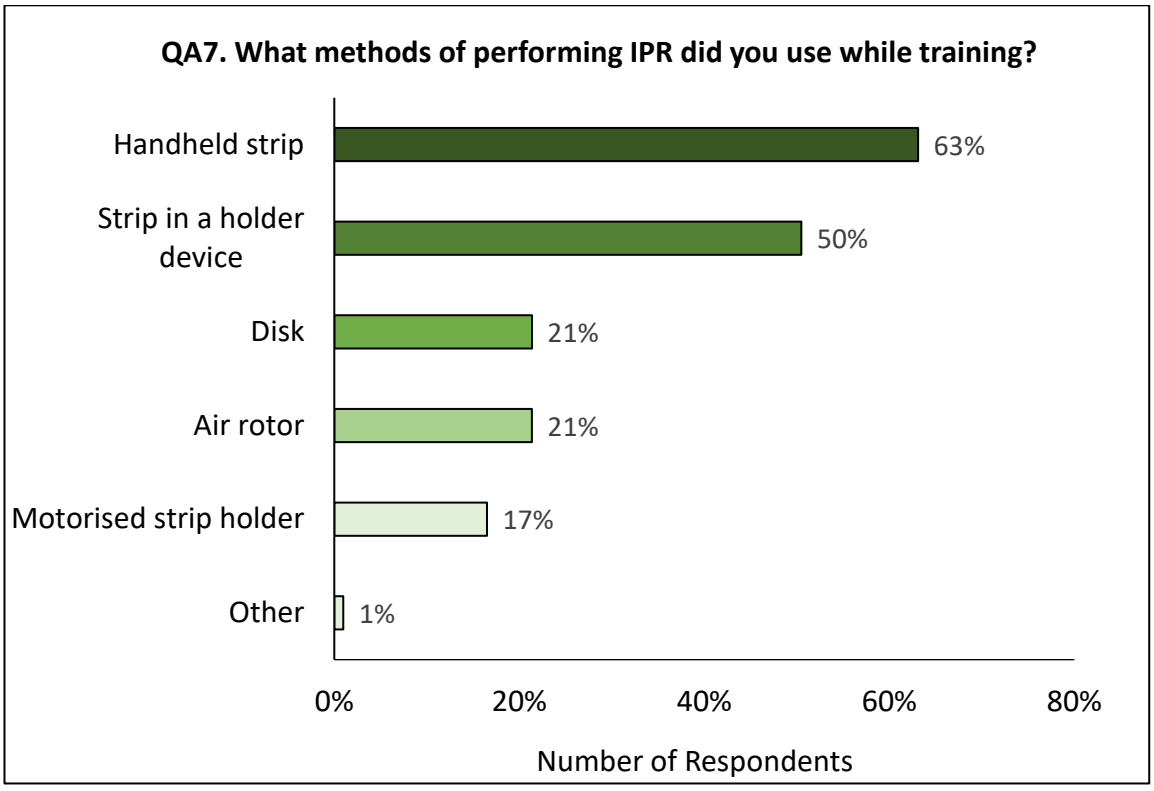


Fig. 11: Methods of IPR used during specialist training (n=105)

5.1.4 Section B: Use of interproximal reduction

Nearly all (98%) orthodontists perform IPR (**Fig. 12**), with almost half (47%) of orthodontists using IPR routinely to gain intra-arch space (**Table 17**). IPR was most often used in adult, followed by adolescent patients in the permanent dentition. Respondents rarely used IPR in the primary or mixed dentition (**Fig. 13**). IPR was most commonly performed in Class I malocclusion but the reported difference in frequency of use of IPR between different malocclusions was small (**Fig. 14**). IPR was most commonly employed during aligner treatment, followed by conventional fixed appliances, and was used least often in conjunction with functional appliances (**Fig. 15**). IPR was undertaken with varying frequency at all stages of treatment, with the most common being after initial tooth alignment. During the retention phase of treatment was the least common time to perform IPR (**Fig. 16**).

Respondents reported using IPR for multiple indications, such as triangular-shaped teeth (97% of orthodontists), reshaping existing restorations (92%), addressing TSDs (89%) and reducing black triangles (66%). The amount of crowding present impacted on whether IPR was indicated or not, as 92% of orthodontists considered mild crowding to be an indication for the use of IPR, reducing to 40% and 12% in moderate and severe crowding respectively (**Fig. 17**).

The most common teeth to be reduced were in the mandibular anterior segment. Mandibular lateral incisors most frequently underwent IPR, with 35% and 14% performing IPR on this tooth ‘often’ and ‘very often’ respectively. The next most frequently treated tooth was the mandibular central incisor, followed by the mandibular canine, maxillary central and maxillary lateral incisor. Orthodontists

reported using IPR with decreasing frequency the more posteriorly the tooth was located. Mandibular premolars were reduced slightly more often than their maxillary counterparts, whereas the inverse was reported for molars (**Table 15** and **Table 16**). Just over a quarter (26%) of orthodontists carried out a Bolton analysis of tooth sizes before reducing the proximal surfaces of teeth (**Fig. 18**).

Respondents varied in the amount of reduction they were comfortable to perform on proximal surfaces. The greatest numbers were comfortable to remove 0.3mm from each proximal surface of the upper (42.7%) and lower (39.2%) anterior teeth. A majority reported not performing IPR in the upper or lower posterior segments (33.7% and 34.7% respectively), but of those who did, the majority were comfortable removing 0.4mm of enamel from each proximal surface (**Fig. 19**). The maximum amount of space orthodontists created with IPR was reported by 60% of respondents to be 2-4mm in both upper and lower arches. One in five was not willing to create more than 2mm of space using IPR, while another one in five was happy to create greater than 4mm of space. No orthodontist was willing to create more than 10mm of space in either arch (**Fig. 20**).

Half of orthodontists reported no change in their frequency of use of IPR over the past 5 years, while 44% noted an increase in use over this time period (**Fig. 21**). Where frequency of use had changed, the most common reasons for this change were an increase in use of aligner treatment (68.5%), an increase in the number of patients presenting with mild crowding (62%), and increasing patient reluctance to extract teeth (57.7%) (**Fig. 22**). Half of orthodontists felt that IPR had influenced how much crowding they were willing to resolve before opting for extractions, while the other

half did not report any difference in extraction decision due to the option of IPR (**Fig. 23**). Use of IPR did not influence retainer choice in a large majority (92%) of respondents (**Fig. 24**). Where retainer choice was influenced, the most common difference was that a bonded retainer was used where IPR was carried out.

Most orthodontists (87%) agreed or strongly agreed that IPR was easier to perform anteriorly rather than posteriorly. For aesthetic reasons, some orthodontists preferred to perform IPR posteriorly rather than anteriorly, although this was not common, with fewer than one in ten orthodontists reportedly doing so. A majority (72%) of orthodontists agreed or strongly agreed that IPR was a minimally invasive procedure which posed little risk for the development of interproximal caries, while just 8% disagreed with this statement. More than half of orthodontists (62%) agreed or strongly agreed that they had researched the effects of IPR on the health of teeth, and 87% would be willing to have IPR performed on their own teeth (**Table 17**).

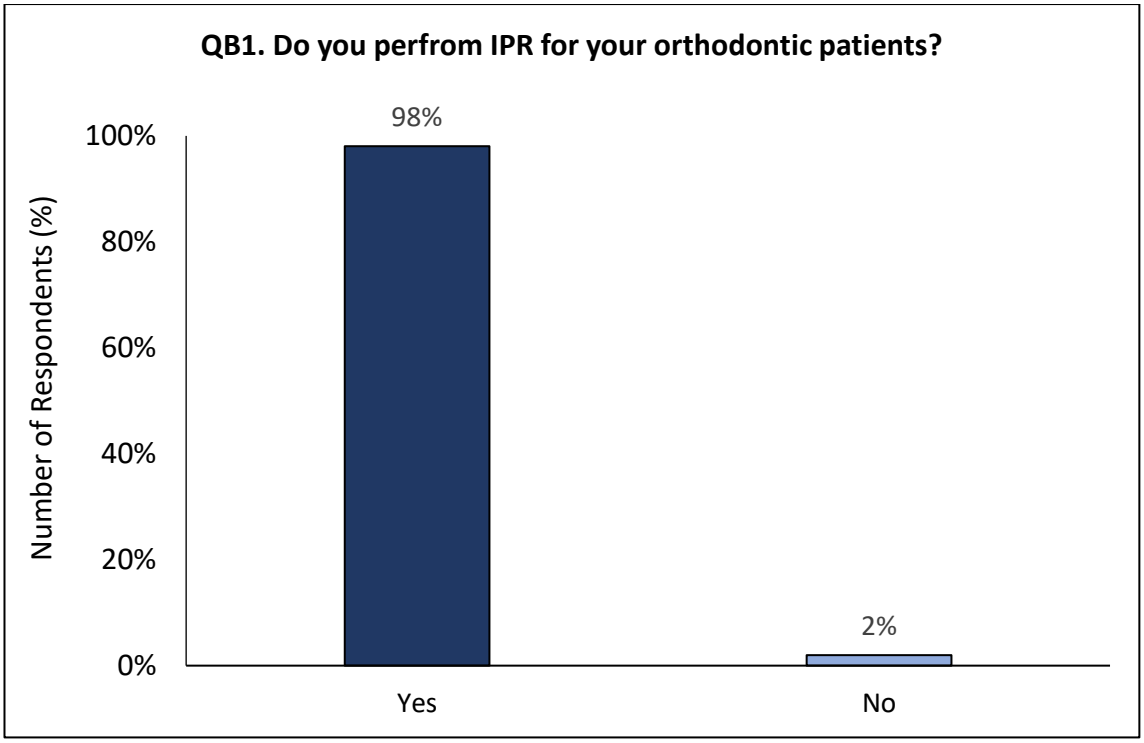


Fig. 12: Proportion of specialist orthodontists who use IPR (n=101)

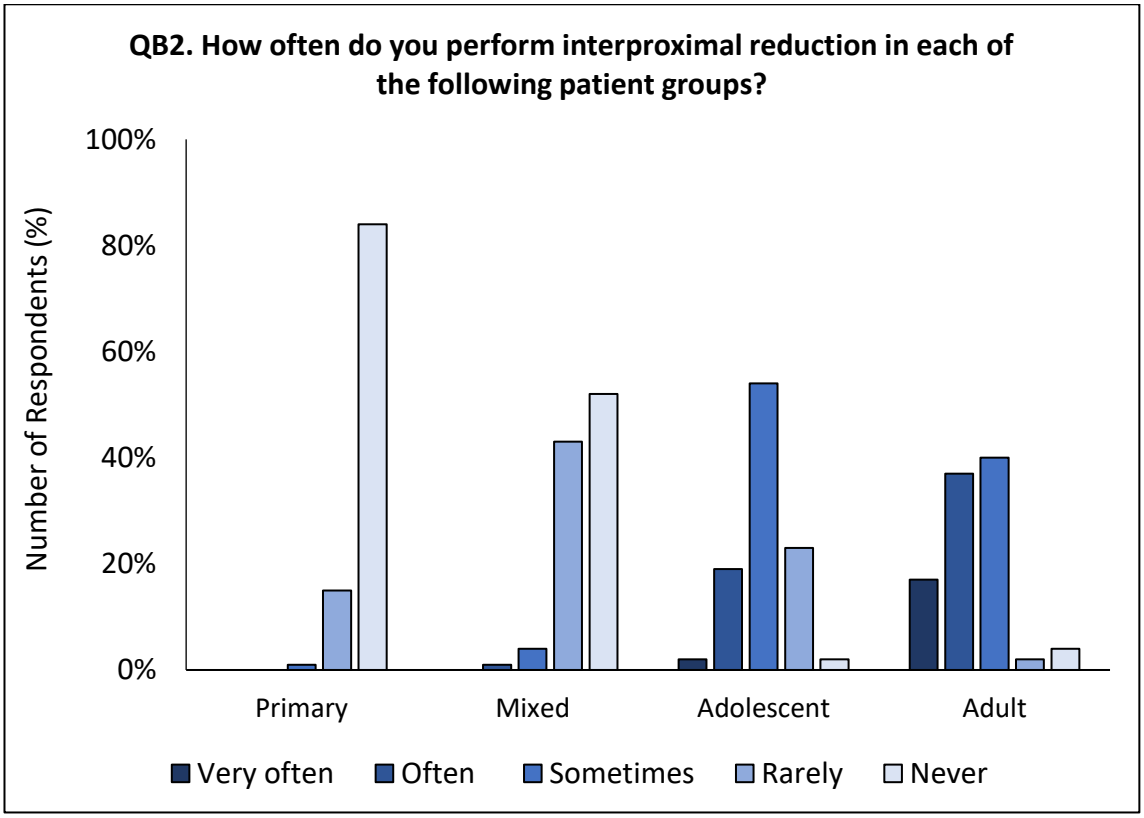


Fig. 13: Use of IPR in different age groups (n=99)

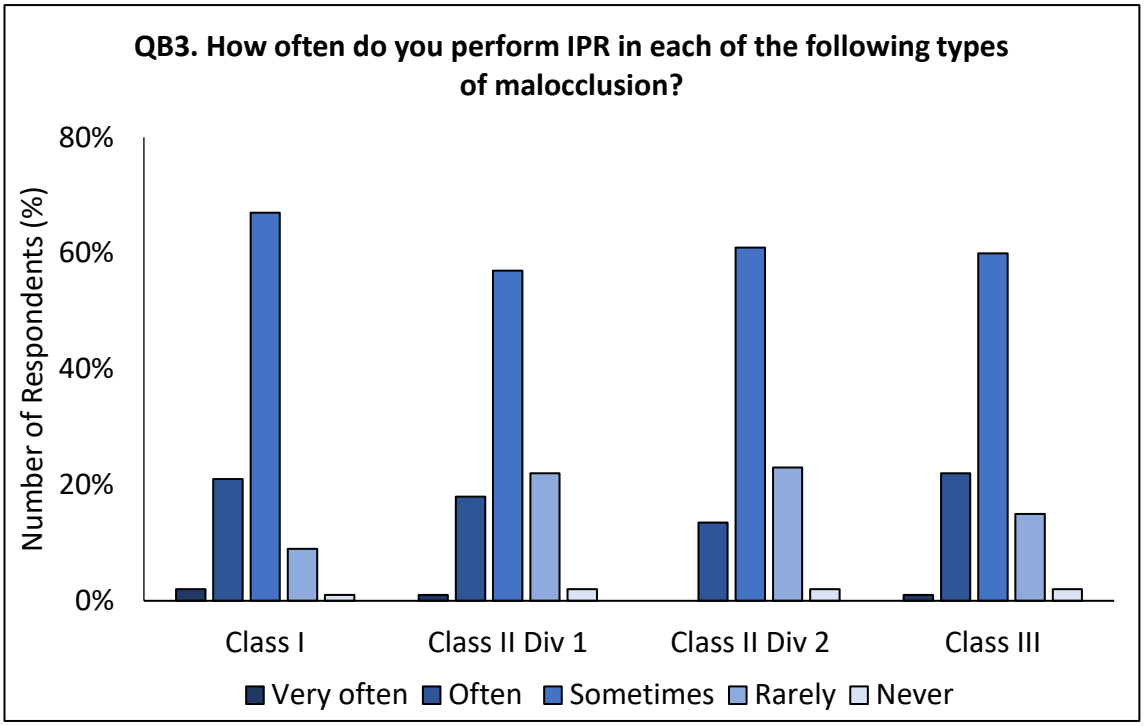


Fig. 14: Use of IPR in different types of malocclusion (n=97)

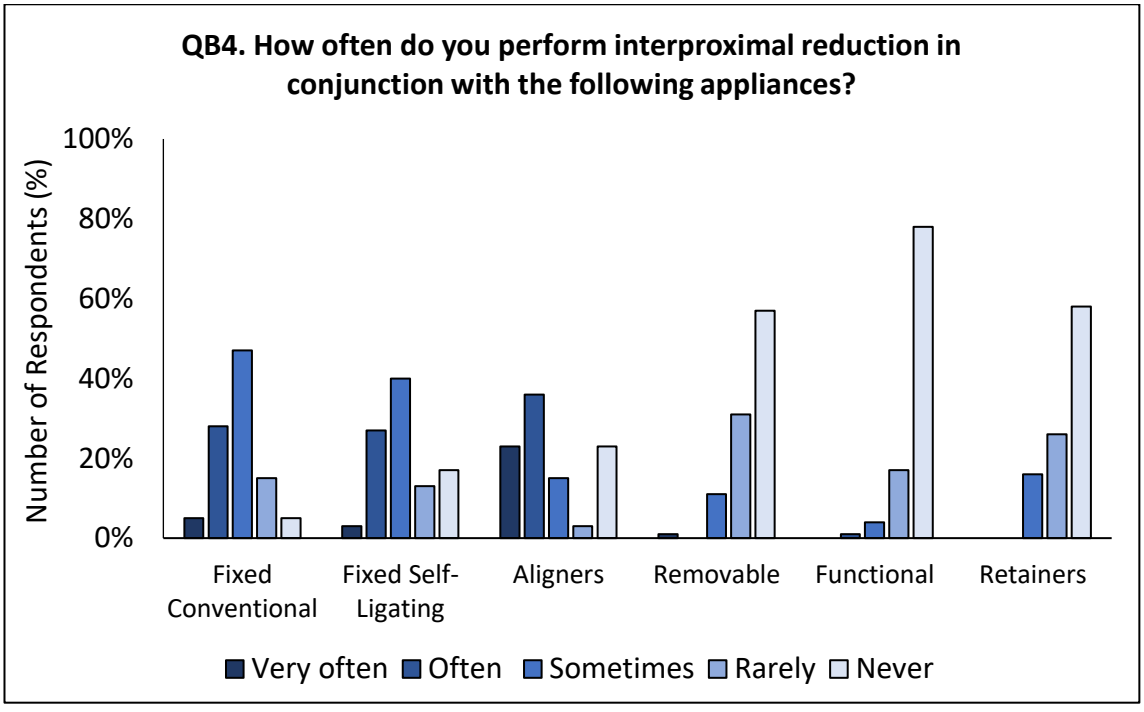


Fig. 15: Use of IPR in conjunction with different appliances (n=98)

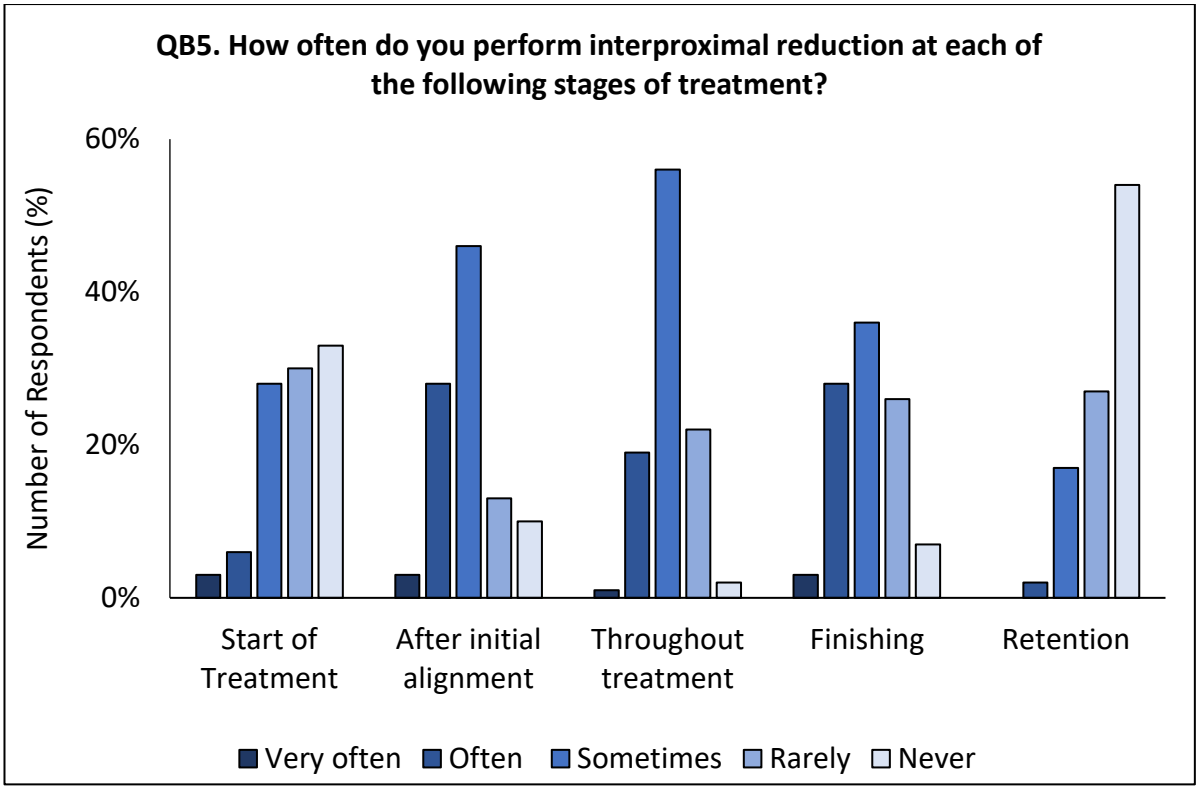


Fig. 16: Use of IPR at different stages of treatment (n=94)

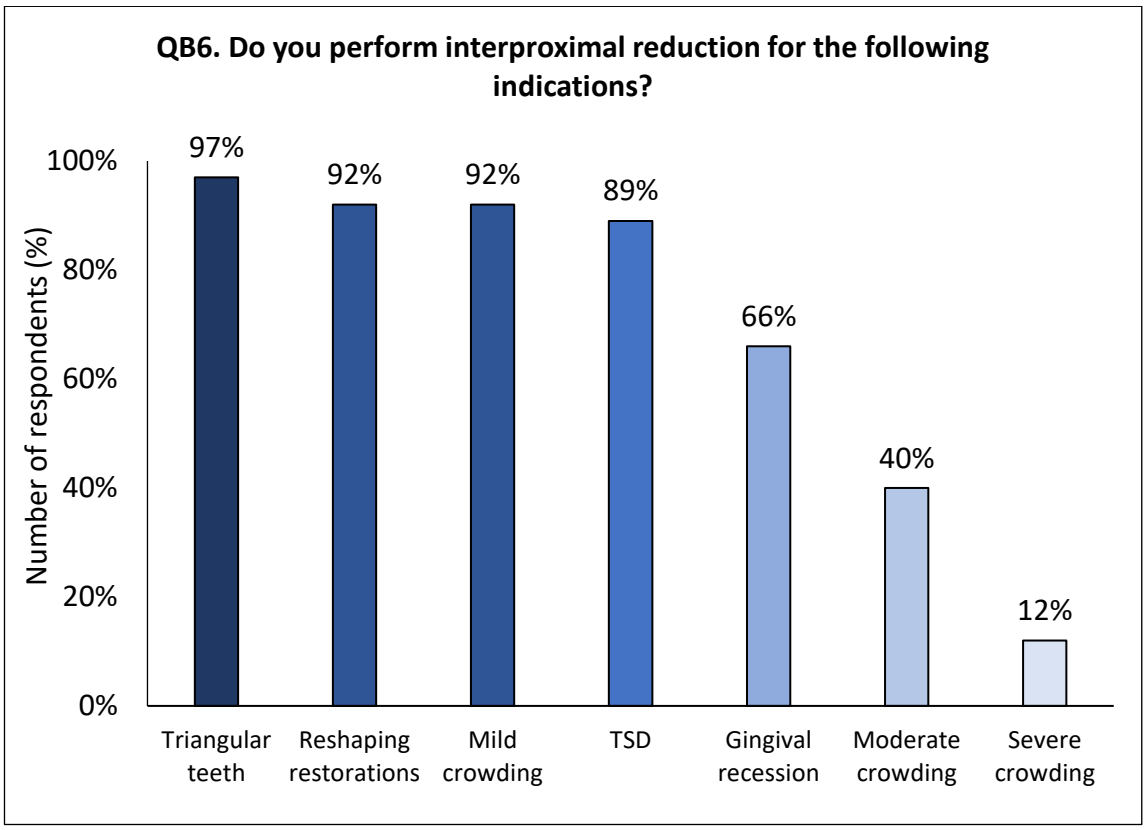


Fig. 17: Indications for use of IPR (n=97)

Table 15: How often IPR is performed on each tooth (n=97)

Tooth	Very Often (%)	Often (%)	Sometimes (%)	Rarely (%)	Never (%)
Mx1	8.2	18.6	49.5	17.5	6.2
Mx2	4.1	18.6	41.2	27.8	8.2
Mx3	1.1	10.5	38.9	33.7	15.8
Mx4	0	2.1	33.7	42.1	22.1
Mx5	0	1	26	46.9	26
Mx6	0	1	10.4	44.8	43.8
Mx7	0	1	3.1	21.9	74
Mn1	13.4	33	43.3	10.3	0
Mn2	14.4	35.1	42.3	8.2	0
Mn3	9.4	22.9	41.7	24	2.1
Mn4	1	6.3	42.7	39.6	10.4
Mn5	1	5.2	30.2	40.6	22.9
Mn6	0	1	9.4	40.6	49
Mn7	0	1	3.1	17.7	78.1

Table 16: Teeth ranked according to how frequently IPR is performed

Tooth	Mean	SD	Rank
Mn2	2.44	0.841	1
Mn1	2.51	0.855	2
Mn3	2.86	0.958	3
Mx1	2.95	0.972	4
Mx2	3.18	0.968	5
Mn4	3.52	0.808	6
Mx3	3.53	0.921	7
Mn5	3.79	0.893	8
Mx4	3.84	0.790	9
Mx5	3.98	0.754	10
Mx6	4.31	0.701	11
Mn6	4.38	0.700	12
Mx7	4.69	0.586	13
Mn7	4.73	0.571	14

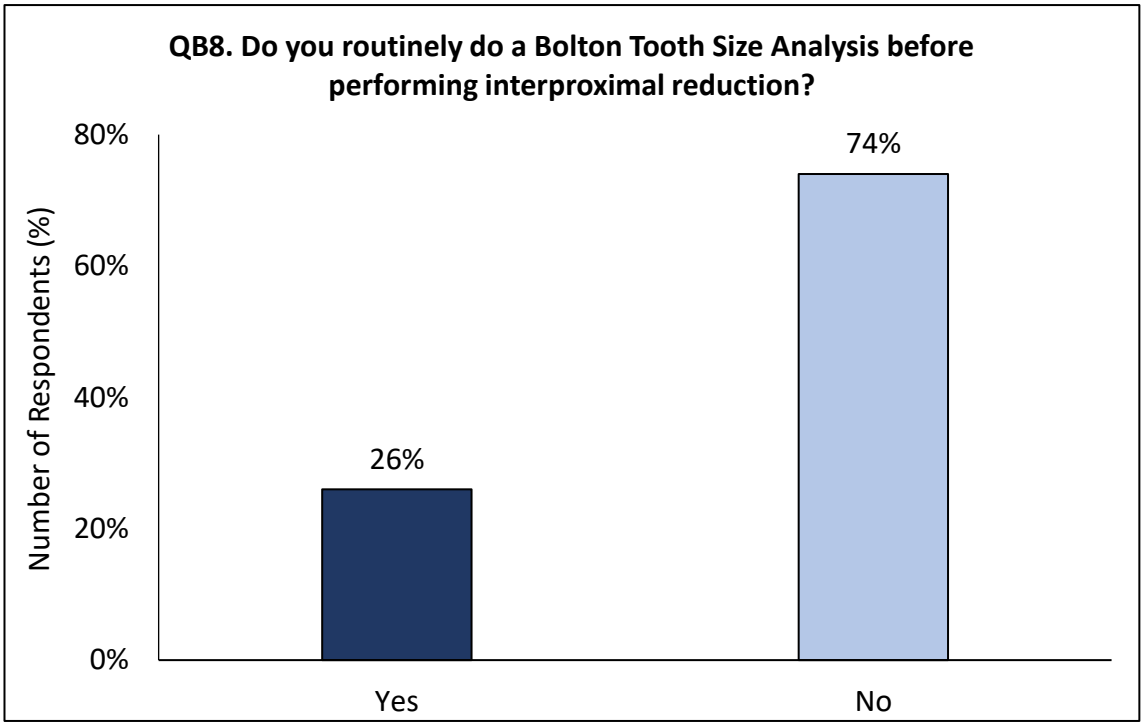


Fig. 18: Prevalence of doing a Bolton Analysis before IPR (n=96)

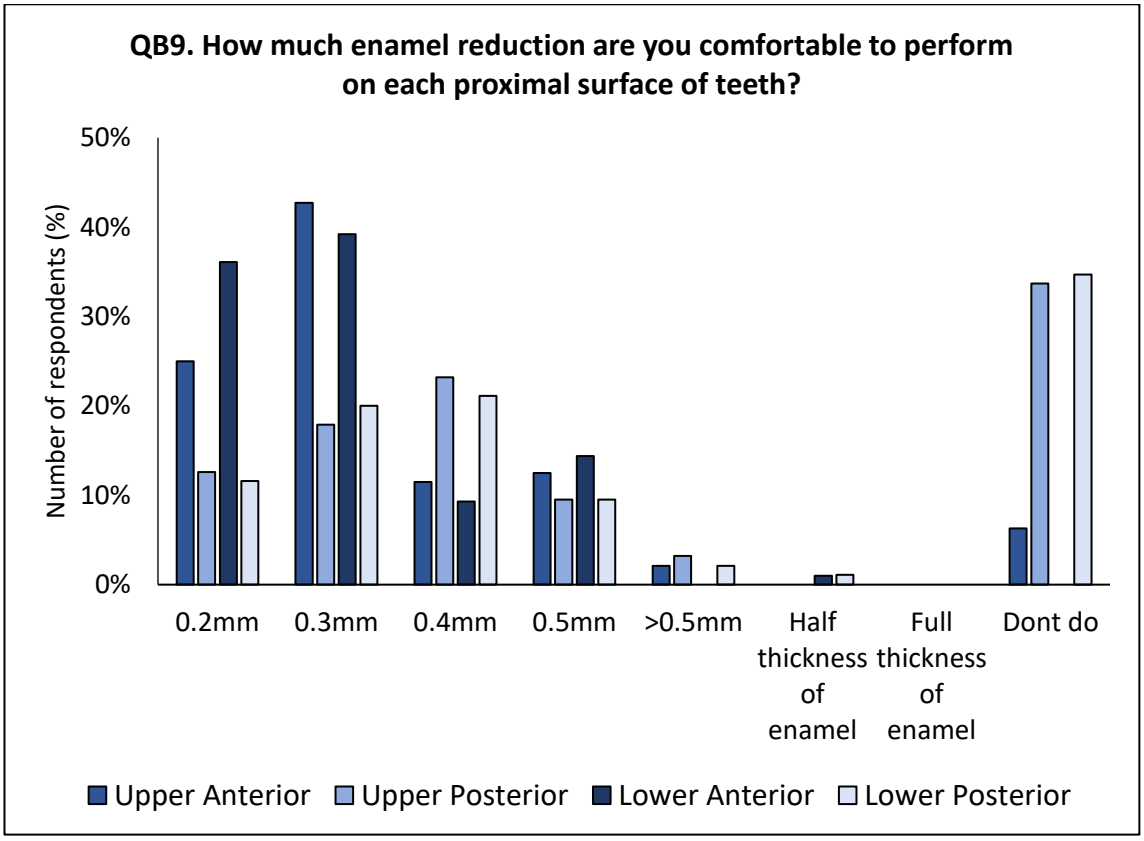


Fig. 19: Amount of enamel reduction performed on each proximal surface (n=97)

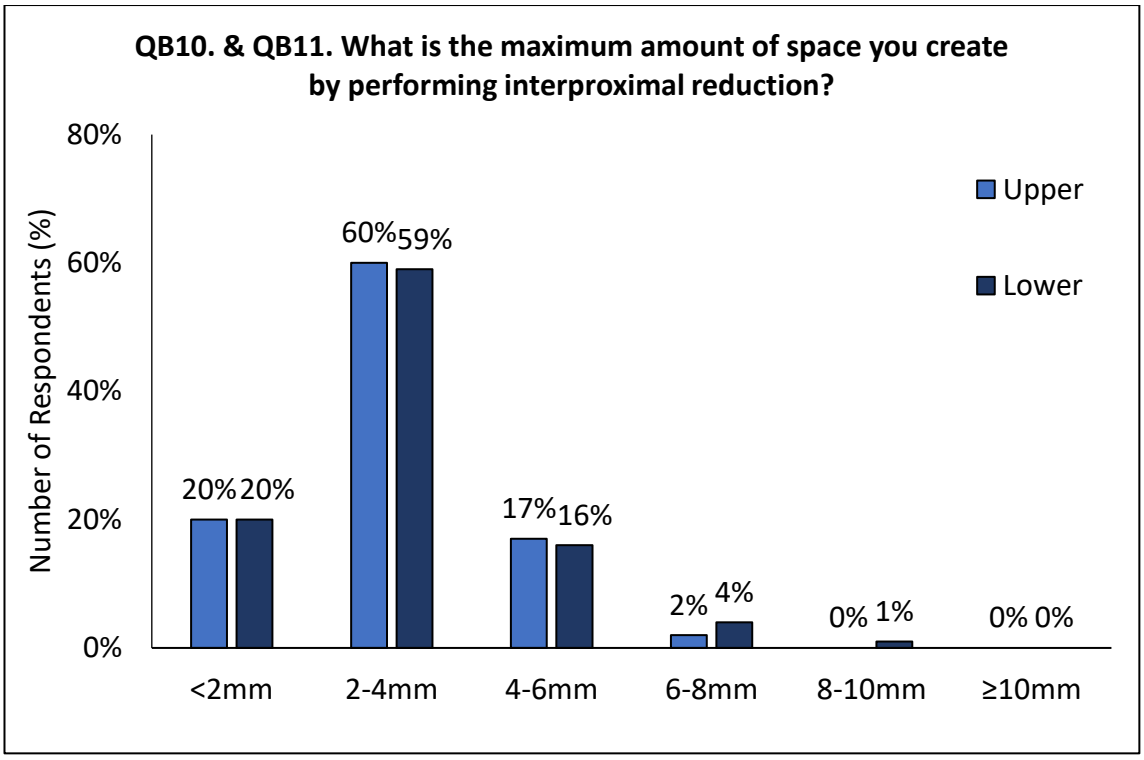


Fig. 20: Amount of space created using IPR (n=98)

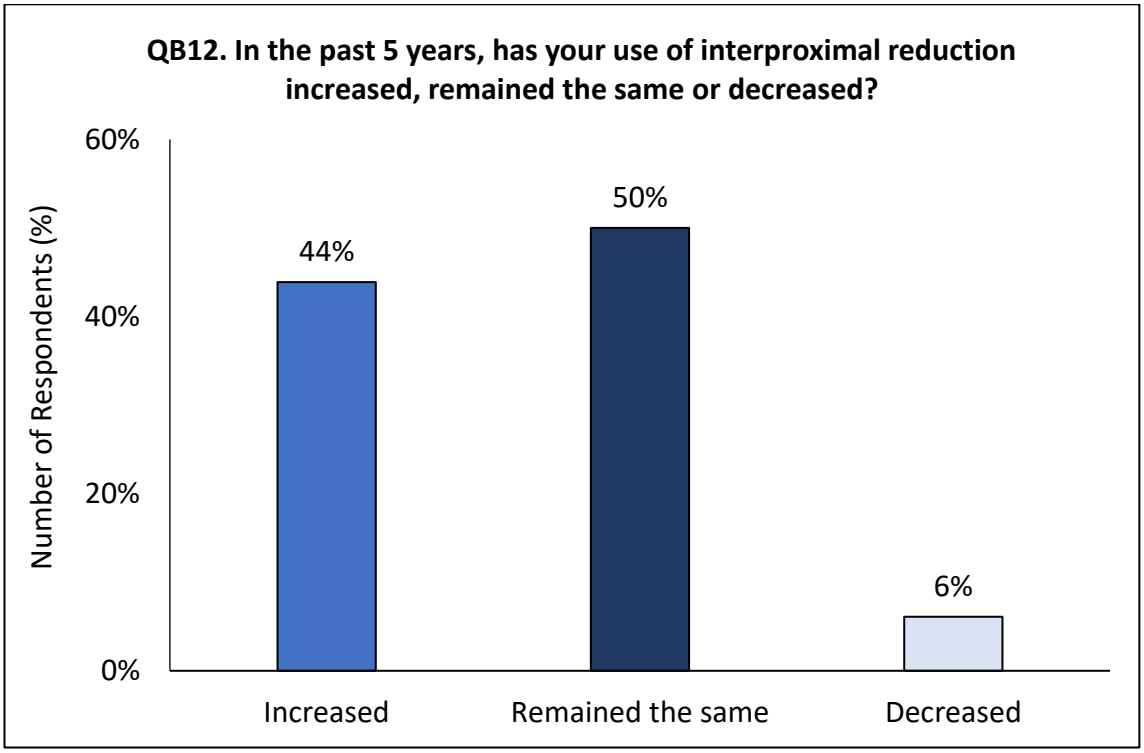


Fig. 21: Change in frequency of use of IPR over the past 5 years (n=98)

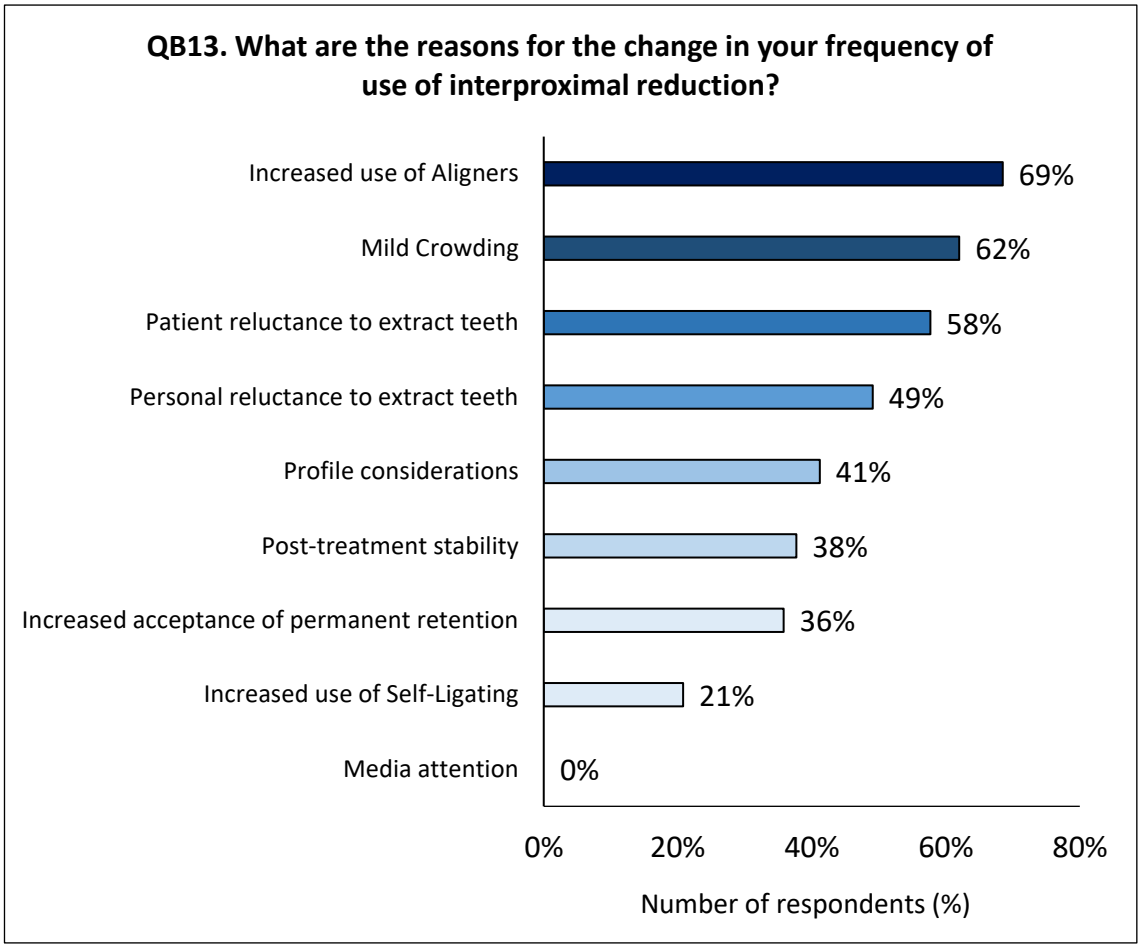


Fig. 22: Reasons for change in frequency of use of IPR over the past 5 years (n=54)

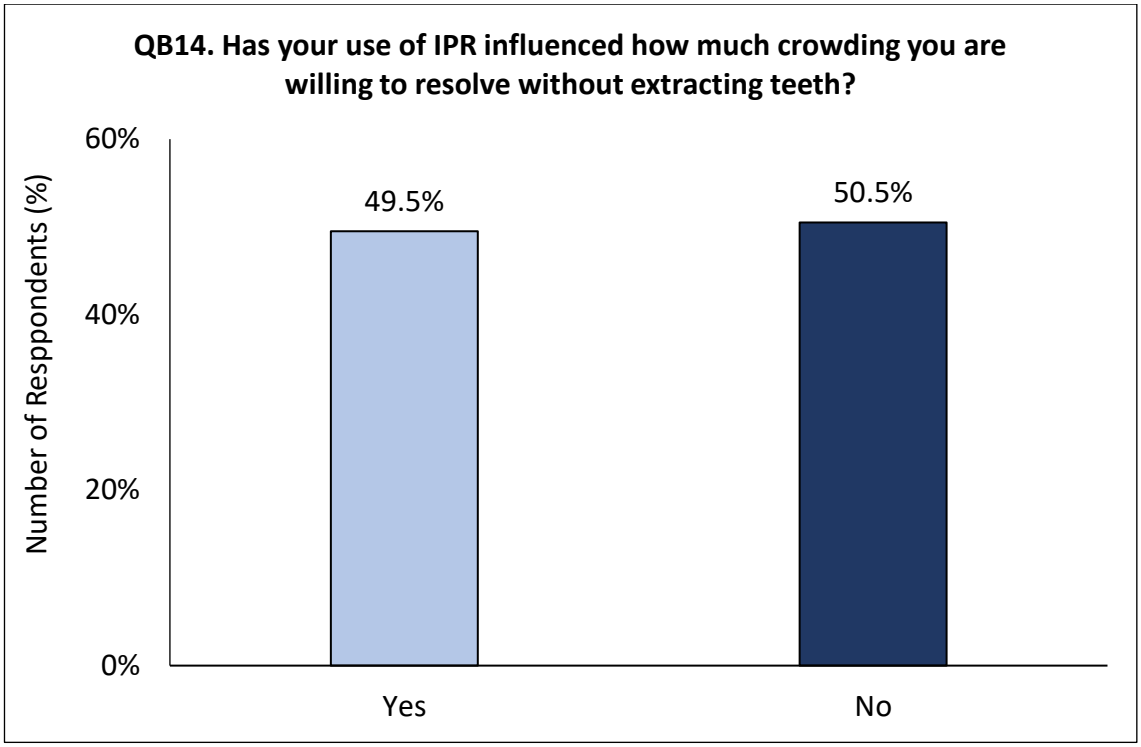


Fig. 23: Influence of IPR on decision to extract (n=99)

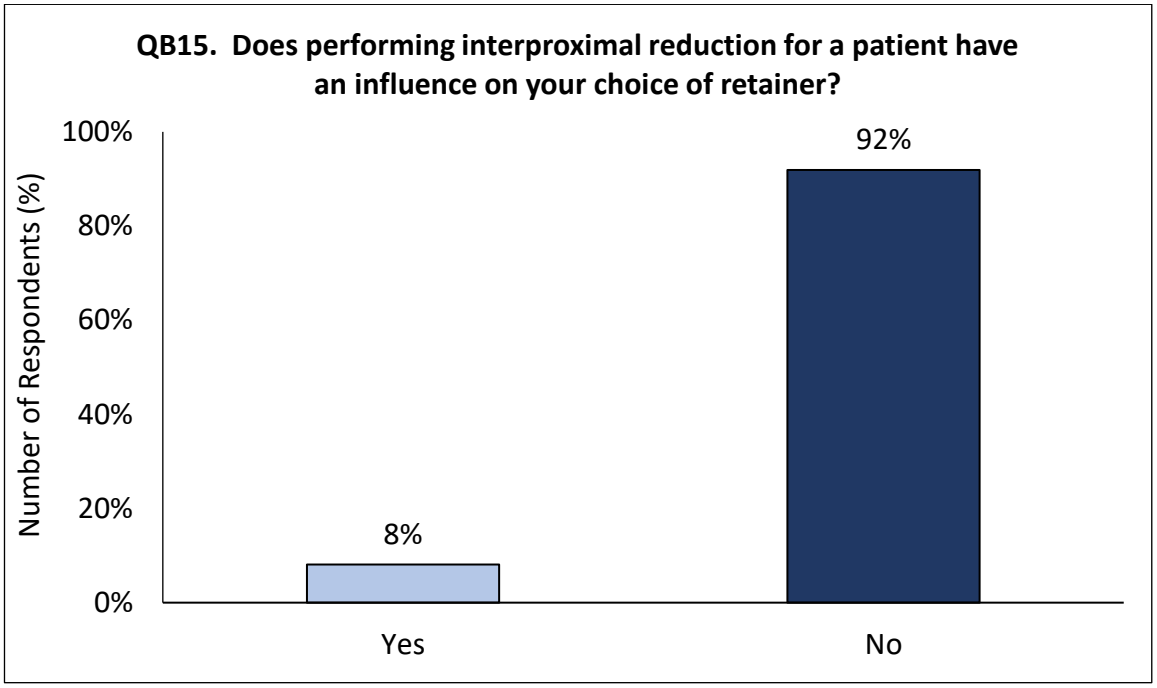


Fig. 24: Influence of IPR on retainer choice (n=99)

Table 17: Opinions of specialist orthodontists about IPR (n=99)

Statement	SA (%)	A (%)	N (%)	D (%)	SD (%)	TA (%)	TD (%)
I routinely perform interproximal reduction to gain intra-arch space	9.1	37.4	17.2	25.3	11.1	46.5	36.4
From an aesthetic standpoint, I prefer performing interproximal reduction on the posterior teeth than the anterior teeth	1.0	8.2	23.7	48.5	18.6	9.2	67.1
Interproximal reduction is easier to perform on anterior teeth than posterior teeth	22.4	64.3	9.2	2.0	2.0	86.7	4.0
Interproximal reduction is a minimally invasive procedure that poses little risk for the development of interproximal caries	13.3	58.2	20.4	6.1	2.0	71.5	8.1
The aesthetic and occlusal benefits of interproximal reduction outweigh the potential risk of caries	12.2	49.0	27.6	9.2	2.0	61.2	11.2
I have researched the effects of interproximal reduction on the health of teeth	13.3	49.0	25.5	6.1	6.1	62.3	12.2
I would be willing to have interproximal reduction performed on my own teeth	21.2	65.7	7.1	5.1	1.0	86.9	6.1

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, TA = Total percentage who agree, TD = Total percentage who disagree

5.1.5 Section C: Performing interproximal reduction

Most orthodontists used a variety of different instruments to perform IPR, including handheld abrasive strips (87%), strip holder devices (58%), air rotors with diamond burs (51%) and others (**Fig. 25**). Handheld abrasive strips were the instrument of choice for the largest number of orthodontists, followed by a diamond bur in an air rotor handpiece (**Fig. 26**).

More than four in five orthodontists performed IPR over a number of visits rather than in a single visit (**Fig. 27**). Separation of teeth was not common before performing IPR, with just 17% of orthodontists having reported that they do this (**Fig. 28**). Most orthodontists (45%) spent less than five minutes carrying out IPR but a fifth (17%) spent longer than 10 minutes (**Fig. 29**).

Use of a leaf gauge was the most common method of measuring the amount of tooth reduction carried out (47%), followed by an estimate based on a known thickness of the device used to reduce the tooth surface (32%). A minority of orthodontists (13%) did not measure the amount of space created (**Fig. 30**).

More than half of orthodontists neither recontoured the teeth after IPR nor polished the surfaces which had been reduced (56% and 55% respectively) (**Fig. 31**). Surface treatment of reduced enamel was not done by a majority of orthodontists, with the most common surface treatment being fluoride varnish, used by 24% of respondents (**Fig. 32**).

Most orthodontists (93%) recorded the teeth on which IPR had been performed, while 64% recorded the amount of tooth reduction performed on each tooth (**Fig. 33**). Use

of a fluoride mouthwash and interdental brushes were the most common oral hygiene measures that patients were routinely advised to follow after IPR, recommended by 57% and 51% of orthodontists respectively (**Fig. 34**).

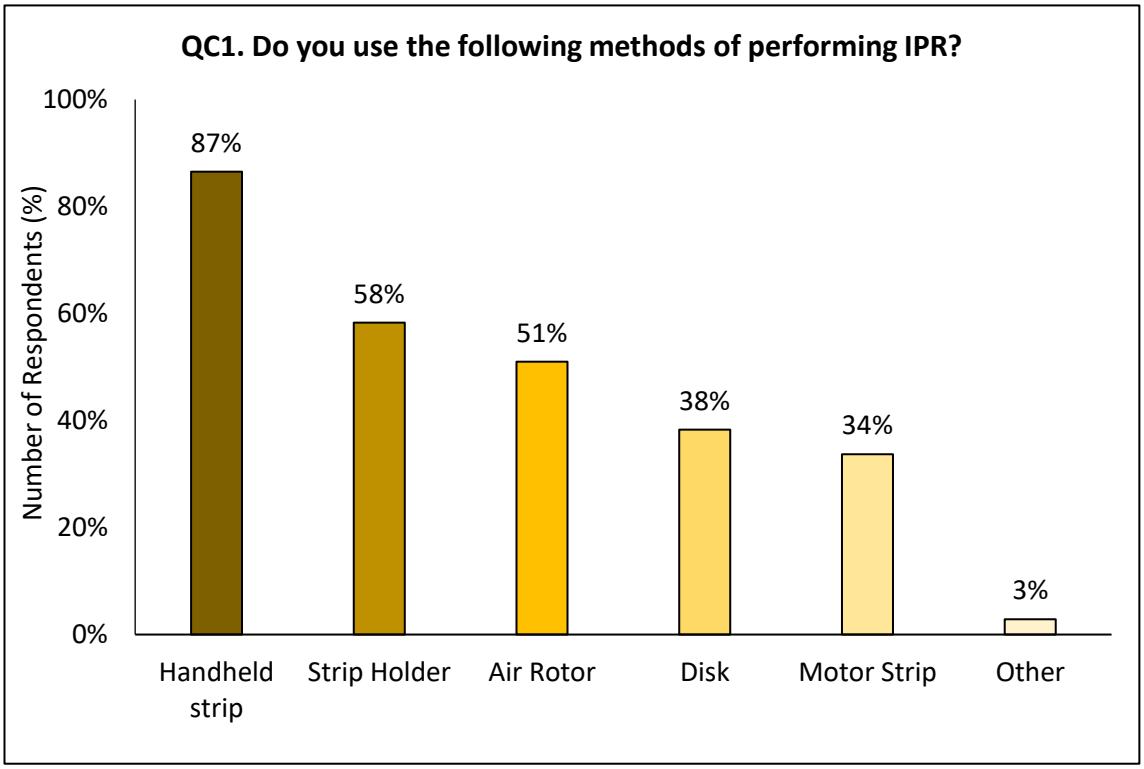


Fig. 25: Instruments used to perform IPR (n=98)

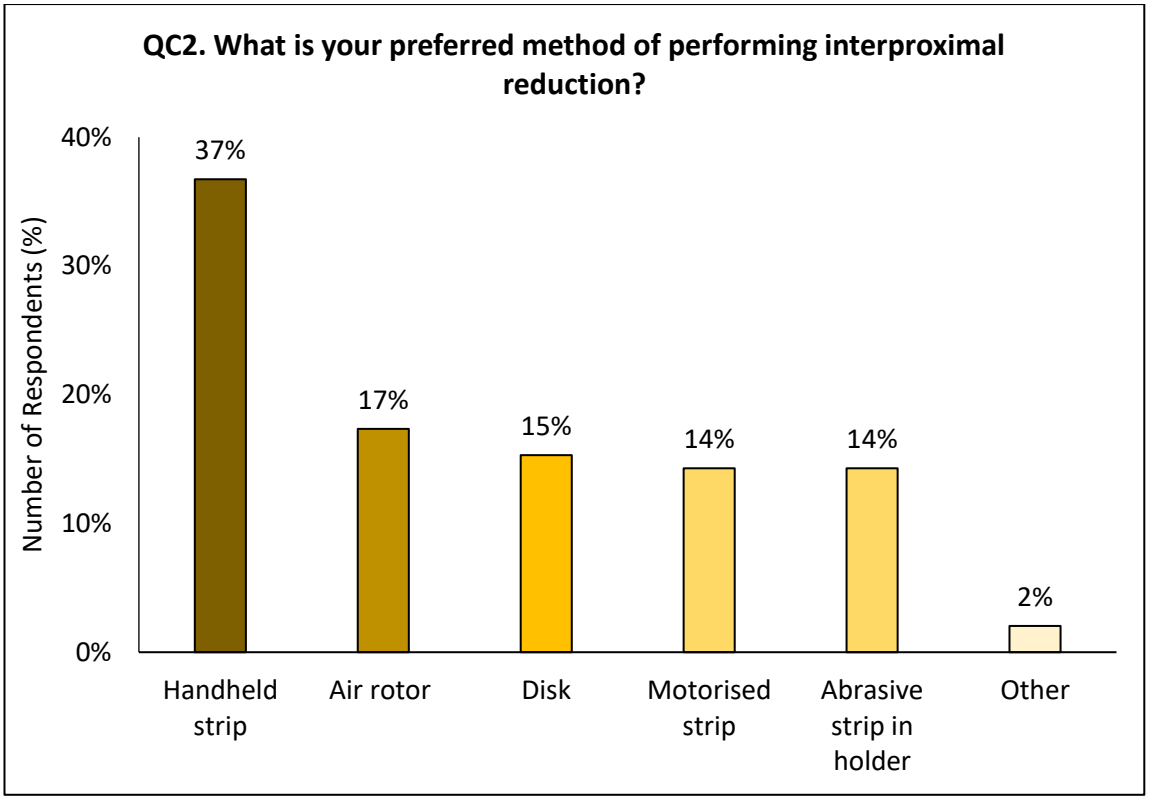


Fig. 26: Preferred instrument to perform IPR (n=98)

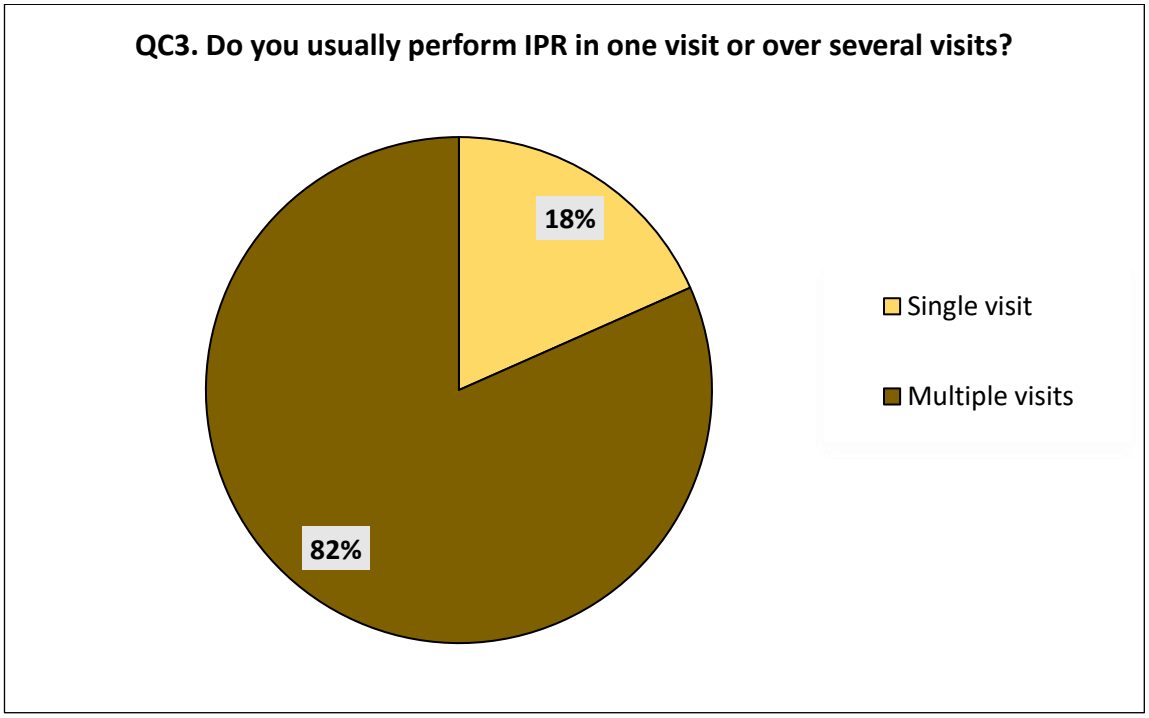


Fig. 27: Number of visits to perform IPR (n=98)

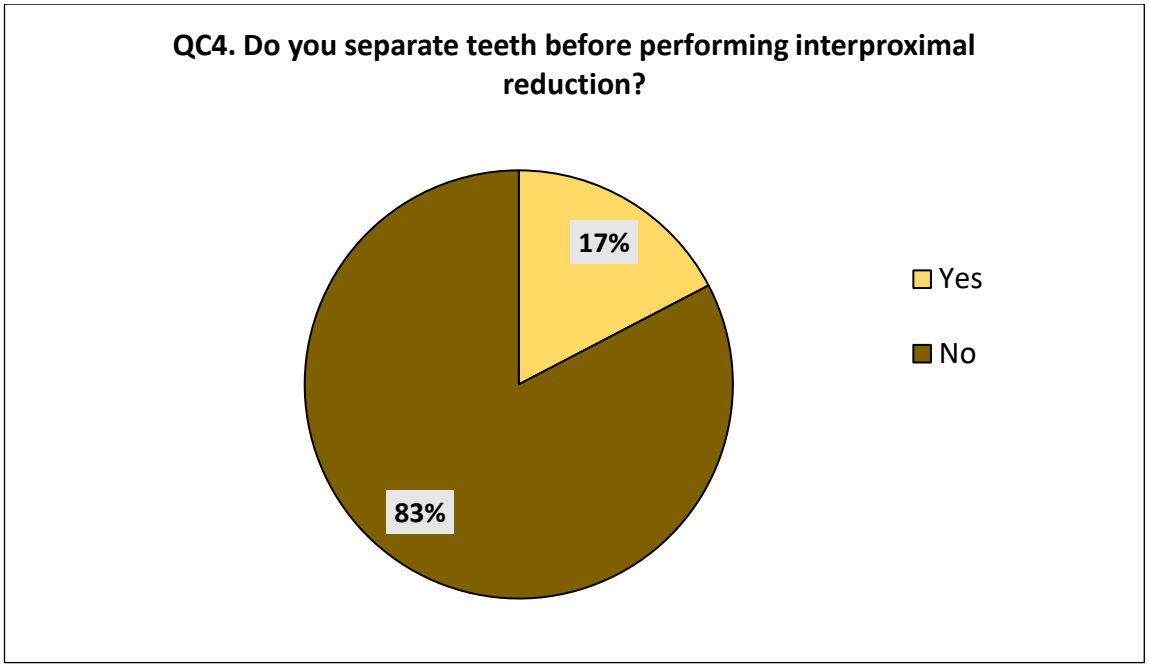


Fig. 28: Separation of teeth prior to IPR (n=98)

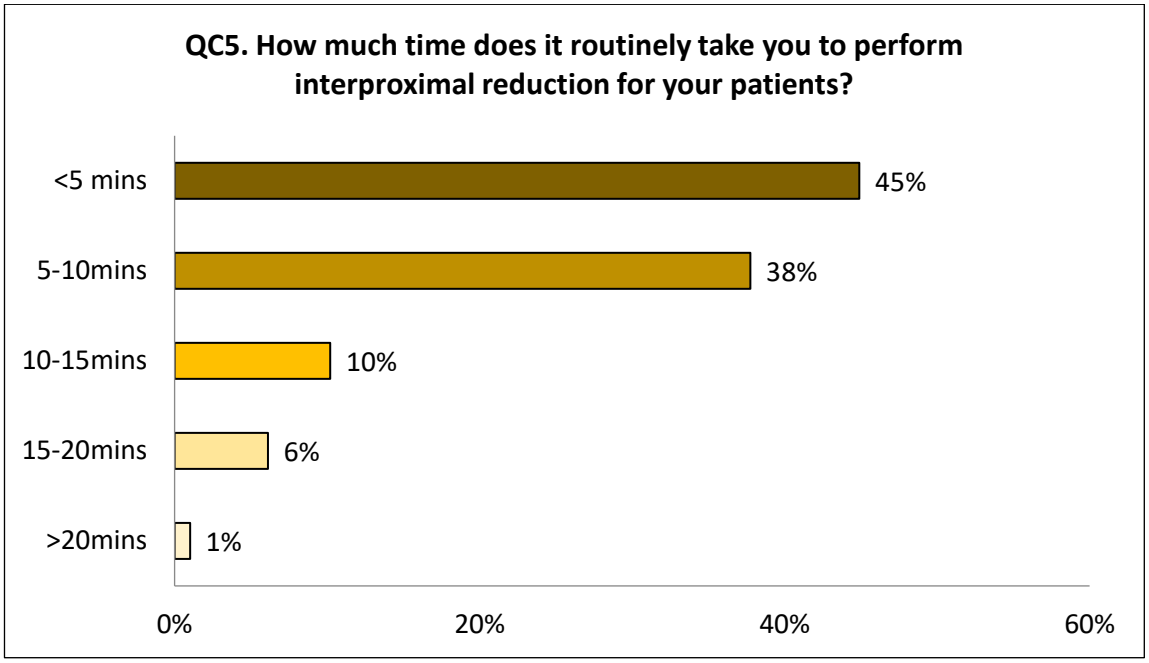


Fig. 29: Time taken to perform IPR (n=98)

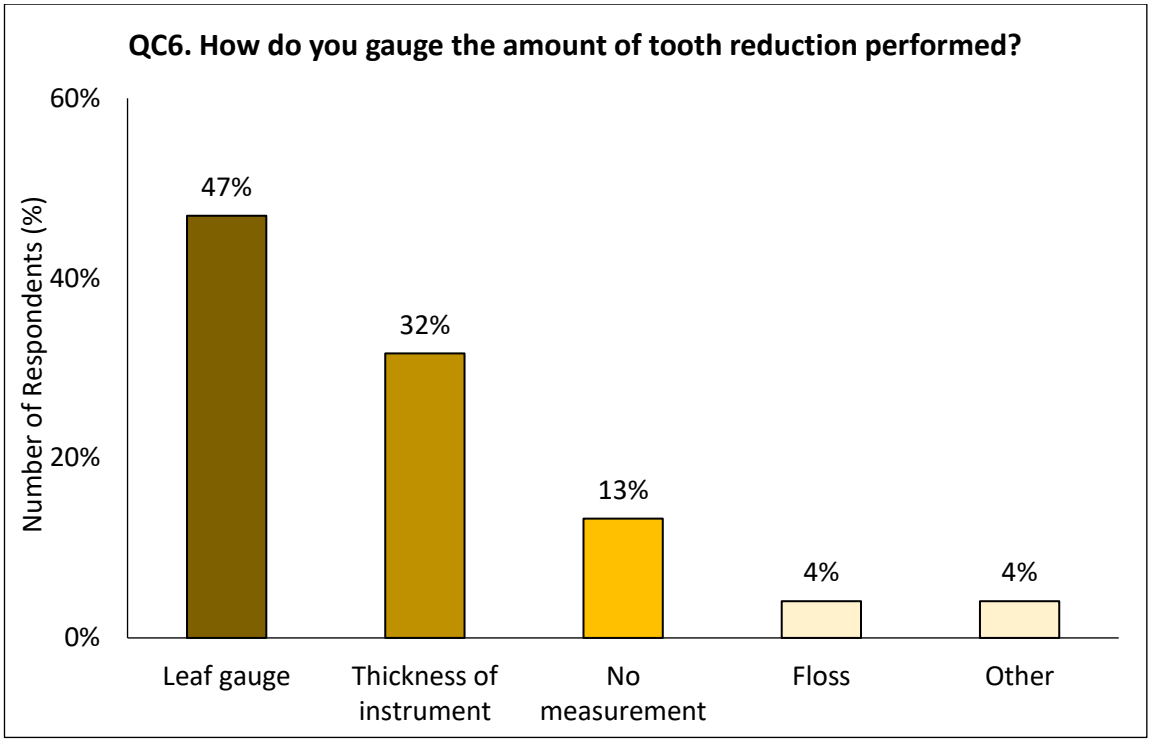


Fig. 30: How the amount of tooth reduction performed is measured (n=98)

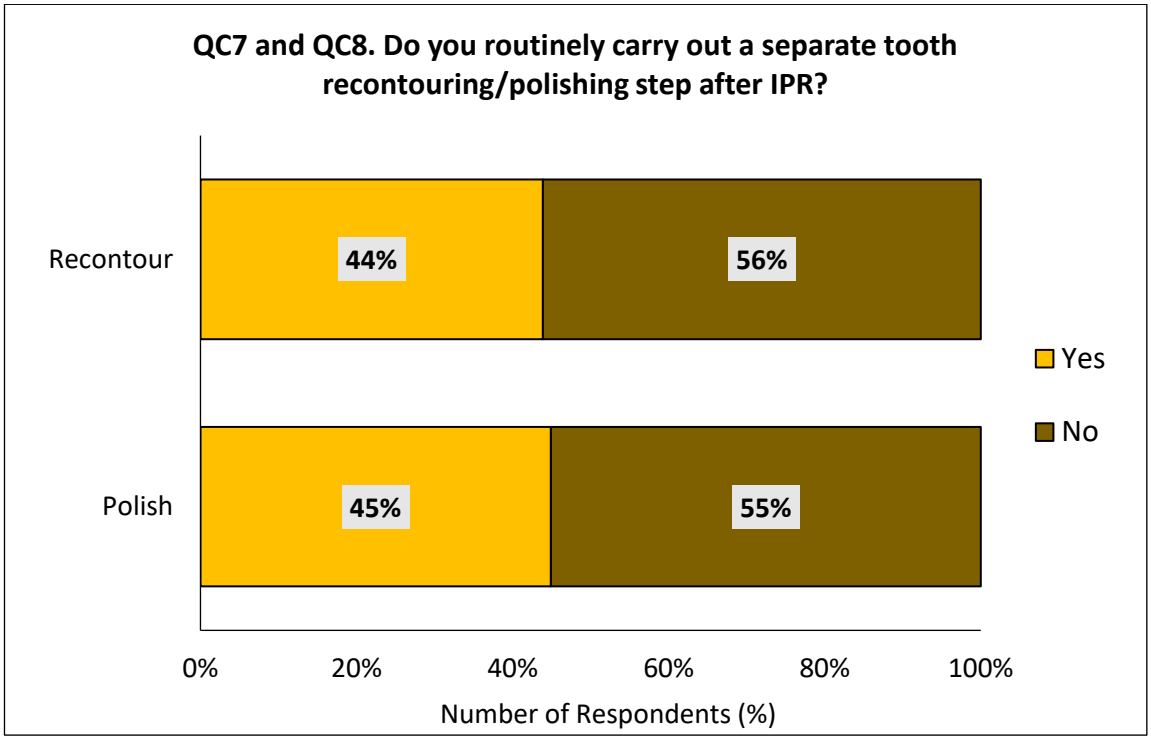


Fig. 31: Recontouring and polishing after IPR (n=98)

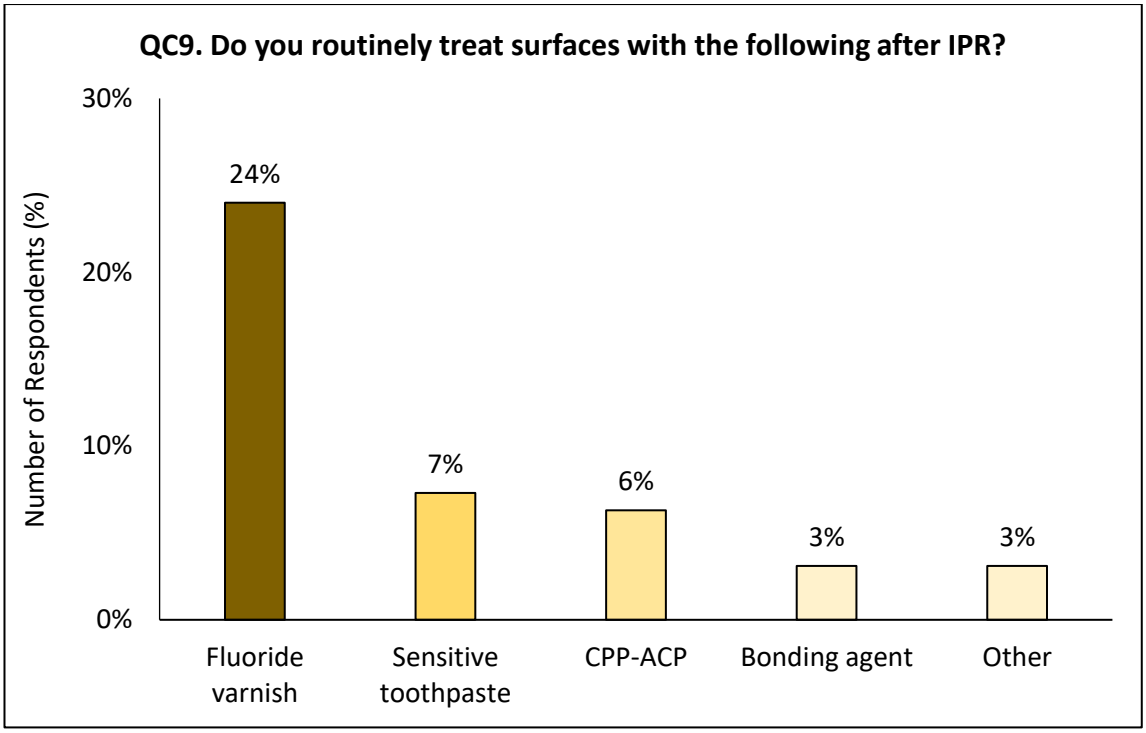


Fig. 32: Surface treatment after IPR (n=96)

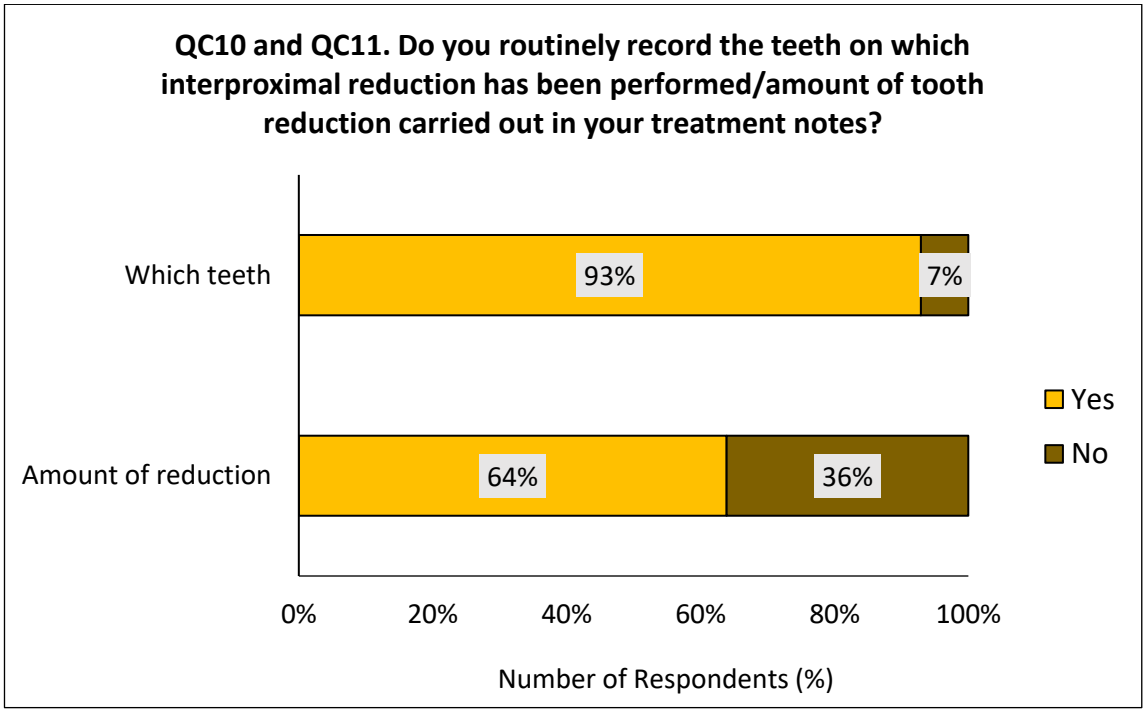


Fig. 33: Recording of IPR in treatment notes (n=98)

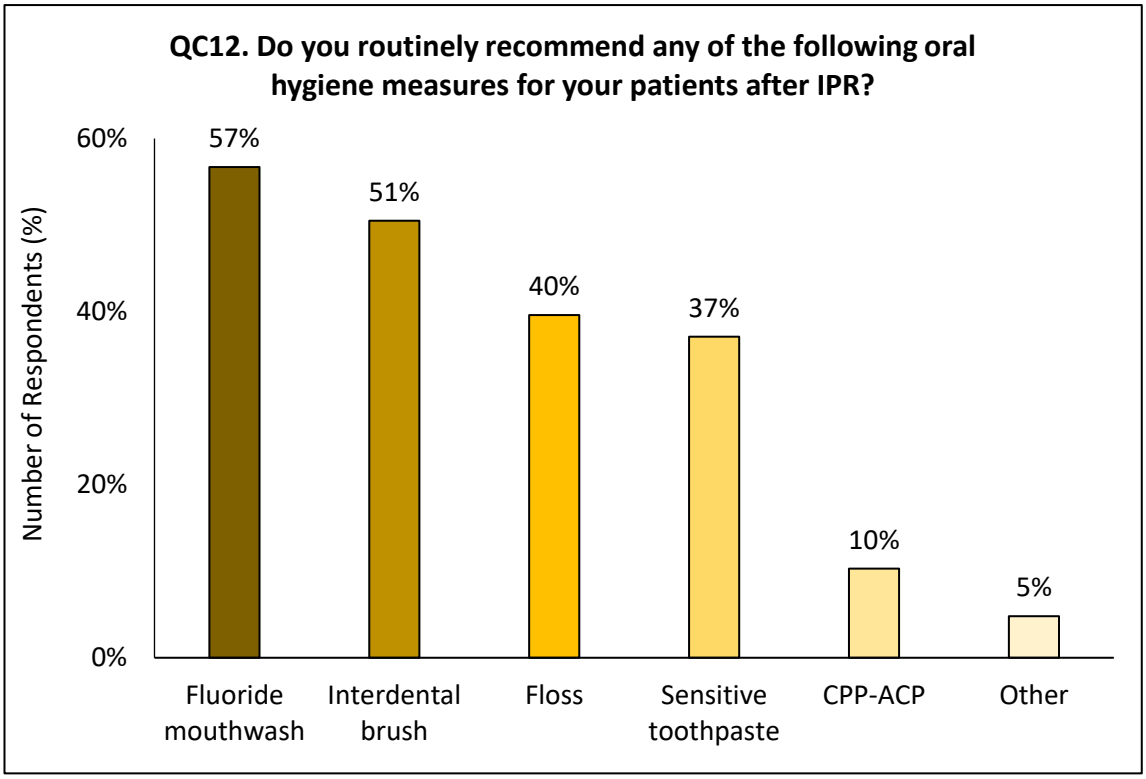


Fig. 34: Oral hygiene measures recommended after IPR (n=97)

5.1.6 Section D: Patients and IPR

Few orthodontists (11%) provided patients with information leaflets on IPR. Of those who did, the majority provided the leaflet developed by the BOS (**Fig. 35**).

Orthodontists reported that they routinely informed patients of many potential benefits of IPR (**Fig. 36**). The most common benefits explained to patients were that IPR may provide space to relieve crowding, reduce the appearance of black triangles, and improve tooth shape. Patients were reportedly also routinely informed of potential risks of IPR, but to a lesser extent (**Fig. 37**). The most common risk explained to patients was the potential for sensitivity following the procedure. Risks and benefits were most commonly discussed with patients at the treatment planning stage (**Fig. 38**).

Respondents to the survey felt their patients did not mind having IPR performed (61%). Most believed that patients found IPR uncomfortable (48%) rather than painful (9%). The majority of orthodontists (71%) felt that most patients would prefer IPR, where possible, to having teeth extracted. Most orthodontists (56%) disagreed that patients had concerns when IPR was proposed as part of their treatment. Orthodontists felt that patients found the concept of IPR easy to understand (89%), but few patients (12%) had heard of IPR previously. Just 2% of orthodontists felt that patients complained of sensitivity after having IPR performed (**Table 18**).

When orthodontists were asked how painful they thought their patients found IPR, the responses ranged from 0 to 7 out of 10, with a mean of 3.3 out of 10 (**Fig. 39**).

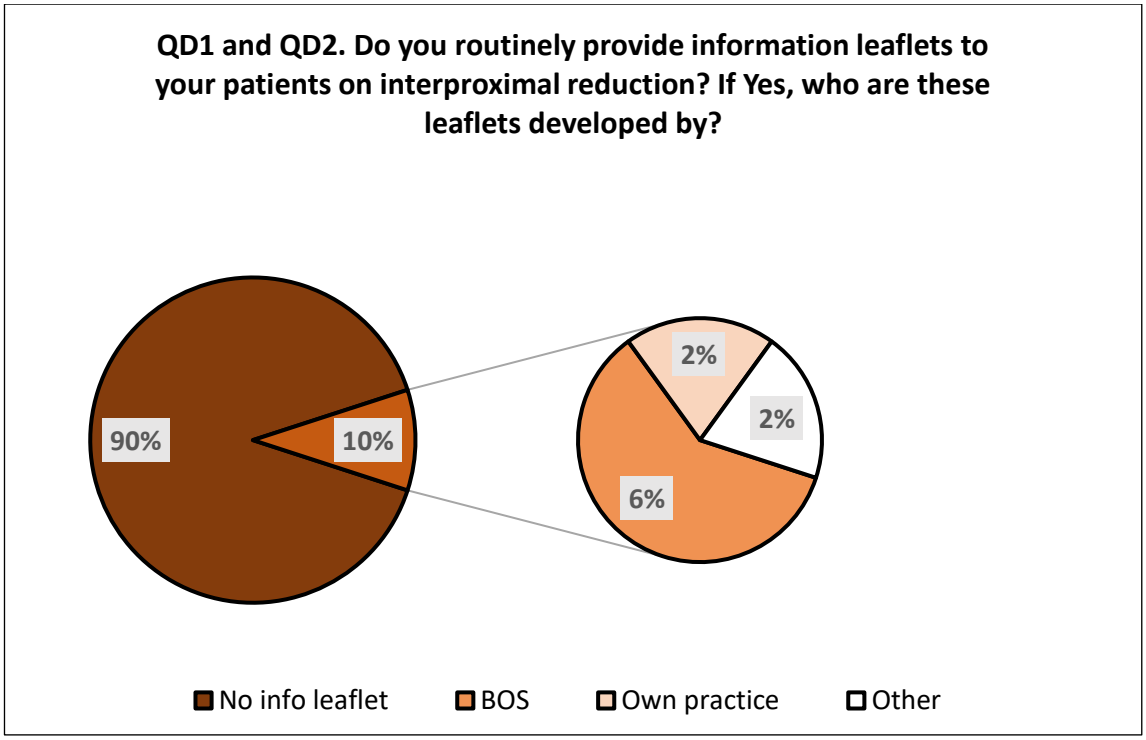


Fig. 35: Information leaflets on IPR provided to patients (n=94)

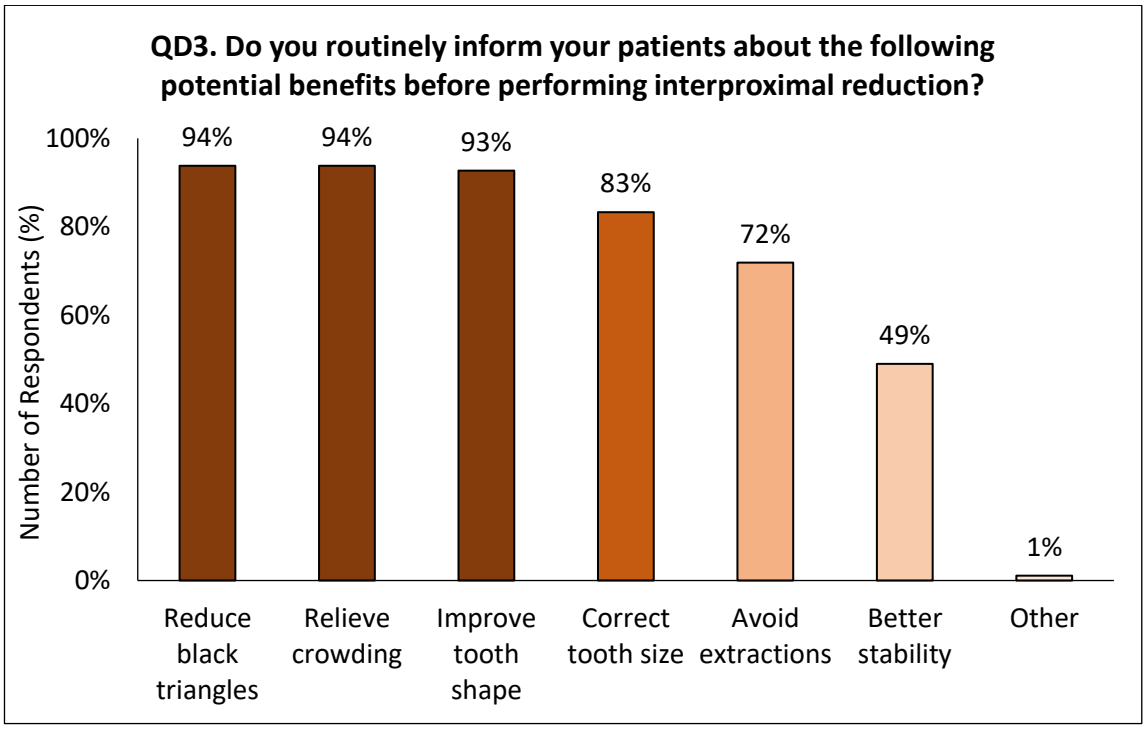


Fig. 36: Benefits that patients are informed of before IPR (n=96)

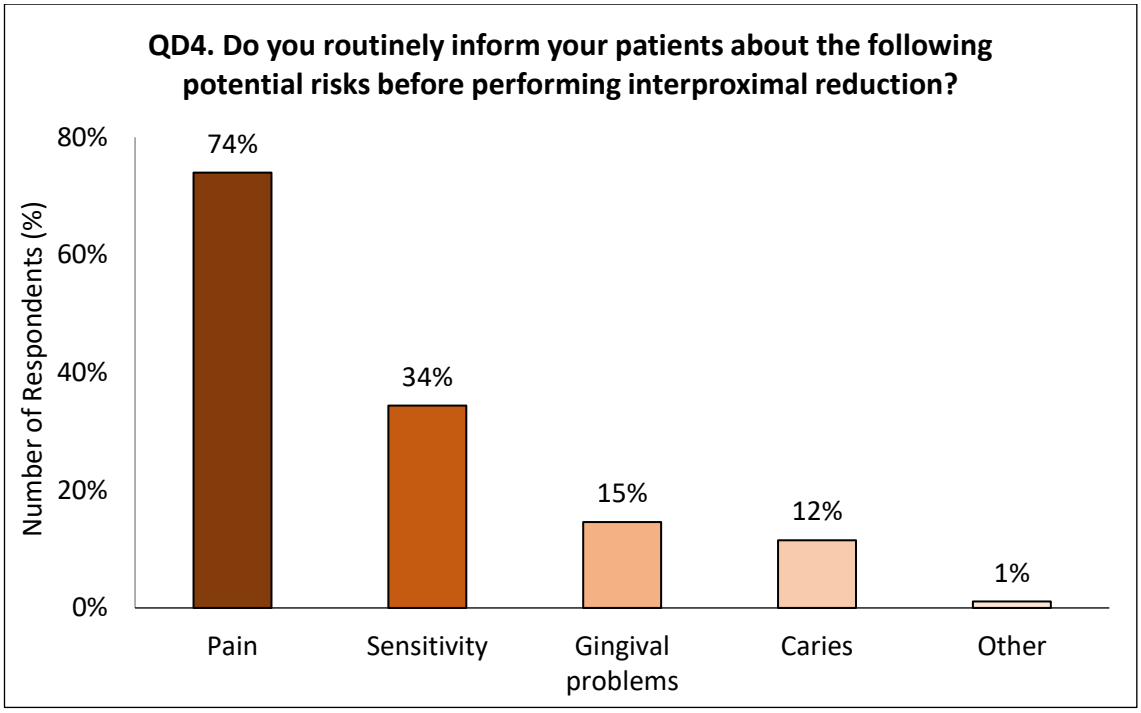


Fig. 37: Risks that patients are informed of before IPR (n=96)

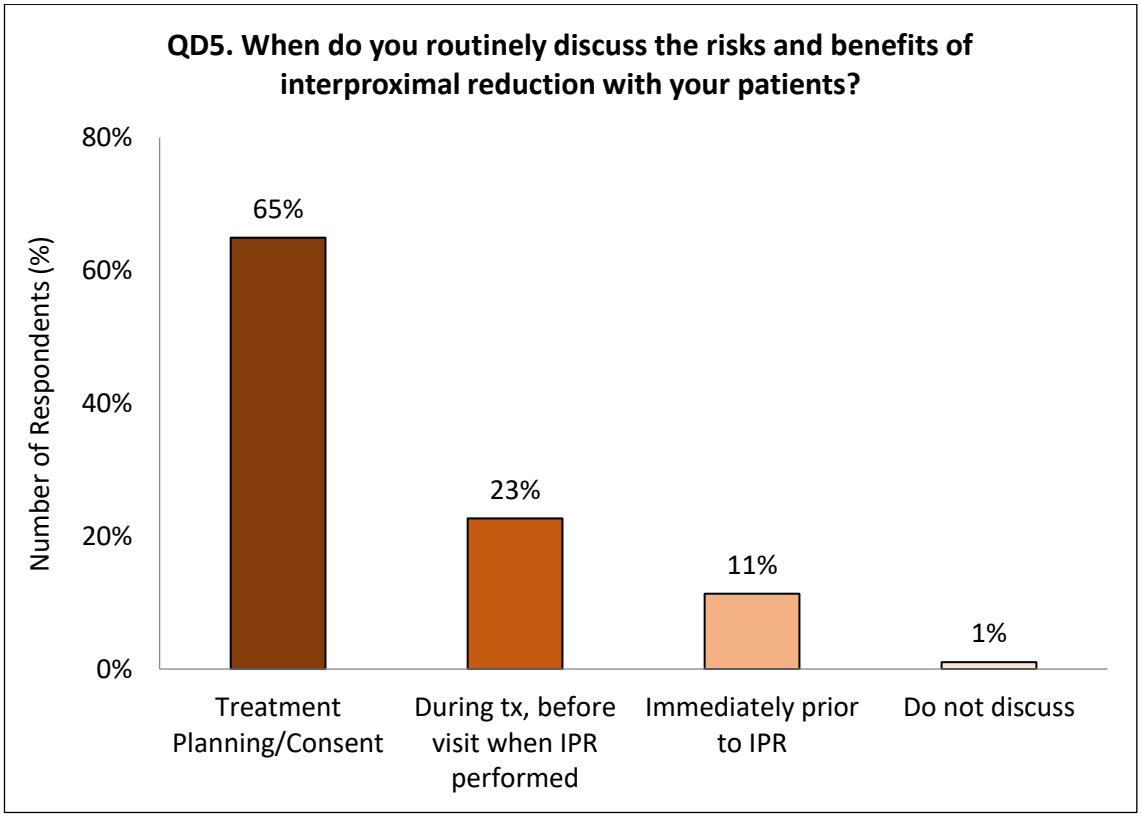


Fig. 38: Timing of discussion with patients about risks and benefits of IPR (n=97)

Table 18: Orthodontists' views on patient perceptions of IPR (n=96)

Statement	SA (%)	A (%)	N (%)	D (%)	SD (%)	TA (%)	TD (%)
My patients do not mind having interproximal reduction done	18.8	41.7	27.1	12.5	0	60.5	12.5
My patients find interproximal reduction uncomfortable	4.2	43.8	29.2	20.8	2.1	48	22.9
My patients find interproximal reduction painful	0	9.4	21.9	60.4	8.3	9.4	68.7
My patients prefer interproximal reduction where possible, rather than extractions	20.2	51.1	25.5	3.2	0	71.3	3.2
My patients complain of sensitivity after interproximal reduction	0	2.1	11.5	67.7	18.8	2.1	86.5
My patients have concerns when I explain interproximal reduction to them	0	11.5	32.3	53.1	3.1	11.5	56.2
My patients find interproximal reduction easy to understand	5.2	83.3	8.3	3.1	0	88.5	3.1
My patients have heard of interproximal reduction before I explain it to them	1.1	10.5	44.2	36.8	7.4	11.6	44.2

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, TA = Total percentage who agree, TD = Total percentage who disagree

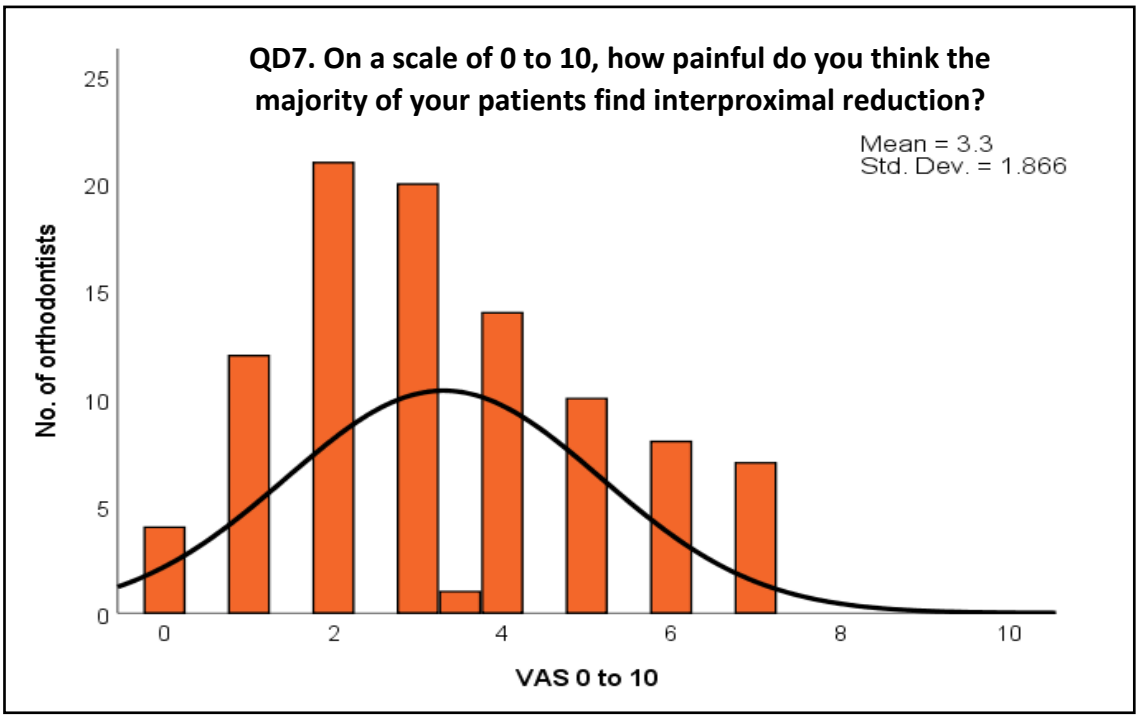


Fig. 39: How painful orthodontists think that patients find IPR (n=97)

5.1.7 Associations between variables

Associations were explored between several questions. These are summarised in **Table 19**.

There was no association between the country where specialist training was undertaken and whether or not a practitioner received training in the use of IPR or whether the specialist reported to subsequently use IPR routinely in practice. The country where the specialist was trained did significantly influence how often they performed IPR for patients in the primary dentition ($p<0.01$), but not for the mixed dentition ($p=0.15$) or permanent dentition in adolescents ($p=0.67$) or adults ($p=0.47$).

The number of years of experience or practice setting did not influence whether a specialist orthodontist used IPR routinely to gain intra-arch space ($p=0.53$). Whether a specialist orthodontist had received training in IPR had no association with the amount of IPR they were comfortable to perform ($p=0.49$).

The methods of performing IPR that were used during a specialist's training were associated with use of the same instruments in practice ($p\leq0.01$), except for handheld abrasive strips ($p=0.37$).

Table 19: Associations between variables in Orthodontist Questionnaire

Question 1	Question 2	Variable	P value
QA2. Where did you study orthodontics?	QA6. Did you receive training in interproximal reduction as part of your specialist training?		0.57
QA2. Where did you study orthodontics?	QB16. (i) I routinely perform interproximal reduction to gain intra-arch space		0.69
QA2. Where did you study orthodontics?	QB2. How often do you perform interproximal reduction in each of the following patient groups?	Primary dentition	<0.01*
		Mixed dentition	0.15
		Adolescents, permanent dentition	0.67
		Adult patients	0.47
QA3. How many years have you been working as a specialist orthodontist?	QB16. (i) I routinely perform interproximal reduction to gain intra-arch space		0.53
QA5. What setting best describes your practice?	QB16. (i) I routinely perform interproximal reduction to gain intra-arch space		0.07
QA6. Did you receive training in interproximal reduction as part of your specialist training?	QB10. In the upper arch, what is the maximum amount of space you create by performing interproximal reduction?		0.49
QA6. Did you receive training in interproximal reduction as part of your specialist training?	QB11. In the lower arch, what is the maximum amount of space you create by performing interproximal reduction?		0.49
QA7. What methods of performing interproximal reduction did you use while training?	QC1. Do you use the following methods of performing interproximal reduction?	Air rotor with diamond bur	<0.01*
		Disk mounted in a handpiece	0.01*
		Motor-driven abrasive strip	<0.01*
		Abrasive strip in a holder device	<0.01*
		Handheld abrasive strip	0.37

*** = significant at p <0.05**

5.2 Survey of Patients

5.2.1 Data entry

No errors were detected in the data entry for the 20 questionnaires chosen at random for re-entry one month after the initial data entry date.

5.2.2 Section A: Patient details

Of the 30 patients who completed the questionnaire, 43% were male (n=13) and 57% were female (n=17) (**Fig. 40**). The age of the patients ranged from 13 to 20 years, with a mean age of 16.2 ± 1.75 years (**Fig. 41**).

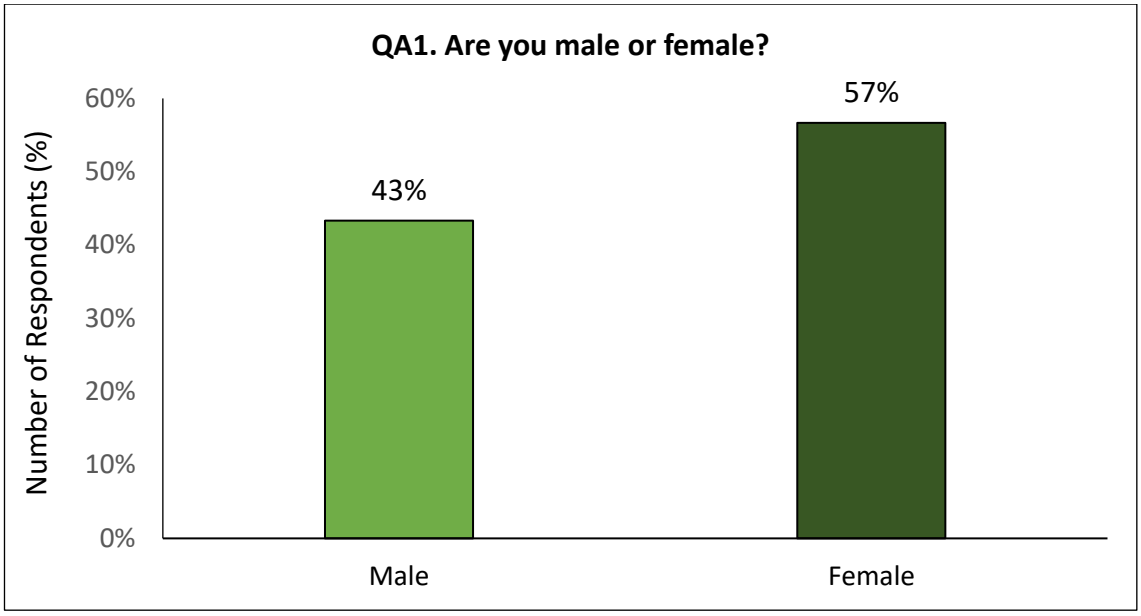


Fig. 40: Gender of subjects who completed the Patient Questionnaire (n=30)

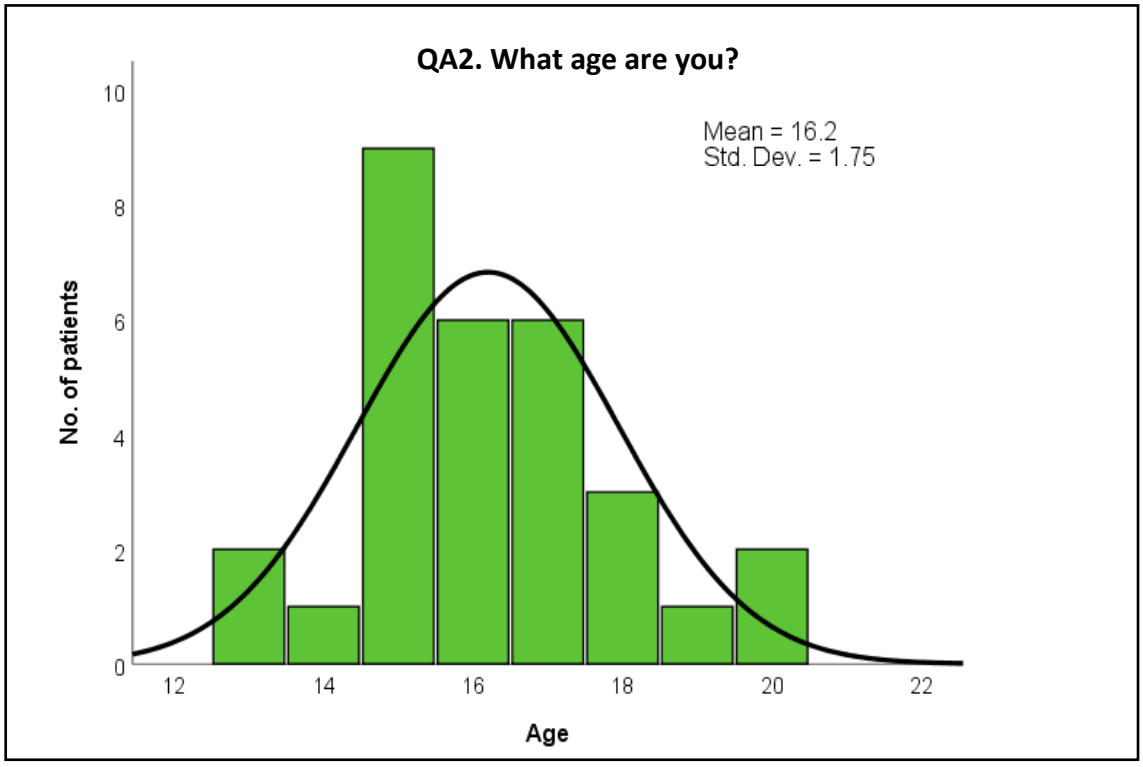


Fig. 41: Age of subjects who completed the Patient Questionnaire (n=30)

5.2.3 Section B: Information about the procedure

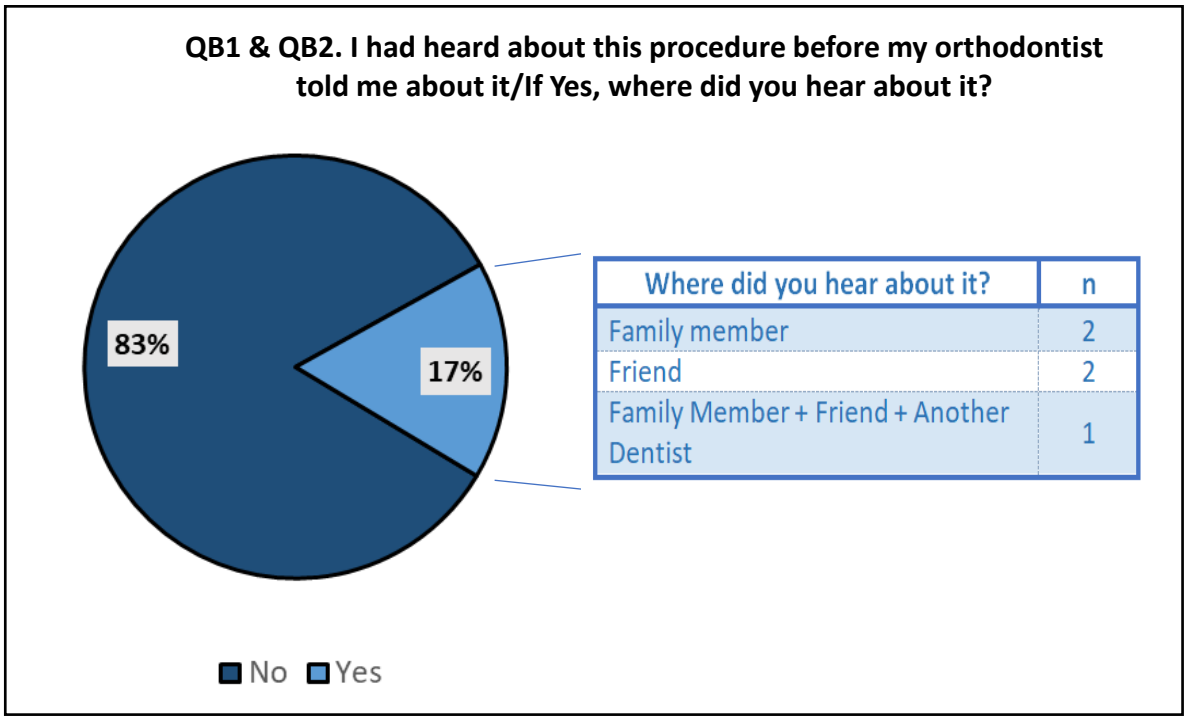
Fewer than 20% of patients had previously heard of IPR. Of those that had, they most commonly heard about it from friends, then family (**Fig. 42**). The majority of patients (72%) reported that they did not receive any written information about the procedure.

The vast majority (93%) of those surveyed were wearing fixed appliances, with 7% wearing upper removable appliances.

All patients felt that the orthodontist explained clearly why IPR was being performed and that they understood clearly why their teeth were being trimmed. The reasons most patients understood their teeth were being trimmed were to relieve slight crowding, or to alter the shape of their teeth (**Fig. 43**).

The most common benefits of IPR that patients reported they were informed about were that the procedure would help solve the crowding of their teeth (77%), the shape of their teeth would be improved (30%) and that their teeth would be trimmed to be the correct size (30%). Twenty percent reported they were informed that IPR would help in avoiding the need for extraction of teeth (**Fig. 44**).

In terms of risks, over half of patients were told that they may experience tooth sensitivity after IPR. A third of patients were not informed of any risks associated with the procedure (**Fig. 45**). Following IPR, 63% of patients reported that they were requested to use fluoride mouthwash, and 37% asked to use interdental brushes. Thirty percent of patients were not instructed about any specific oral hygiene measures (**Fig. 46**).



Where did you hear about it?	n
Family member	2
Friend	2
Family Member + Friend + Another Dentist	1

Fig. 42: If and where patients had previously heard about IPR (n=30)

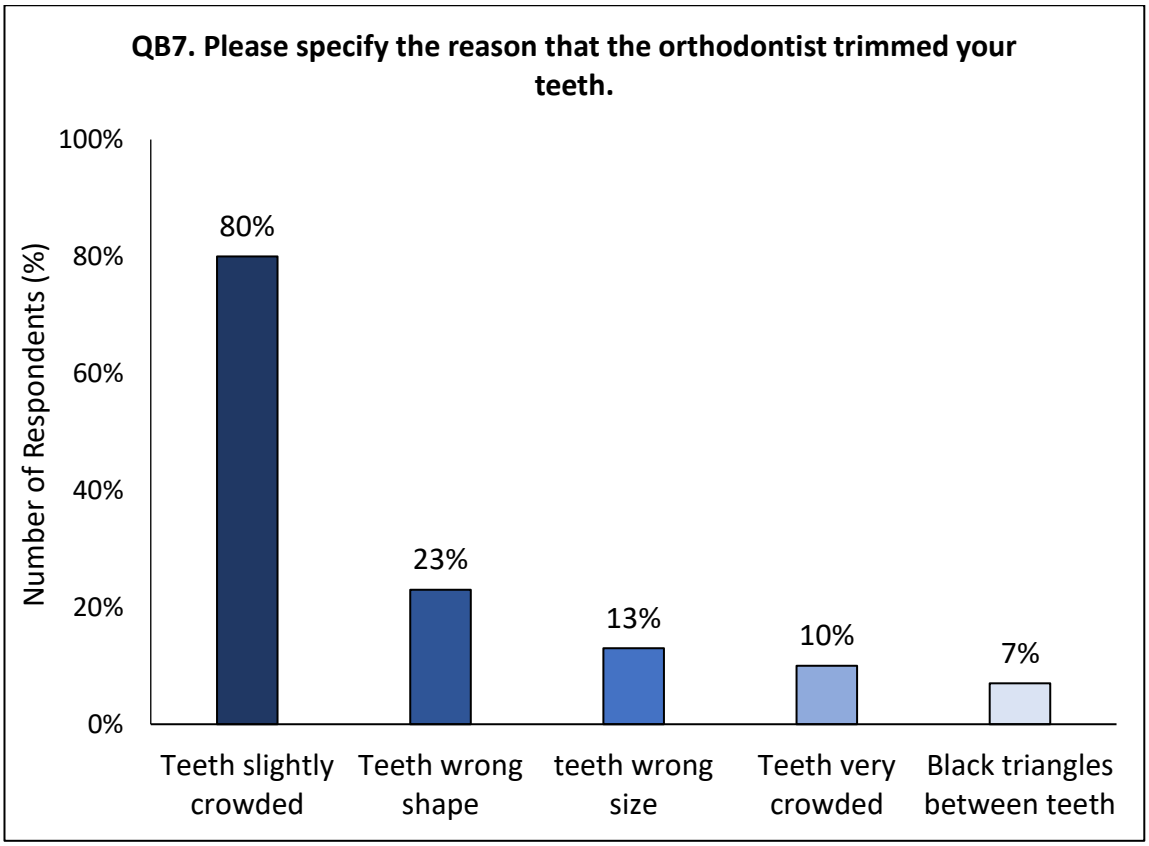


Fig. 43: Reasons why patients reported they were receiving IPR (n=30)

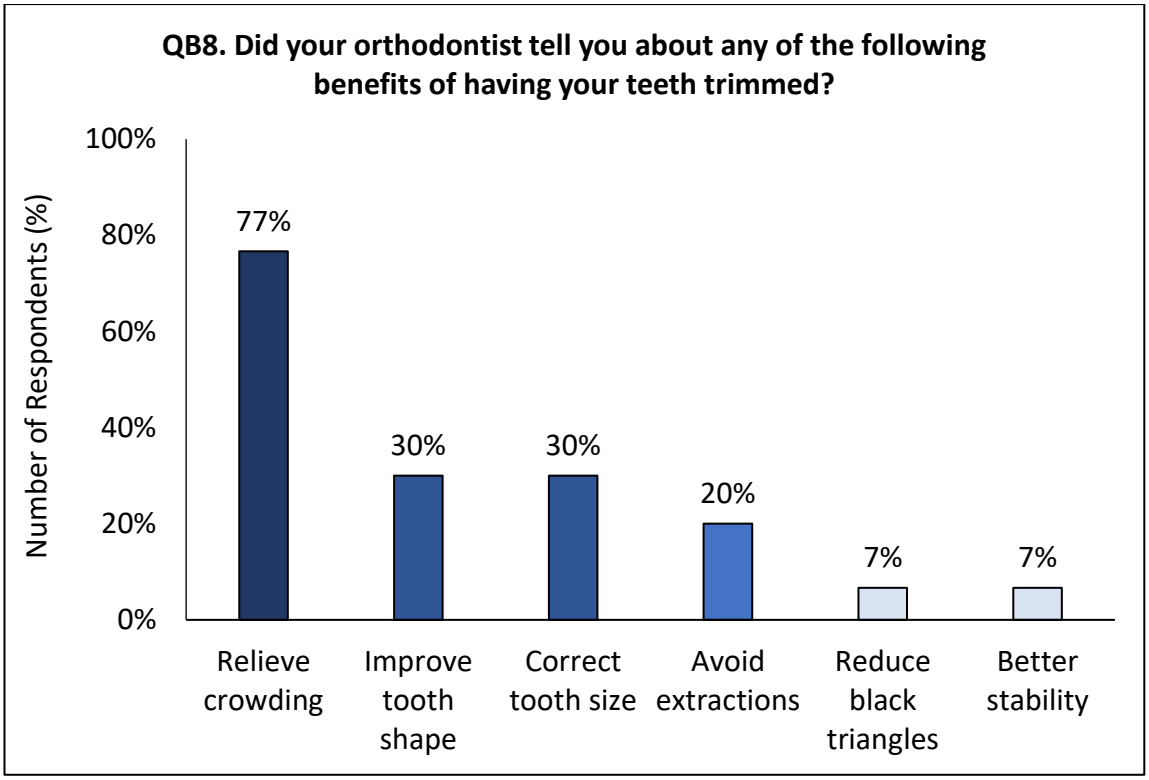


Fig. 44: Benefits patients reported were told about before IPR (n=30)

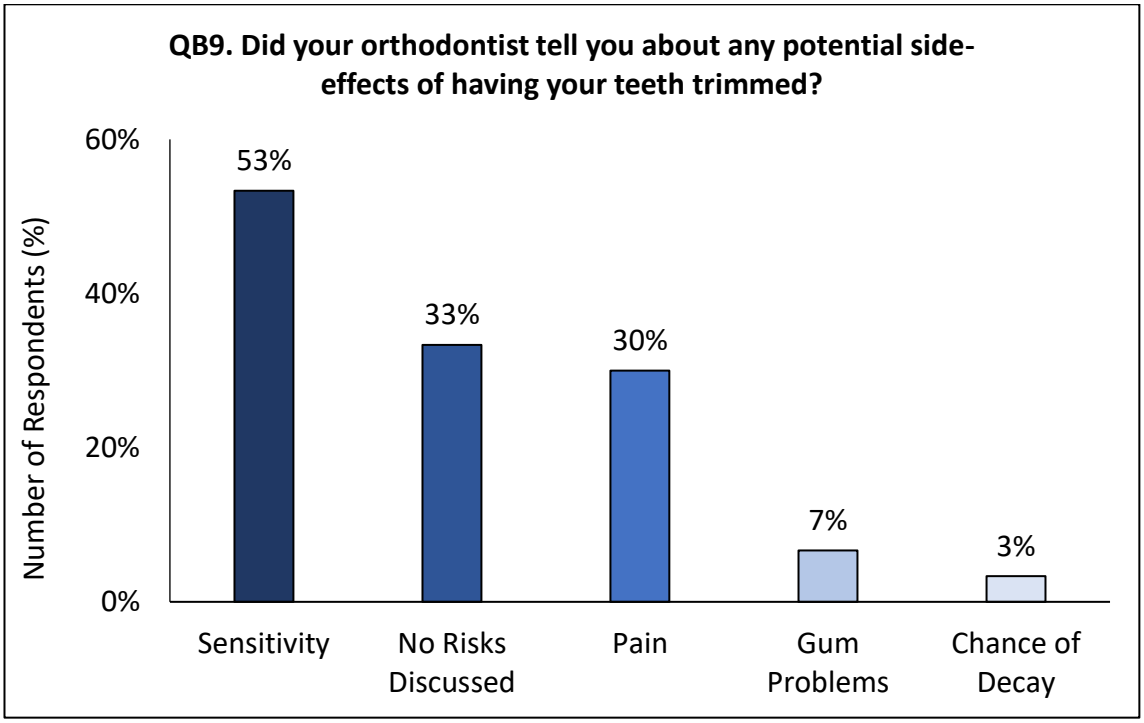


Fig. 45: Risks patients reported they were told about before IPR (n=30)

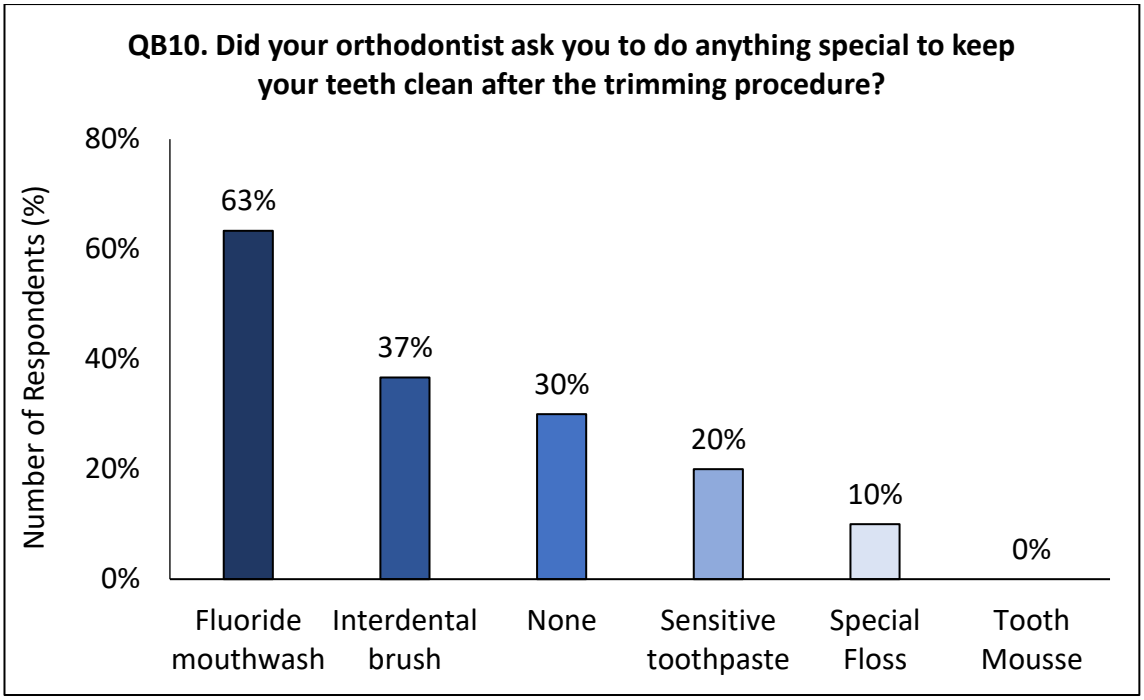


Fig. 46: Oral hygiene instructions reportedly given to patients after IPR (n=30)

5.2.4 Section C: Patient perception of the procedure

When patients were asked how painful they found IPR, the responses ranged from 0 to 6 out of 10, with a mean of 2.3 out of 10 (**Fig. 47**).

All patients thought that having teeth trimmed was preferable over having teeth extracted. A variety of reasons for this opinion were given (**Table 20**). Common themes in the responses included that IPR would cause less pain than extractions, that the procedure would take less time than an extraction, all teeth would be retained, the procedure itself would be less invasive, no anaesthetic would be required for trimming and that overall treatment would be faster.

Few patients (10%) reported being worried about the procedure before it was carried out. No patient felt that their teeth would be made weaker by IPR, and just 7% felt that their teeth might be more prone to caries due to having the enamel trimmed. The vast majority (93%) said that they did not mind having the procedure done. There were mixed views regarding whether the procedure was uncomfortable (37%) or produced no discomfort (30%), with a smaller percentage (13%) stating that IPR was a painful procedure. Three patients (10%) reported sensitivity after the procedure. Most patients said that they would agree to have the procedure done if recommended to them by their orthodontist; 80% felt they would agree to have IPR performed on their upper front teeth and upper back teeth, while 90% were agreeable to having IPR done on lower front and lower back teeth. A majority of patients reported that they would prefer to have several teeth trimmed in the upper (90%) and lower (87%) arches, rather than extracting a tooth (**Table 21**).

Patients were asked what they would tell a friend or family member about the procedure, if they were about to have IPR done. There were a variety of responses, which were grouped into common themes: pain, discomfort, comparing the procedure to extraction, speed, benefits of treatment, bleeding, reassurance about the procedure, side effects and recommending the procedure (**Table 22**).

When asked if there was anything else the respondent would like to mention, most responded that they did not. A small number of additional comments were made regarding the instruments used, their experience of the procedure and protection of soft tissues during the procedure.

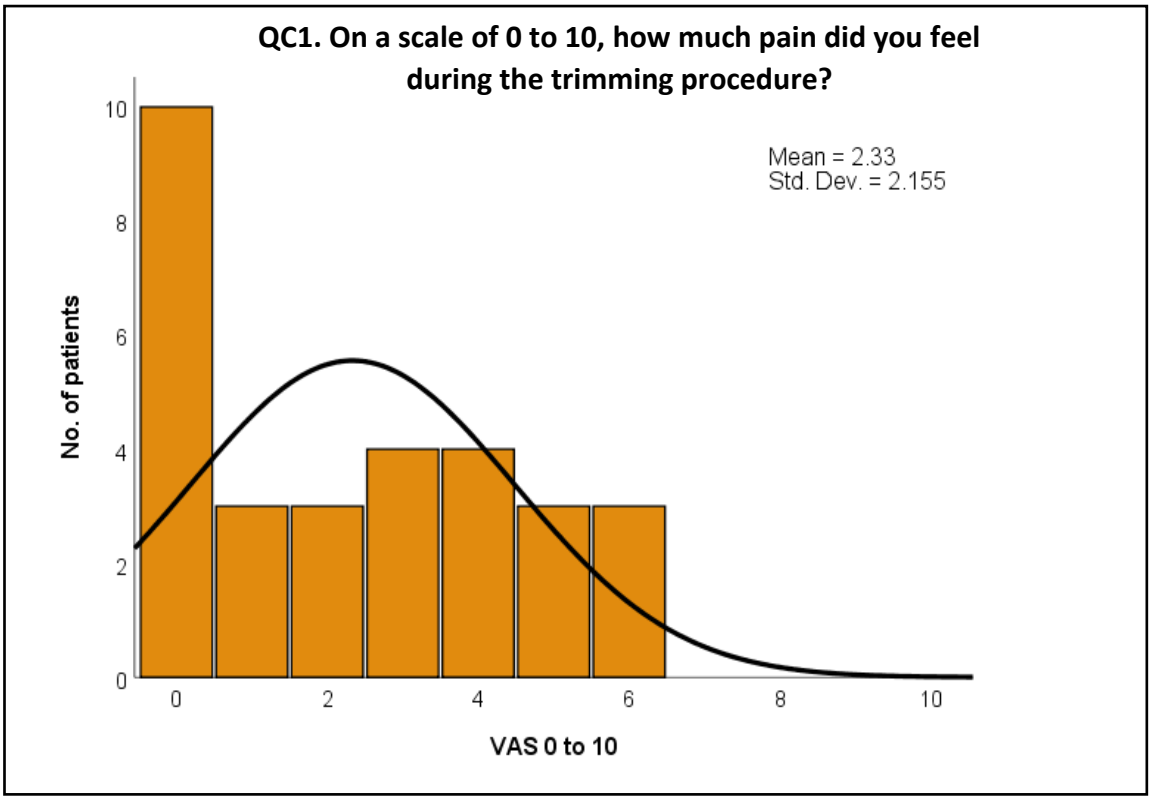


Fig. 47: How painful patients find IPR (n=30).

Table 20: Patient-perceived advantages of IPR vs extraction (n=28)

Theme	Number of similar responses	Example Quote
Less painful	17	*"It doesn't hurt as much as getting teeth out"*
Faster procedure	7	*"I feel trimming is better because it takes less time"*
Retain natural teeth	6	*"Wouldn't like to lose any teeth"*
Less invasive	4	*"Because it's not that big of a procedure than getting teeth pulled"*
No anaesthetic required	3	*"no numbing needed"*
Reduce overall treatment time	1	*"because it means that I won't have to have my braces on longer for the gap to fill in"*

Table 21: Patients' opinions about IPR (n=30)

Statement	SA (%)	A (%)	N (%)	D (%)	SD (%)	TA (%)	TD (%)
Before the procedure, I was WORRIED about having the sides of my teeth trimmed	3.3	6.7	20	43.3	26.7	10	70
By trimming my teeth, my teeth will be WEAKER	0	0	13.3	66.7	20	0	86.7
By trimming my teeth, my teeth will be more PRONE TO DECAY	0	6.7	26.7	56.7	10	6.7	66.7
I DID NOT MIND having my teeth trimmed	62.1	31	3.4	3.4	0	93.1	3.4
I found the procedure UNCOMFORTABLE	13.3	23.3	33.3	20	10	36.6	30
I found the procedure PAINFUL	6.7	6.7	23.3	33.3	30	13.4	63.3
I experienced increased SENSITIVITY to hot/cold after having my teeth trimmed	0	10	23.3	50	16.7	10	66.7
If it was recommended by my orthodontist, I would agree to having this procedure done on my UPPER FRONT TEETH	23.3	56.7	10	6.7	3.3	80	10
If it was recommended by my orthodontist, I would agree to having this procedure done on my UPPER BACK TEETH	30	50	13.3	6.7	0	80	6.7
If it was recommended by my orthodontist, I would agree to having this procedure done on my LOWER FRONT TEETH	23.3	66.7	6.7	3.3	0	90	3.3
If it was recommended by my orthodontist, I would agree to having this procedure done on my LOWER BACK TEETH	30	60	10	0	0	90	0
If my upper teeth were crowded, I would PREFER to have several upper teeth trimmed to make room for the rest of the teeth, INSTEAD OF EXTRACTING a tooth	66.7	23.3	6.7	3.3	0	90	3.3
If my lower teeth were crowded, I would PREFER to have several lower teeth trimmed to make room for the rest of the teeth, INSTEAD OF EXTRACTING a tooth	63.3	23.3	6.7	6.7	0	86.6	6.7

SA = Strongly Agree, A = Agree, N = Neutral, D = Disagree, SD = Strongly Disagree, TA = Total percentage who agree, TD = Total percentage who disagree

Table 22: Information that patients who have had IPR would impart to others (n=29)

Theme	Number of similar responses	Example Quotes
Pain	21	*"I would recommend it because it wasn't painful it was just slightly uncomfortable"* *"I would say they will feel a slight bit of pain and sensitivity at first but you will be ok after a couple of seconds"*
Discomfort	13	*"It might be uncomfortable, but it's not painful and will be over soon"* *"The very first tooth is uncomfortable but after that they're grand"*
Compare to extraction	7	*"That it doesn't hurt and doesn't take long at all compared to getting a tooth extracted"*
Speed	6	*"It's a fast process"*
Beneficial for tx	5	*"I would tell them not to worry it doesn't hurt and it won't cause any damage. It will help your teeth to look better"*
Not to worry	3	*"That having your teeth trimmed is nothing to worry about as it is quick and very little to no pain"*
Bleeding	3	*"Sometimes your gums could bleed a small bit but overall it's fine"*
Side effects	3	*"I would… inform them of the side effects my dentist told me about"*
Recommendation	3	*"I would recommend that they do it as it will help your teeth come together"*

5.2.5 Associations between variables

Associations were explored between several questions. These are summarised in **Table 23**.

Neither patient age (p=0.81) nor gender (p=0.26) was associated with a difference in reported perception of the pain experienced during IPR.

Whether or not a patient was informed of pain as a potential side effect of IPR was associated with a difference in reported pain from the procedure. Those patients who reported that they were informed of pain as a potential side effect reported significantly higher levels of pain from IPR than those who had not been informed (p=0.04).

Table 23: Associations between variables in Patient Questionnaire

Variable 1	Variable 2	P value
QA1. Are you male or female?	QC1. On a scale of 0 to 10, how much pain did you feel during the trimming procedure?	0.26
QA2. What age are you?	QC1. On a scale of 0 to 10, how much pain did you feel during the trimming procedure?	0.81
QB9. (i) Did your orthodontist tell you about any potential side effects of having your teeth trimmed?	Pain reported on VAS	0.04*

*** = significant at p<0.05**

Chapter 6. Discussion

This purpose of this research project was to explore the adjunctive procedure of IPR, which is increasing in use and popularity in orthodontic practice (Fleming et al., 2018; Keim et al., 2020). There has been a reasonable volume of scientific and technical data published on this topic, looking at clinical aspects and the short and long-term effects of IPR (Zachrisson et al., 2007; Koretsi et al., 2014). The IPR practices of specialist orthodontists in ROI and patient perceptions of this procedure, however, have not been explored prior to this study. To investigate this topic and achieve the aims of this research project, both specialist orthodontists and a patient sample were surveyed with *de novo* questionnaires developed, pre-tested and piloted by the research team.

6.1 Survey of Specialist Orthodontists

6.1.1 Response rate

This survey was the first comprehensive exploration of the interproximal reduction practices of specialist orthodontists in RoI. The response rate to the survey was considered 'extremely good' at 75%, according to Williams (2003). This means that bias in the results is less likely, leading to greater confidence in the validity of the survey findings. The response rate was significantly higher than similar surveys of orthodontists overseas; a recent UK survey on premolar extraction by Fleming et al. (2018) achieved a response of 16% while a survey of orthodontic techniques in USA received responses from less than 1% of the target sample (Keim et al., 2020). The response rate and overall number of responses to this study was in line with similar surveys of specialist orthodontists in Ireland (McGuinness & Collins, 2007; Murray et al., 2012; Meade & Millett, 2013; McMorrow & Millett, 2017).

Several techniques for increasing response rates were adopted when implementing this survey as recommended by Dillman (2014): contacting participants in advance to invite them to participate, offering more than one sampling frame, personalising the cover letter included with the survey, providing self-addressed pre-paid return envelopes, offering a prize as an incentive and sending a reminder to non-responders with another copy of the survey. The response rate may have been improved if a second reminder was sent as recommended by several authors (Williams, 2003; Dillman, 2014). A second reminder was not sent out of consideration to the participants who were likely to be preoccupied either personally or professionally by the first lockdown of the Covid-19 pandemic, which is discussed further in Section 6.5.

Of the two sampling frames, the response rate was higher for the electronic than the postal version of the survey (78% vs 69% respectively), which is contrary to what has typically been reported (Hayslett & Wildemuth, 2004). This is potentially because those who were uncontactable by phone were automatically sent the postal version of the survey, so any participant who received the electronic survey had already verbally agreed to participate and had opted to receive it in that format.

6.1.2 Demographics

A roughly equal number of males and females responded to the survey, the majority of whom were trained in the UK and worked in private practice, or to a lesser extent in HSE practice. This profile of respondents was consistent with a recent study of the orthodontic workforce in Ireland, which reported the same findings with regard to gender, location of specialist training and work setting (Higgins et al., 2019).

6.1.3 Use of IPR

This survey found that IPR was a widely used technique among orthodontists in RoI. The procedure was performed by 98% of orthodontists in this survey, which is in line with the findings of a study in USA where all respondents reported using IPR (Sheridan, 2006).

Routine use of IPR to gain intra-arch space was reported by 46.5% of respondents. This result is intermediate between the findings of two surveys from the USA. One reported that 66.4% of orthodontists routinely used IPR to gain intra-arch space (Barcoma et al.,

2015) while the other reported a lower number (35%) routinely slenderizing teeth, while a further 54% reported occasional use of this technique (Keim et al., 2020). The latter result needs to be considered with caution due to the low survey response rate, which was less than 1% of the target population.

The use of IPR appears to be on the rise in RoI, as 44% of orthodontists reported an increased frequency of use over the past 5 years, with just 6% reporting a decrease in the same period. IPR is most frequently employed in adult and adolescent patients in the permanent dentition, which tallied with the findings of a recent survey of members of the BOS (Fleming et al., 2018). The similarity in findings between that UK survey and the present study are perhaps not surprising given that a majority of specialist orthodontists in ROI are UK trained. In contrast, the only study that has reported longitudinal frequency of use of IPR in the USA suggested that the use of the technique neither increased nor decreased meaningfully from 2014 – 2020 (Keim et al., 2020).

In the study reported here, IPR was used in all malocclusion types in conjunction primarily with aligners or fixed appliances, over the course of multiple visits and usually after initial alignment. Most orthodontists spent less than five minutes performing this procedure, echoing the findings of Zhong (2000) that IPR is a short procedure. Just 17% of orthodontists placed separators before performing IPR, a practice which has been criticised for adding visits to treatment and making the amount of tooth reduction more difficult to measure (Florman et al., 2007). Shorter procedure duration may reduce the amount of pain experienced by patients, which may be a favourable finding for IPR (Fagade & Oginni, 2005).

6.1.4 Training in IPR

Over three quarters of orthodontists reported that they received formal training in IPR during their specialist training, mostly using handheld strips or strips in a holder device. Handheld strips were the most popular instrument used to perform IPR in practice also. Interestingly, the next most preferred method of performing IPR in practice was a diamond bur in a fast handpiece, for which only 21% of respondents reported receiving any formal training.

6.1.5 Indications for use of IPR

The indications for use of IPR among respondents to this survey were for triangular-shaped teeth, mild crowding, reshaping existing restorations, TSDs and reducing black triangles. The more severe the crowding, the less likely respondents were to use IPR. This finding is in line with the consensus in the existing literature (Jadhav et al., 2011; Lapenaite & Lopatiene, 2014). The only other survey to investigate the indications for IPR had a similar result; TSDs and relief of anterior crowding were the most commonly reported indications by orthodontists (Sheridan, 2006).

6.1.6 Where IPR is performed

IPR was most frequently performed on teeth in the mandibular labial segment, with mandibular lateral incisors, followed by mandibular central incisors and mandibular canines being the three most common teeth treated with this procedure. IPR was least frequently performed on molar teeth. Eighty-seven percent of orthodontists agreed

that IPR was easier to perform on anterior teeth. These findings are in keeping with those of Sheridan (2006) and Keim et al. (2020); the latter reported 35% of orthodontists used IPR routinely in the anterior segment in comparison to 6% in the posterior segments, although the arch was not specified in that survey.

Mandibular premolars were more frequently reduced than their maxillary counterparts, which was potentially a result of the greater variability in size of the former (Gaddam et al., 2015). A Bolton analysis, which can aid in identifying the location of TSDs and thus the best areas in which to reduce tooth width, was reportedly not done by 74% of specialist orthodontists in this survey. This finding is almost identical to a USA survey of orthodontists, which reported that 73% did not carry out this analysis routinely (Keim et al., 2020).

6.1.7 Space created by IPR

Most orthodontists reported that they created a maximum of 2-4mm of space in each arch with IPR, which is considerably less than what is deemed to be possible (Stroud et al., 1998; Sarig et al., 2015). This suggests that specialist orthodontists in RoI used IPR relatively conservatively. Respondents were most comfortable with removal of 0.3mm from each proximal surface of anterior teeth and 0.4mm from each proximal surface of posterior teeth, which is in line with the recommendations of Zachrisson (2011). There is a discrepancy between the space gain that would be achieved if such reduction was done throughout the mouth (8-10mm), and the maximum amount of space respondents reported to create (2-4mm). This is likely to be a function of the number of teeth on which IPR is being performed. It did not appear from this survey that

orthodontists in the RoI used IPR as a means of creating significant amounts of space. Instead, it was more frequently employed where smaller amounts of space were required, such as mildly crowded cases. This was consistent with the armamentarium used for IPR by specialists in RoI, where handheld strips were most popular. It has been alleged that handheld strips are ineffective at creating space to the same extent as other methods of IPR, such as ARS (Sheridan, 1985; Florman et al., 2007). Handheld strips were similarly reported to be the most popular instrument used to perform IPR in the USA (Sheridan, 2006; Keim et al., 2020).

Almost half of respondents felt IPR influenced how much crowding they were willing to resolve without extracting teeth. This mirrored the findings of Fleming et al (2018), who found 63% and 53% of BOS members would favour IPR or IPR plus arch lengthening respectively as their treatment approach rather than extractions in crowded cases. It was noted by specialist orthodontists in RoI that patients are showing increasing reluctance to extract teeth, which is an indicator that alternative methods of space creation may continue to increase in popularity. There was consensus that patients would have a preference for IPR over extractions, where possible; just 3% of orthodontists disagreed with this statement.

6.1.8 Aids to IPR and procedures after IPR performed

The amount of reduction was measured primarily using a leaf gauge or using an instrument of known thickness, which reflected the main methods recommended in the literature (Johner et al., 2013; Livas et al., 2013). The popularity of leaf gauges may be due to the suggestion that their use gives an accurate reading of the amount of

tooth reduction performed and may thus reduce the discrepancy between planned and actual IPR (Kalemaj & Levrini, 2021).

The majority of orthodontists did not report that they recontoured, polished, or treated tooth surfaces which had been reduced. While dental and periodontal health has been shown to be unaffected by IPR in long-term studies where surfaces have been reduced, the creation of ledges during enamel reduction may risk plaque accumulation and sensitivity (Zachrisson et al., 2007). Even where furrows are created there is no evidence that the patient has an increased risk of caries at those sites (Koretsi et al., 2014). The effects of IPR on the health of teeth were reported to be researched by 62% of orthodontists in RoI, compared to 81% of orthodontists in USA (Barcoma et al., 2015). Correspondingly, fewer orthodontists (72%) in RoI agreed that IPR posed little risk to the development of interproximal caries, compared to orthodontists in USA where 94% agreed with this statement. This hints that the existing literature is convincing to orthodontists that IPR has little detrimental effect on dental health, and may also point to education differences between specialist orthodontic training in different parts of the world. Despite slight differences in opinion on risks to dental health, similar high numbers of orthodontists in both surveys reported they would have been willing to have IPR performed on their own teeth (87% in RoI and 92% in USA).

6.1.9 Informed consent for IPR

In obtaining informed consent, orthodontists reported that they routinely discussed risks and benefits of IPR with their patients, the former more often than the latter. This

was most commonly at the treatment planning stage and done verbally; just 11% of orthodontists reported that they provided patients with written information on IPR.

The most common written information provided to patients was the BOS leaflet (**Appendix 7 – BOS Patient Information Leaflet on Interproximal Reduction**). The most common benefits that patients were informed of were the potential to reduce the appearance of black triangles, the creation of space to relieve crowding and improvement in tooth shape, which agreed with the common indications for IPR in the literature (Jadhav et al., 2011; Livas et al., 2013). The most common risk that patients were advised of was the potential for sensitivity after the procedure, although paradoxically just 2% of orthodontists stated that their patients complained of sensitivity following IPR. A 10 - 15 year follow-up of patients who had received IPR had similar findings, where just 3% reported increased thermal sensitivity (Zachrisson et al., 2007). A survey in India, conversely, reported 54% of orthodontists felt their patients experienced this side-effect; this may reflect differences in how IPR is performed in different parts of the world (Srivastava et al., 2012).

6.1.10 Perceived patient opinions of IPR

Orthodontists felt that patients did not mind having IPR performed and that their patients found the procedure uncomfortable, rather than painful. This perception was shared by respondents to a USA survey, which reported that orthodontists perceived patients to have few problems with IPR with the exception of some mild discomfort (Sheridan, 2006). Orthodontists perceived that, on average, patients considered the procedure to score 3.3 out of 10 in terms of pain on a VAS. It is worth noting that there

is a reported tendency in the existing literature for underestimation of pain experienced by patients as perceived by orthodontists (Krukemeyer et al., 2009).

6.1.11 Associations between variables

There was an apparent association between the instruments used during specialist training and those subsequently used in practice, particularly for the less commonly used instruments. This suggests that an orthodontist may become familiar with the use of an instrument during training and continuing to employ that technique thereafter. Handheld strips were the only instrument where this association was not found, which may reflect their ineffectiveness as a method of creating space compared to other methods (Sheridan, 1985; Florman et al., 2007). Their use as the sole method of performing IPR during training may have coloured the practitioner's judgement of IPR and its effectiveness.

Where a specialist received their training had an influence on how frequently IPR was done in the primary dentition, which was the only finding that potentially reflected different education and different practices in different countries. Aspects of IPR have been explored in surveys in countries such as India, the UK and USA but none of these explored the use of IPR at different stages of dental development (Srivastava et al., 2012; Barcoma et al., 2015; Fleming et al., 2018). No associations were found with other potential variables based on where an orthodontist was trained, such as how often using IPR in general was reported or whether formal training in IPR had been received.

6.2 Survey of Patients

Unfortunately, there is a paucity of previous studies of patient perceptions of IPR with which to directly compare the findings of this survey.

6.2.1 Population surveyed

To the author's knowledge, this is the first survey to comprehensively investigate patient perceptions of IPR. This survey was carried out prospectively on a convenience sample of 30 consecutive patients who were receiving IPR as part of their orthodontic treatment in the Orthodontic Unit of CUDSH.

6.2.2 Response to survey

The questionnaire was laid out according to the recommendations of Williams (2003) and Dillman (2014). The questionnaire included a mix of closed and open questions. As the questionnaire was being conducted in the orthodontic clinic, the use of techniques to increase response rate to the survey were not necessary. Methods to improve response to free-form questions were adopted, as these are frequently left unanswered which reduces the value of the survey results (Dillman, 2014). This was highly effective; 29 out of 30 participants completed all sections of the questionnaire in full, which is significantly higher than the average of 34.6% full completion rate reported in a previous meta-analysis of survey response rates (Cook et al., 2016). In total, patients of five different clinicians took part in the survey, four of whom were postgraduate orthodontic students and one consultant orthodontist.

6.2.3 Demographics

Almost equal numbers of males (n=13) and females (n=17) responded, with an average age of 16 years. All but two of the patients were wearing fixed appliances, with the remainder wearing removable appliances. Aligner treatment was not routinely offered in the Orthodontic Unit where this survey was carried out.

6.2.4 Patient understanding of IPR

All patients reported that they understood why IPR was being performed. They identified resolution of crowding of their teeth as the most common indication, followed by improvement in tooth shape and tooth size. Few patients felt that IPR was being performed to reduce black triangles, which is more commonly an indication for IPR in adult patients (Jadhav et al., 2011; Livas et al., 2013). Just over half (53%) of patients reported they were informed of the risk of tooth sensitivity after IPR, which was the most common risk of the procedure discussed with patients.

6.2.5 Patients views on IPR vs extractions

Every patient thought that IPR was preferable to having teeth extracted where possible. They felt that IPR would: cause less pain, take less time, allow them to retain all their natural teeth, not require any anaesthetic and reduce overall treatment time compared to extraction. These points illustrate a high level of insight from patients as to the potential advantages of IPR versus space creation by extraction, and reflect the advantages of this procedure expounded in the scientific literature (Livas et al., 2013).

This level of understanding is despite less than 20% of patients having heard of this procedure prior to undergoing it themselves.

Single tooth extraction had a higher mean reported discomfort (3.4/10 for males and 2.9/10 for females) (Fagade & Oginni, 2005) than that reported for IPR in the present study (2.3/10). Patients, however, in the study reported here expressed a preference for IPR over extractions, primarily due to the avoidance of pain with the former.

6.2.6 Patient perceptions of IPR

Patients reported that they were not worried about IPR before it was performed. A large majority disagreed that the procedure would make their teeth weaker or more prone to decay. Most (93%) stated they did not mind their teeth being trimmed, and a similar majority felt that they would agree to have IPR done in all areas of the mouth if recommended by their orthodontist. Patients were more likely to describe the procedure as 'uncomfortable' rather than 'painful'. On average, pain during the procedure was rated by patients as 2.3 out of 10 on a VAS. This is remarkably similar to the only other known study which gathered patient feedback on IPR, which reported a mean level of discomfort of between 2.22 – 2.34 out of 10 on a VAS (Zhong et al., 2000)

6.2.7 Associations between variables

There were no statistically significant age or gender differences in the amount of pain reported by patients receiving IPR, which was consistent with the findings of previous

research on the influence of these factors on pain perception (Pickering et al., 2002; Petrini et al., 2015).

A significant association was found between patients being told of the risk of pain with the procedure and subsequently reporting more pain than a patient who was not informed of this potential risk. This concept has been previously explored in the literature by Linton & Shaw (2011), who described the phenomenon of '*vigilance*', the interaction of cognitive awareness and perception of pain. By directing the patient's attention and focus to possible sources of pain, it may heighten their perception of this stimulus (Linton & Shaw, 2011). This phenomenon requires more investigation in the context of orthodontics.

6.3 Links between Surveys of Orthodontists and Patients

The survey of orthodontists was intended to provide a comprehensive overview of the IPR practices of specialist orthodontists throughout RoI. The survey of patients, because it was carried out on a convenience sample in just one postgraduate orthodontic teaching unit, is less generalisable. Nevertheless, there are comparisons that can be made between both surveys which may be useful to inform and guide future research in this area.

6.3.1 Patient profile

Patients who completed the Patient Questionnaire were aged between 13 and 20 years, with a mean age of 16.2 ± 1.75 years. All resided in the HSE North Cork catchment area, and qualified under HSE guidelines for orthodontic treatment. This is perhaps a biased sample, compared to the respondents to the Orthodontist Questionnaire, who practice throughout RoI and treated a mix of private and HSE orthodontic patients. Although no information was available on the mean age of orthodontic patients in RoI, many practitioners are reportedly seeing an increase in adult patients (McMorrow & Millett, 2017). This makes it likely that the age range and mean age of orthodontic patients treated by specialist orthodontists throughout RoI differed to that of respondents to the Patient Questionnaire in this study.

6.3.2 Operator profile

The influence of the operator on various aspects of orthodontic treatment has been identified (Banks et al., 2004; El-Huni et al., 2019). All respondents to the Orthodontist Questionnaire were registered orthodontic specialists with a variety of training backgrounds and experience, which may have influenced the responses to questions relating to their patients. The patients who completed the Patient Questionnaire were predominantly treated by postgraduate orthodontic students under supervision of a consultant or specialist orthodontist.

6.3.3 Appliances

IPR was reported to be most commonly used in conjunction with aligners by specialist orthodontists, followed by fixed appliances. Aligners were not offered at the Orthodontic Unit where the patient survey was conducted; the majority (93%) of patients who completed the questionnaire were wearing fixed appliances. Therefore, the opinions of patients receiving IPR in conjunction with aligners was not possible to ascertain.

6.3.4 Instruments used to perform IPR

A wide armamentarium was used by specialist orthodontists to perform IPR including handheld strips, ARS burs, discs, abrasive strips in a holder device, ultrasonic instruments and others. Operators in the Orthodontic Unit where the Patient Questionnaire was conducted used either handheld strips or ARS burs only. As these

two instruments were reportedly used by 87% and 51% of specialist orthodontists respectively and were the two 'most preferred' instruments used for IPR, patient experience was likely to be similar between groups.

6.3.5 Patient knowledge about IPR

IPR was evidently not a well-known adjunctive procedure among orthodontic patients. It is conceivable that most patients would have previously heard of extractions, but orthodontists felt that only 12% of patients would have heard of IPR. Patients reported similar levels of prior knowledge, with just 20% having heard of the procedure before, usually from a friend or family member.

When IPR is discussed with a patient, 89% of orthodontists felt that patients found it easy to understand. All patients reported that they fully understood the procedure before it was carried out corroborating the orthodontists' view.

6.3.6 Indications for IPR

In both surveys, IPR was primarily carried out for the same indications: provision of space for relief of crowding, to correct the shape of teeth, or to correct the size of teeth. Specialist orthodontists also reported that improving black triangles was one of the main indications for IPR. This is usually indicated in adults rather than in the adolescents, accounting for it not being reported in the patient survey.

6.3.7 Risks and benefits of IPR

In gaining informed consent a discussion of both the benefits and risks of a procedure are important so that the patient fully understands the proposed procedure. Over 80% of orthodontists reported that they routinely informed patients of the benefits of IPR, such as reducing black triangles, providing space to relieve crowding, improving the shape of teeth and correcting the size of teeth.

Over 70% of orthodontists similarly reported that they informed patients that IPR could avoid the need for extractions, with 50% reporting they informed patients their teeth would be more stable after treatment. More than three quarters (77%) of patients reported they were told IPR would help to relieve crowding, but reported much lower awareness of the other potential benefits. One third (30%) indicated that they were told the size or shape of their teeth would be improved, 20% were informed that IPR may help to avoid extractions, while 7% were told their teeth would be more stable after treatment or that black triangles between their teeth could be reduced with IPR.

The difference in the benefits that patients are aware of could have been due to differences in the content of discussions between the clinicians involved in each survey. Alternatively, this discrepancy could have reflected that patients tend to only remember certain aspects of discussions around consent, especially where only verbal information is provided (Ahn et al., 2019). This highlighted the potential advantage of providing written as well as verbal information about IPR to patients during the informed consent process, to increase their awareness of the procedures they will be undergoing as part of their orthodontic treatment. Providing written information

about IPR appeared not to be common practice; just 11% of orthodontists reported they provided written information to patients and 28% of patients said they received written information on the procedure beforehand.

The most common risks that patients reported being told about matched closely with the information that specialist orthodontists reported providing to their patients routinely. Sensitivity following the procedure was the most common risk discussed; 53% of patients reported being told about this risk and 74% of orthodontists reported that they routinely informed patients of this risk. For the risk of pain, the reported figures were 30% and 34% respectively. Small numbers of patients were informed of potentially adverse effects on the gingiva (7%) and an increased risk of caries (3%) following IPR, while 12% and 15% of orthodontists reported they routinely informed patients of these risks respectively.

6.3.8 Oral hygiene measures

The most common oral hygiene measure that orthodontists reportedly recommended to their patients following IPR was use of a fluoride mouthwash (57%), followed by use of interdental brushes (51%), floss (40%) and densensitising toothpaste (37%). Patients reported being told similar oral hygiene measures to follow, with 63% having stated they were requested to use a fluoride mouthwash after IPR. Interdental brushes (37%), floss (10%) and desensitising toothpaste (20%) were advised for patients less commonly than reported by specialist orthodontists. This may have again been due to operator differences or patient recall of their clinician's advice.

6.3.9 Patient perceptions of IPR

Orthodontists and patients completing their respective questionnaires were asked matching questions to compare how orthodontists thought their patients perceived IPR to the perceptions of patients.

More than half of orthodontists (61%) agreed that patients did not mind having IPR performed, while patients themselves had a more favourable view of IPR, with 93% in agreement with this statement. Few orthodontists (13%) and even fewer patients (3%) disagreed.

Orthodontists and patients shared the view that patients tended to find IPR uncomfortable, rather than painful; 48% of orthodontists and 37% of patients agreed that the procedure was uncomfortable. Just 9% of orthodontists and 13% of patients felt that IPR was painful for patients. When asked to rate the pain that IPR elicited out of 10 on a VAS, patients gave a mean score of 2.3 out of 10 which was lower than the mean score estimated by orthodontists of 3.3 out of 10. Previous research has suggested orthodontists tended to underestimate the pain experienced by patients in orthodontics, in contrast to the findings here (Krukemeyer et al., 2009).

A majority (71%) of orthodontists felt that patients would have a preference for IPR over extractions, where possible. Patients overwhelmingly agreed with this; they expressed a preference to have multiple teeth trimmed in the upper (90%) and lower (87%) arches over extraction of a tooth. This was reinforced by the qualitative questions in the Patient Questionnaire, where all patients felt that having teeth trimmed was better than having teeth extracted. They gave reasons such as IPR being less painful, faster, less invasive and allowing them to retain all their natural teeth.

6.4 Strengths and Weaknesses of this Research Project

6.4.1 Strengths

- This was a novel research project in the RoI, where no existing research had looked at either clinical practices or patient perceptions regarding IPR.
- Rigorous methodology was followed for both questionnaire surveys.
- The excellent response rates to both surveys strengthens the validity of the findings.
- Comprehensive assessment of what patients perceive about IPR has not been undertaken formerly.
- Several hypotheses were generated by this research project, which can be used to inform and guide future research projects.

6.4.2 Weaknesses

- The patients who took part in this study came from a single centre, which limits the generalisability of the results.
- If patients of those who completed the Orthodontist Questionnaire had been the subjects completing the Patient Questionnaire, more detailed comparison of clinician and patient perceptions of IPR could have been undertaken.
- This project did not survey either general dental practitioners or orthodontic therapists. Both groups are increasingly involved in the provision of orthodontics in RoI and may also perform IPR. They may have different practices and perspectives of IPR to specialist orthodontists.

6.5 Recommendations for future work

Further work assessing patient-reported outcomes of IPR should be conducted. This could take the form of a qualitative or mixed-method study, using the information gathered from this survey to create an evidence-based topic guide. This survey could also be extended to a more representative sample of orthodontic patients, including adult patients being treated by a larger number of operators and appliance types in different parts of RoI.

Alternatively, a randomised controlled trial assessing patient-reported outcomes of different methods of IPR could be conducted, for example comparing patient-reported outcomes when IPR is performed using the two most popular methods - handheld strips and air-rotor stripping.

The finding that patients reported lower levels of discomfort when pain was not discussed prior to the procedure was an interesting finding and warrants further exploration in the context of IPR and indeed orthodontic treatment in general.

Extending the survey of specialist orthodontists to general dental practitioners who practice orthodontics in RoI would also be of benefit, to more fully understand how and why IPR is used by different types of practitioners throughout the country.

6.6 Impact of Covid-19 on this research project

Covid-19 had a profound impact on all aspects of life in RoI since the first nationwide lockdown in March 2020. Research activities in general were affected, particularly data collection (Prommegger et al., 2021).

Covid-19 and resulting lockdowns did not have a major detrimental impact on this research project but did influence the number of reminders sent to participants in the orthodontist survey and the length of time it took to collect responses to the patient survey.

For the orthodontist survey, two reminders were initially planned for non-responders, as per the guidance of both Williams (2003) and Dillman (2014) to maximise the survey response rate. After the first of these reminders had been sent, RoI went into its first lockdown. A decision was taken by the author and project supervisor to accept the response rate and to not send the second reminder for several reasons. Firstly, it was considered insensitive to send a survey reminder given the personal, professional and financial stress that the pandemic had potentially brought about for participants. It was also deemed important to maintain goodwill with this pool of participants, whose opinions have been sought in previous surveys and are likely to be contacted again with other research questions in the future. Finally, the response rate was already considered 'very good' at 75% according to Williams (2003) at the time the second reminder was due to be sent out.

Over two-thirds (23/30) of the desired number of patient responses had been collected by the initial lockdown in March 2020, at which point clinical activity and face-to-face contact with patients paused for an extended period. While this did

lengthen the period of data collection, when clinical activity resumed the remaining responses were collected promptly. Data collection was completed within the planned timeframe of one year, but may have been significantly faster had Covid-19 not affected the provision of orthodontic treatment in CUDSH.

Chapter 7. Conclusions

7.1 Conclusions relating to Aim 1

Aim 1

To assess interproximal reduction practices of specialist orthodontists in the Republic of Ireland.

Conclusions

- Specialist orthodontists in RoI routinely performed IPR, mostly using handheld strips in the lower labial segment of the adult or adolescent permanent dentition as part of aligner or fixed appliance treatment.
- IPR was used primarily to reshape triangular teeth or existing restorations, resolve mild crowding, or address tooth-size discrepancies or black triangles.
- Conservative enamel reduction of <0.5mm per surface, creating 2-4mm of space per arch, in <5 minutes over multiple visits without subsequent polishing, recontouring or treating enamel was most commonly adopted.
- Patients were rarely given written information on IPR, were perceived by orthodontists to be unfamiliar with IPR prior to treatment, found the procedure uncomfortable rather than painful and preferable to extractions.

7.2 Conclusions relating to Aim 2

Aim 2

To evaluate patient perceptions of interproximal reduction as part of orthodontic treatment.

Conclusions

- Patients were unfamiliar with IPR but found it easy to understand.
- Patients did not mind having IPR done and considered the procedure uncomfortable rather than painful.
- Patients expressed a preference for IPR over extraction where possible, because IPR was perceived as less painful, less invasive, faster, maintaining all teeth, not requiring anaesthetic and reducing overall treatment time.
- When given the opportunity to express their opinion of IPR to others, patients were generally positive and discussed the topics of pain, comfort, comparison to extraction, time taken, benefits, concerns including bleeding and side effects but recommended the procedure.

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Chapter 9. Appendices

Appendix 1 – Ethical Approval

COISTE EITICE UM THAIGHDE CLINICIÚIL

Clinical Research Ethics Committee of the Cork Teaching Hospitals

Tel: +353-21-4901901
Email: crec@ucc.ie

University College Cork
Lancaster Hall
6 Little Hanover Street
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Ireland

CREC Review Reference Number: ECM 4 (aa) 10/09/19 & ECM 3 (l) 22/10/19

Date: 26th September 2019

Professor Declan Millett
Professor of Orthodontics
Cork University Dental School and Hospital
Wilton
Cork

Study Title: Interproximal reduction in orthodontics: a survey of specialist orthodontists and patients.

Dear Professor Millett

The following documents have been approved:

- Cover Letter received 16th September 2019
- Revised Application Form
- Proof of Insurance: Clinical Indemnity Scheme
- Study Protocol Version 2 dated 2nd September 2019
- Patient Information/Assent Sheet 12-18 years Version 2 dated September 2019
- Parent Information Sheet Version 1 dated September 2019
- Patient Consent Form Version 2 dated September 2019
- Proof of Garda Vetting.

Full approval is now granted to carry out the above study.

Please keep a copy of this signed approval letter in your study master file for audit purposes.

You should note that ethical approval will lapse if you do not adhere to the following conditions:

1. Submission of an Annual Progress Report/Annual Renewal Survey (due annually from the date of this approval letter)
2. Report unexpected adverse events, serious adverse events or any event that may affect ethical acceptability of the study
3. Submit any change to study documentation (minor or major) to CREC for review and approval. Amendments must be submitted on an amendment application form and revised study documents must clearly highlight the changes and contain a new version number and date. Amendments cannot be implemented without written approval from CREC.
4. Notify CREC of discontinuation of the study
5. Submit an End of Trial Declaration Form and Final Study Report/Study Synopsis when the study has been completed.

Yours sincerely

Professor David Kerins
Chairman
Clinical Research Ethics Committee
of the Cork Teaching Hospitals

Appendix 2 – Orthodontist Questionnaire

INTERPROXIMAL REDUCTION IN ORTHODONTICS

A SURVEY OF ORTHODONTISTS



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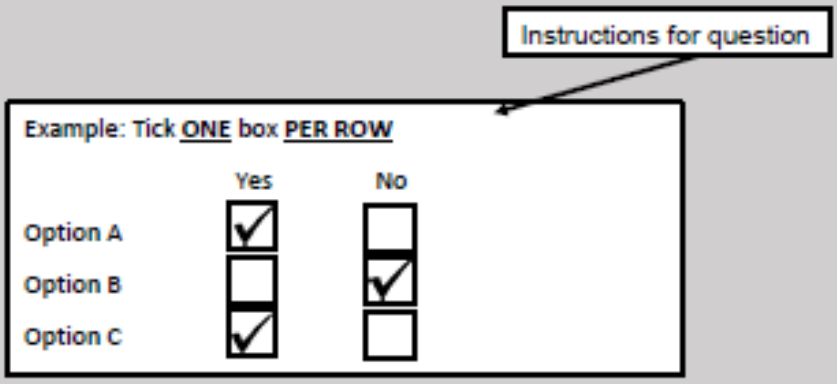
Coláiste na hOllscoile Corcaigh, Éire
University College Cork, Ireland

CORK UNIVERSITY DENTAL SCHOOL & HOSPITAL Wilton, Cork

Page 1 of 18

For office use only	
Subject no.	
Form ID.	
Version 2	July 2019

- Please read the instructions for each question.
- This questionnaire on interproximal reduction is divided into **four sections** – basic details about you, information about your use of interproximal reduction, your technique for performing interproximal reduction, and questions about your patients' perceptions of interproximal reduction.
- Please answer **ALL** the questions in this booklet.
- This questionnaire will be given a unique identifier number, so the answers you give will be **anonymous**
- It should take you **no more than 15 minutes** to complete
- Please **return the questionnaire** to us by post using the prepaid self-addressed envelope.
- Please ensure you have filled in your **prize draw form** and return that to us **separately** in the allocated pre-paid envelope.



SECTION A – YOUR DETAILS

A1. Are you male or female?

i. Male ☐

ii. Female ☐

A2. **WHERE** did you study orthodontics?

Tick **ONE** box only

i. Ireland ☐

ii. UK ☐

iii. USA ☐

iv. Other (please specify) _____

A3. **HOW MANY YEARS** have you been working as a specialist orthodontist?

☐ years

A4. Where is your main **REGION** of work?

Tick **ONE** box only

i. Dublin ☐

ii. Rest of Leinster ☐

iii. Munster ☐

iv. Connacht ☐

v. Ulster ☐

A5. What **SETTING** best describes your practice?

Tick **ONE** box only

i. Private Practice ☐

ii. HSE Orthodontic Clinic ☐

iii. Teaching Hospital ☐

iv. Private Practice & HSE Orthodontic Clinic ☐

v. Private Practice & Teaching Hospital ☐

vi. HSE Orthodontic Clinic & Teaching Hospital ☐

vii. Private Practice & HSE Orthodontic Clinic & Teaching Hospital ☐

viii. Other (please specify) _____

A6. Did you receive **TRAINING** in interproximal reduction as part of your specialist training?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

A7. If yes, what **METHODS** of performing interproximal reduction did you use **WHILE TRAINING**?

Tick **ALL THAT APPLY**

i. Air rotor with diamond bur ☐

ii. Disk mounted in a handpiece ☐

iii. Motor-driven abrasive strip ☐

iv. Abrasive strip in a holder device ☐

v. Handheld abrasive strip ☐

vi. Other method(s) (please specify) _____

_____

SECTION B – YOUR USE OF INTERPROXIMAL REDUCTION

This section contains questions about **when** and **why** you perform interproximal reduction for your patients.

B1. Do you perform interproximal reduction for your orthodontic patients?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

If you answered 'No' to the above question, the questionnaire is now complete, thank you.

Please turn to page 2 for instructions on returning the questionnaire.

B2. **HOW OFTEN** do you perform interproximal reduction in each of the following **PATIENT GROUPS?**

Tick **ONE** box **PER ROW**

	Very often	Often	Sometimes	Rarely	Never
i. Patients with primary dentition	☐	☐	☐	☐	☐
ii. Patients with mixed dentition	☐	☐	☐	☐	☐
iii. Adolescent patients with permanent dentition	☐	☐	☐	☐	☐
iv. Adult patients	☐	☐	☐	☐	☐

B3. **HOW OFTEN** do you perform interproximal reduction in each of the following **TYPES OF MALOCCLUSION?**

Tick **ONE** box **PER ROW**

	Very often	Often	Sometimes	Rarely	Never
i. Class I	☐	☐	☐	☐	☐
ii. Class II Division 1	☐	☐	☐	☐	☐
iii. Class II Division 2	☐	☐	☐	☐	☐
iv. Class III	☐	☐	☐	☐	☐

B4. **HOW OFTEN** do you perform interproximal reduction in conjunction with the following **APPLIANCES?**

Tick **ONE** box **PER ROW**

	Very often	Often	Sometimes	Rarely	Never
i. Fixed appliances – Conventional pre-adjusted edgewise	☐	☐	☐	☐	☐
ii. Fixed appliances – Self-ligating	☐	☐	☐	☐	☐
iii. Aligners	☐	☐	☐	☐	☐
iv. Removable appliances	☐	☐	☐	☐	☐
v. Functional appliances	☐	☐	☐	☐	☐
vi. Retainers	☐	☐	☐	☐	☐

B5. **HOW OFTEN** do you perform interproximal reduction at each of the following **STAGES OF TREATMENT?**

Tick **ONE** box **PER ROW**

	Very often	Often	Sometimes	Rarely	Never
i. Start of treatment	☐	☐	☐	☐	☐
ii. After initial alignment	☐	☐	☐	☐	☐
iii. Throughout treatment	☐	☐	☐	☐	☐
iv. Finishing	☐	☐	☐	☐	☐
v. Retention	☐	☐	☐	☐	☐
vi. Other time point (please specify)_____	☐	☐	☐	☐	☐

B6. Do you perform interproximal reduction for the following **INDICATIONS?**

Tick **ONE** box **PER ROW**

	Yes	No
i. Triangular teeth	☐	☐
ii. Tooth size discrepancy	☐	☐
iii. Gingival recession/retraction	☐	☐
iv. Reshaping existing restorations	☐	☐
v. Mild crowding (<4mm)	☐	☐
vi. Moderate crowding (4 - <8mm)	☐	☐
vii. Severe crowding (>8mm)	☐	☐

viii. Other indication(s) (please specify) _____

_____

B7. **HOW OFTEN** do you perform interproximal reduction on each of the following **TEETH?**

Tick **ONE** box **PER ROW**

	Very often	Often	Sometimes	Rarely	Never
i. Upper Central Incisor	☐	☐	☐	☐	☐
ii. Upper lateral Incisor	☐	☐	☐	☐	☐
iii. Upper Canine	☐	☐	☐	☐	☐
iv. Upper first premolar	☐	☐	☐	☐	☐
v. Upper second premolar	☐	☐	☐	☐	☐
vi. Upper first molar	☐	☐	☐	☐	☐
vii. Upper second molar	☐	☐	☐	☐	☐
viii. Lower Central Incisor	☐	☐	☐	☐	☐
ix. Lower lateral Incisor	☐	☐	☐	☐	☐
x. Lower Canine	☐	☐	☐	☐	☐
xi. Lower first premolar	☐	☐	☐	☐	☐
xii. Lower second premolar	☐	☐	☐	☐	☐
xiii. Lower first molar	☐	☐	☐	☐	☐
xiv. Lower second molar	☐	☐	☐	☐	☐

B8. Do you **ROUTINELY** do a **BOLTON TOOTH SIZE ANALYSIS** before performing interproximal reduction?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

B9. **HOW MUCH** enamel reduction are you comfortable to perform **ON EACH PROXIMAL SURFACE** of teeth in the following areas?

Tick **ONE** box **PER ROW**

	≤0.2mm	0.3mm	0.4mm	0.5mm	>0.5mm	Half of the thickness of enamel	Full thickness of enamel	I don't perform interproximal reduction on these teeth
i. Upper Anterior	☐	☐	☐	☐	☐	☐	☐	☐
ii. Upper posterior	☐	☐	☐	☐	☐	☐	☐	☐
iii. Lower anterior	☐	☐	☐	☐	☐	☐	☐	☐
iv. Lower posterior	☐	☐	☐	☐	☐	☐	☐	☐

B10. In the **UPPER ARCH**, what is the **MAXIMUM** amount of space you create by performing interproximal reduction?

Tick **ONE** box only

☐ <2mm ☐ 2 - <4mm ☐ 4 - <6mm ☐ 6 - <8mm ☐ 8 - <10mm ☐ ≥10mm

B11. In the **LOWER ARCH**, what is the **MAXIMUM** amount of space you create by performing interproximal reduction?

Tick **ONE** box only

☐ <2mm ☐ 2 - <4mm ☐ 4 - <6mm ☐ 6 - <8mm ☐ 8 - <10mm ☐ ≥10mm

B12. In the **PAST 5 YEARS**, has your use of interproximal reduction increased, remained the same or decreased?

Tick **ONE** box only

i. Increased ☐

ii. Remained the same ☐

iii. Decreased ☐

B13. What is/are the **REASON(S) FOR THE CHANGE** in your frequency of use of interproximal reduction?

Tick **ONE** box **PER ROW**

	Yes	No
i. Increased use of aligners	☐	☐
ii. Increased use of self-ligating appliances	☐	☐
iii. Increased acceptance of permanent retention	☐	☐
iv. Patient reluctance to extract teeth	☐	☐
v. Personal reluctance to extract teeth	☐	☐
vi. Profile considerations	☐	☐
vii. More patients presenting with mild crowding	☐	☐
viii. Post-treatment stability	☐	☐
ix. Media attention	☐	☐

x. Other reasons (please specify) _____

_____

B14. Has your use of interproximal reduction **INFLUENCED HOW MUCH CROWDING** you are willing to resolve **WITHOUT EXTRACTING TEETH?**

Tick **ONE** box only

i. Yes ☐

ii. No ☐

B15. Does performing interproximal reduction for a patient have an **INFLUENCE** on your **CHOICE OF RETAINER** for that patient?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

If 'Yes', please specify how your retainer choice differs if interproximal reduction has been performed _____

_____

B16. Please indicate **HOW MUCH YOU AGREE OR DISAGREE** with the following statements

Tick **ONE** box in **EACH ROW**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
i. I routinely perform interproximal reduction to gain intra-arch space	☐	☐	☐	☐	☐
ii. From an aesthetic standpoint, I prefer performing interproximal reduction on the posterior teeth than the anterior teeth	☐	☐	☐	☐	☐
iii. Interproximal reduction is easier to perform on anterior teeth than posterior teeth	☐	☐	☐	☐	☐
iv. Interproximal reduction is a minimally invasive procedure that poses little risk for the development of interproximal caries	☐	☐	☐	☐	☐
v. The aesthetic and occlusal benefits of interproximal reduction outweigh the potential risk of caries	☐	☐	☐	☐	☐
vi. I have researched the effects of interproximal reduction on the health of teeth	☐	☐	☐	☐	☐
vii. I would be willing to have interproximal reduction performed on my own teeth	☐	☐	☐	☐	☐

SECTION C –PERFORMING INTERPROXIMAL REDUCTION

This section contains questions about **your technique** for performing interproximal reduction for your patients.

C1. Do you use the following **METHODS** of performing interproximal reduction?
Tick **ONE** box **PER ROW**

	Yes	No
i. Air rotor with diamond bur	☐	☐
ii. Disk mounted in a handpiece	☐	☐
iii. Motor-driven abrasive strip	☐	☐
iv. Abrasive strip in a holder device	☐	☐
v. Handheld abrasive strip	☐	☐

vi. Other methods (please specify) _____

_____

C2. What is your **PREFERRED METHOD** of performing interproximal reduction?
Tick **ONE** box only

i. Air rotor with diamond bur ☐
ii. Disk mounted in a handpiece ☐
iii. Motor-driven abrasive strip ☐
iv. Abrasive strip in a holder device ☐
v. Handheld abrasive strip ☐

vi. Other method (please specify) _____

_____

C3. Do you usually perform interproximal reduction in **ONE VISIT OR OVER SEVERAL VISITS?**

Tick **ONE** box only

i. In a single visit ☐

ii. Over several visits ☐

C4. Do you **SEPARATE** teeth before performing interproximal reduction?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

C5. **HOW MUCH TIME** does it routinely take you to perform interproximal reduction for your patients?

Tick **ONE** box only

i. <5 minutes ☐

ii. 5 - <10 minutes ☐

iii. 10 - <15 minutes ☐

iv. 15 - <20 minutes ☐

v. ≥20 minutes ☐

C6. **HOW** do you **GAUGE THE AMOUNT** of tooth reduction performed?

Tick **ONE** box only

i. Interproximal gauge/Leaf gauge ☐

ii. Floss to check for open contact ☐

iii. Thickness of abrasive strip/disk used as a measure ☐

iv. Other measurement method ☐

(please specify other method used) _____

v. I don't formally measure the amount of tooth reduction performed ☐

C7. Do you **ROUTINELY** carry out a separate tooth **RECONTOURING** step after performing interproximal reduction?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

C8. Do you **ROUTINELY** carry out a separate **POLISHING** step after performing interproximal reduction?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

C9. Do you **ROUTINELY TREAT SURFACES** with the following after interproximal reduction?

Tick **ONE** box **PER ROW**

	Yes	No
i. Fluoride varnish	☐	☐
ii. CPP-ACP (e.g. Tooth Mousse®)	☐	☐
iii. Desensitising paste	☐	☐
iv. Bonding agent/sealant	☐	☐
v. Other surface treatment	☐	☐

(please specify other surface treatment) _____

C10. Do you **ROUTINELY RECORD** the **TEETH** on which interproximal reduction has been performed in your treatment notes?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

C11. Do you **ROUTINELY RECORD** the **AMOUNT** of tooth reduction carried out in your treatment notes?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

C12. Do you **ROUTINELY RECOMMEND** any of the following **ORAL HYGIENE** measures for your patients after interproximal reduction?

Tick **ONE** box **PER ROW**

	Yes	No
i. Use of a fluoride mouthrinse	☐	☐
ii. Use of floss/superfloss	☐	☐
iii. Use of interdental brushes	☐	☐
iv. Use of desensitising toothpaste	☐	☐
v. Use of Tooth Mousse®/similar	☐	☐
vi. Other	☐	☐

(**please specify** other surface treatment) _____

SECTION D –YOUR PATIENTS

This section contains questions about **the information your patients receive** and **your perception of what your patients think** about interproximal reduction.

D1. Do you **ROUTINELY PROVIDE INFORMATION LEAFLETS** to your patients on interproximal reduction?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

D2. If 'Yes', who are these leaflets developed by?

Tick **ONE** box only

i. British Orthodontic Society ☐

ii. Your practice ☐

iii. Other ☐

(please specify) _____

D3. Do you **ROUTINELY** inform your patients about the following potential **BENEFITS** before performing interproximal reduction?

Tick **ONE** box **PER ROW**

	Yes	No
i. The shape of the tooth/teeth can be improved	☐	☐
ii. The tooth/teeth can be reduced to the correct size	☐	☐
iii. Black triangles can be reduced/ resolved	☐	☐
v. Space can be created to relieve crowding	☐	☐
vi. Space can be created which may avoid dental extractions	☐	☐
vii. The teeth may have more stable contacts/stability may improve	☐	☐
viii. Other benefits	☐	☐

(please specify other benefits)_____

_____

D4. Do you **ROUTINELY** inform your patients about the following potential **RISKS** before performing interproximal reduction?

Tick **ONE** box **PER ROW**

	Yes	No
i. Pain	☐	☐
ii. Tooth sensitivity	☐	☐
iii. Gingival/Periodontal problems	☐	☐
iv. Increased risk of caries	☐	☐
vi. Other risk	☐	☐

(please specify other risks)_____

_____

D5. **WHEN** do you **ROUTINELY DISCUSS** the **RISKS AND BENEFITS** of interproximal reduction with your patients?

Tick **ONE** box only

- i. At treatment planning/consent stage ☐
- ii. During treatment, but before the visit when interproximal reduction is to be performed ☐
- iii. Immediately prior to performing interproximal reduction ☐
- iv. I do not routinely discuss the risks and benefits of interproximal reduction in detail with my patients ☐

D6. Please indicate **HOW MUCH YOU AGREE OR DISAGREE** with the following statements

Tick **ONE** box **PER ROW**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
i. My patients do not mind having interproximal reduction done	☐	☐	☐	☐	☐
ii. My patients find interproximal reduction uncomfortable	☐	☐	☐	☐	☐
iii. My patients find interproximal reduction painful	☐	☐	☐	☐	☐
iv. My patients prefer interproximal reduction where possible, rather than extractions	☐	☐	☐	☐	☐
v. My patients complain of sensitivity after interproximal reduction	☐	☐	☐	☐	☐
vi. My patients have concerns when I explain interproximal reduction to them	☐	☐	☐	☐	☐
vii. My patients find interproximal reduction easy to understand	☐	☐	☐	☐	☐
viii. My patients have heard of interproximal reduction before I explain it to them	☐	☐	☐	☐	☐

D7. On a scale of 0 to 10, **HOW PAINFUL** do you think the majority of your **PATIENTS** find interproximal reduction?

CIRCLE A NUMBER on the scale



Not at all painful

Extremely painful

D8. Is there **ANYTHING ELSE** you would like to mention about interproximal reduction?

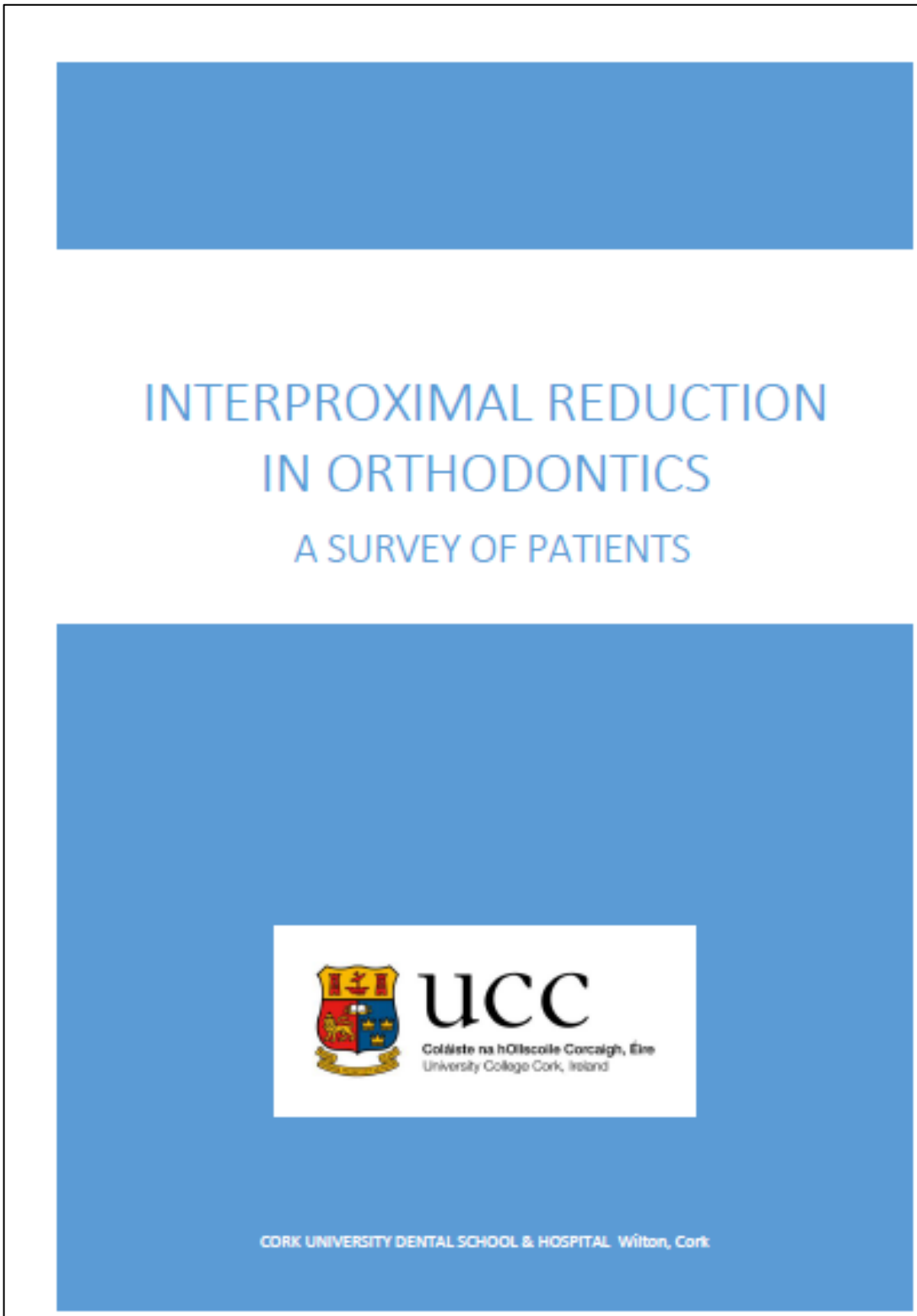
Please **WRITE** your response

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.

Please see **page 2** for instructions on how to return the questionnaire to us.

Don't forget to complete your **prize draw form** and return that separately in the envelope provided.

Appendix 3 – Patient Questionnaire



For office use only

Subject no. ☐

Form ID. ☐

Version 2 July 2019

- Please **READ THE INSTRUCTIONS** for each question
- This questionnaire on tooth trimming is divided into **THREE PARTS** – basic details about you, your knowledge about the procedure and your thoughts on the procedure
- Please answer **ALL** the questions in this booklet
- This questionnaire will be given a unique identifier number, so the answers you give will be **ANONYMOUS**
- It should take you **APPROXIMATELY 10 MINUTES** to complete

Instructions for question

Example: Tick **ONE** box only **IN EACH ROW**

	Yes	No
Option A	☑	☐
Option B	☐	☑
Option C	☑	☐

SECTION A – YOUR DETAILS

A1. Are you male or female?

i. Male ☐

ii. Female ☐

A2. What age are you?

I am ☐ years old

SECTION B – INFORMATION ABOUT THE PROCEDURE

This section contains questions about **what you knew** and **what you were told** about the **tooth trimming procedure**, which you have had as part of your orthodontic treatment

B1. I **HAD HEARD** about this procedure **BEFORE** my orthodontist told me about it

Tick **ONE** box only

- i. Yes ☐ **If 'Yes', Go to Question B2**
- ii. No ☐ **If 'No', Go to Question B3**

B2. **WHERE** did you hear about it?

Tick **ALL** that apply

- i. Friend ☐
- ii. Family member ☐
- iii. Another dentist ☐
- iv. Internet ☐
- v. Facebook ☐
- vi. Instagram ☐
- vii. Twitter ☐
- viii. Other (please specify) _____

B3. Did your orthodontist give you any **WRITTEN INFORMATION** (e.g. an information booklet) about the trimming procedure?

Tick **ONE** box only

- i. Yes ☐
- ii. No ☐

B4. What **TYPE OF BRACES** were you wearing when you had the trimming done?

Tick **ONE** box only

i. Upper removable appliance (upper "plate") ☐

ii. Fixed braces ("train-tracks") ☐

iii. Clear aligners (e.g. Invisalign®) ☐

iv. Upper and lower blocks (e.g. "Twin-blocks") ☐

v. Retainers ☐

B5. Did your orthodontist **EXPLAIN** clearly **WHY** your teeth were being trimmed?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

B6. Did you **UNDERSTAND** clearly **WHY** your teeth were being trimmed?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

B7. Please specify the **REASON** that the orthodontist trimmed your teeth?

Tick **ALL** that apply

i. My teeth were the wrong shape ☐

ii. My teeth were the wrong size ☐

iii. My teeth had spaces in between them ☐

iv. My gums were receding ☐

v. My teeth were slightly crowded ☐

vi. My teeth were very crowded ☐

vii. Other (**please specify**) _____

viii. Don't know why ☐

B8. Did your orthodontist tell you about any of the following **BENEFITS** of having your teeth trimmed?

Tick **ALL** that apply

i. The shape of my teeth would improve ☐

ii. My teeth would be reduced to the correct size ☐

iii. Black spaces in between my teeth would be removed ☐

iv. It would help solve the crowding of my teeth ☐

v. It would avoid having to take out any teeth ☐

vi. The teeth will stay put after braces and not easily move ☐

vii. Other (**please specify**) _____

viii. None of the above ☐

B9. Did your orthodontist tell you about any **POTENTIAL SIDE EFFECTS** of having your teeth trimmed?

Tick ALL that apply

i. Pain ☐

ii. Sensitivity to hot/cold ☐

iii. Gum problems ☐

iv. Risk of tooth decay ☐

v. Other (please specify) _____

vi. None of the above ☐

B10. Did your orthodontist ask you to do anything special **TO KEEP YOUR TEETH CLEAN** after the trimming procedure?

Tick ALL that apply

i. Use a fluoride mouthwash ☐

ii. Use a special type of floss ☐

iii. Use a special small brush in between the teeth ☐

iv. Use a toothpaste for sensitive teeth (e.g. Sensodyne©) ☐

v. Use a special cream for teeth (e.g. Tooth Mousse©) ☐

vi. Other (please specify) _____

vii. None of the above ☐

SECTION C – YOUR PERCEPTION OF THE PROCEDURE

This section contains questions about **what you thought** about the **tooth trimming procedure**.

C1. On a scale of 0 to 10, **HOW MUCH PAIN** did you feel during the trimming procedure?

CIRCLE A NUMBER on the scale



No Pain Extreme Pain

C2. Do you think having your teeth **TRIMMED** is **BETTER** than having teeth **EXTRACTED**?

Tick **ONE** box only

i. Yes ☐

ii. No ☐

Please give a **REASON** for your answer

_____

_____

_____

_____

C3. Please indicate **HOW MUCH YOU AGREE OR DISAGREE** with the following statements

Tick **ONE** box in **EACH ROW**

	Strongly Agree	Agree	Neutral	Disagree	Strongly Disagree
i. Before the procedure, I was **WORRIED** about having the sides of my teeth trimmed	☐	☐	☐	☐	☐
ii. By trimming my teeth, my teeth will be **WEAKER**	☐	☐	☐	☐	☐
iii. By trimming my teeth, my teeth will be more **PRONE TO DECAY**	☐	☐	☐	☐	☐
iv. I **DID NOT MIND** having my teeth trimmed	☐	☐	☐	☐	☐
v. I found the procedure **UNCOMFORTABLE**	☐	☐	☐	☐	☐
vi. I found the procedure **PAINFUL**	☐	☐	☐	☐	☐
vii. I experienced increased **SENSITIVITY** to hot/cold after having my teeth trimmed	☐	☐	☐	☐	☐
viii. If it was recommended by my orthodontist, I would agree to having this procedure done on my **UPPER FRONT TEETH**	☐	☐	☐	☐	☐
ix. If it was recommended by my orthodontist, I would agree to having this procedure done on my **UPPER BACK TEETH**	☐	☐	☐	☐	☐
x. If it was recommended by my orthodontist, I would agree to having this procedure done on my **LOWER FRONT TEETH**	☐	☐	☐	☐	☐
xi. If it was recommended by my orthodontist, I would agree to having this procedure done on my **LOWER BACK TEETH**	☐	☐	☐	☐	☐
xii. If my upper teeth were crowded, I would **PREFER** to have several upper teeth trimmed to make room for the rest of the teeth, **INSTEAD OF EXTRACTING** a tooth	☐	☐	☐	☐	☐
xiii. If my lower teeth were crowded, I would **PREFER** to have several lower teeth trimmed to make room for the rest of the teeth, **INSTEAD OF EXTRACTING** a tooth	☐	☐	☐	☐	☐

C4. Do you have any other **CONCERNS** about having your teeth trimmed?

Please **WRITE** your response

C5. If a **FRIEND OR FAMILY** member told you that they were also going to have their teeth trimmed by the orthodontist, **WHAT WOULD YOU TELL THEM** about it?

Please **WRITE** your response

This question is very important for us to understand your overall experience of this procedure. Please take your time answering it.

C6. Is there **ANYTHING ELSE** you would like to mention about the trimming procedure?

Please **WRITE** your response

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE.

Appendix 4 – Feedback Form on Pilot Patient Questionnaire

Feedback on pilot questionnaire for patients

Time taken to complete survey. ☐ minutes

Feedback on **specific** questions

Question number (e.g. B2)	**Comment**

Readability/clarity of questions: /10

Suggestions: _____

_____

Options given for each question: /10

Suggestions: _____

_____

Layout of questionnaire: /10

Suggestions: _____

_____

Order of questions: /10

Suggestions: _____

_____

Any other questions you would ask in this questionnaire?

_____

_____

General Feedback on questionnaire

_____

_____

Appendix 5 – Feedback Form on Pilot Orthodontist Questionnaire (Postal)

Feedback on pilot questionnaire for orthodontists

Time taken to complete survey . ☐ minutes

Feedback on **specific** questions

Question number (eg C4)	**Comment**

Readability/clarity of questions: /10

Suggestions: _____

_____

Options given for each question: /10

Suggestions: _____

_____

Layout of questionnaire: /10

Suggestions: _____

_____

Order of questions: /10

Suggestions: _____

_____

Any other questions you would ask in this questionnaire?

_____

_____

General Feedback on questionnaire

_____

_____

Appendix 6 – Feedback Form on Pilot Orthodontist Questionnaire (Online)

Feedback on pilot questionnaire for orthodontists (online)

Time taken to complete survey . ☐ minutes

Feedback on **specific** questions

Question number (eg C4)	**Comment**

Readability/clarity of questions: /10

Suggestions: _____

_____

Options given for each question: /10

Suggestions: _____

_____

Layout of questionnaire: /10

Suggestions: _____

_____

Order of questions: /10

Suggestions: _____

_____

Any other questions you would ask in this questionnaire?

_____

_____

General Feedback on questionnaire

_____

_____

Appendix 7 – BOS Patient Information Leaflet on Interproximal Reduction

Reproduced with the kind permission of the BOS

Are my teeth more likely to decay if enamel is removed?
No. The orthodontist will only remove the minimum amount of enamel required to get your teeth straight. Each tooth will be left with enough enamel to continue to remain healthy and sound.
Studies have shown that the decay rates of teeth that have had interproximal reduction are no higher than normal teeth. Your orthodontist may coat the teeth in a temporary fluoride varnish after the procedure to help the enamel "repair" itself. You may also be advised to use an alcohol-free fluoride mouthrinse to help keep the enamel strong.

Will my teeth be painful?
No. Some patients, however, may experience some temporary sensitivity to hot or cold foods and drinks but this usually returns to normal within a few days.

Will it give me gum disease?
No. The procedure does not make your teeth more at risk to gum disease. It is important for you to keep your teeth and gums clean and healthy throughout your orthodontic treatment.

What are the possible risks of Interproximal reduction?
Plaque can collect more readily on teeth that have undergone interproximal reduction, if the tooth surface is not smoothed and polished by the orthodontist afterwards.

Is there a chance that my treatment won't be successful?
For orthodontic treatment to be successful you will need to be committed to your treatment. You will need to attend regularly and look after your teeth and your brace.

As a general rule, patients who cooperate well with treatment get good results, whilst those who do not cooperate well, get poor results. If your brace breaks repeatedly or you do not keep your teeth clean, treatment may be stopped, leaving your teeth in a worse position than when you started.

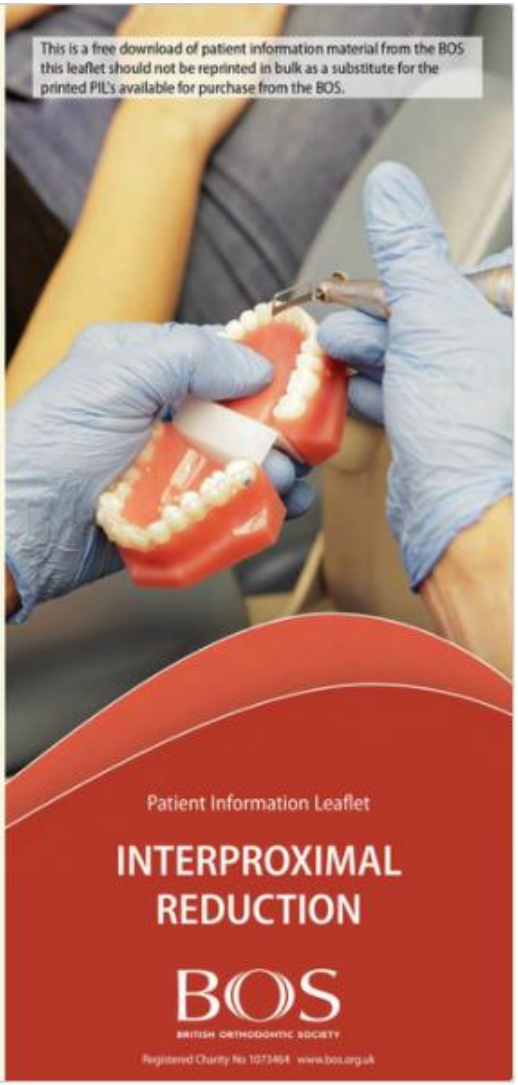
Are there any other risks?
There may be other rare risks which could affect you. These will be explained to you in greater detail by your orthodontist.

If you have any further questions that you feel you would like to ask, then please write them down and bring them with you to your next appointment.

It is important that you fully understand what is involved in having the procedure of interproximal reduction before you decide to go ahead.

This leaflet has been produced with guidance from the Plain English Campaign and British Dyslexia Association to make it easier for you to read

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Your orthodontist is considering carrying out a procedure on your teeth called **"interproximal reduction"** (IPR) - also known as interdental enamel reduction, slenderising, stripping, selective enamel reduction and enamel reproximation.
You will need to know about the benefits and risks of this procedure.
You may have some questions you would like answered before you decide to go ahead.

What is interproximal reduction?

Interproximal reduction is the mechanical removal of some of the outer tooth surface, called enamel, between teeth. It is possible to reduce the width of certain teeth by up to ½ mm. The space created by interdental reduction can then be used to straighten the teeth.

Why do I need interproximal reduction?

Your orthodontist needs to gain enough space in order to straighten your teeth and improve your bite. If the space required is small, then it can be achieved by interproximal reduction of several teeth. This could avoid the need for extracting teeth. It can also be done to reshape teeth.

How is it done?

The enamel is removed by using either:

- a fine dental bur
- a disc in a dental handpiece (drill) or
- by hand with an abrasive strip (file)

How long does it take?

Interproximal reduction takes only a few minutes and can be done in a single visit or spread over several visits.



Enamel reduction by dental bur



Enamel reduction by rotating disc



Enamel reduction by hand using an abrasive strip (file)

Does it hurt?

No. Enamel is the material that makes up the outer shell of our teeth. It does not contain any nerves and so no discomfort is felt. As only a very thin layer of enamel is removed, no anaesthetic is required. You may, however, feel a strange pulling/pushing pressure during the procedure.

Sometimes, to make some temporary space between teeth beforehand, small rubber rings called separators are placed between the teeth, a week before the interproximal reduction procedure is carried out, in order to move the teeth apart slightly.



Elastic separators between back teeth



Spaces created between the back teeth



Spaces closed by fixed braces and front teeth straight