Prevalence of open gingival embrasures after comprehensive orthodontic treatment at the Wits Oral Health Centre

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Declaration

I, Mashudu Lucky Muthavhine, declare that this research project, “Prevalence of open gingival embrasures after comprehensive orthodontic treatment at the Wits Oral Health Centre”, is my own unaided work. It is being submitted for the Master of Dentistry in Orthodontics degree in the Department of Orthodontics at the University of Witwatersrand, Johannesburg. This work has not been submitted for the award of any degree or examination at any other university.

Date: 15 September 2025

Dedication

To God.

For never abandoning me and for being my steadfast source of strength throughout my academic path.

To Rabelani, my beloved wife, and our children, Tshedza, Andani, and Mashudu.

Thank you for your constant support, patience, and the sacrifices you've made throughout this journey.

To my late parents, Ratshilumela and Gladys — thank you for believing in me and planting the seeds of ambition and perseverance.

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- I am grateful to Dr. S Matjila, the CEO, for kindly allowing me to access the project records.
- To my family: my God-sent wife, Rabelani, whose love and encouragement were my pillars of strength; and my daughters, Tshedza and Andani, and son, Mashudu, whose love and playful nature brought joy and peace during the hardest moments.

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List of abbreviations

AP	Antero-Posterior
bCEJ	Buccal Cemento-Enamel Junction
CEJ	Cemento-Enamel Junction
iCEJ	Interproximal Cemento-Enamel Junction
κ	Kappa
mm	Millimetres
OGE	Open Gingival Embrasure
OR	ODDS Ratio
PCA	Proximal Contact Areas
PI	Primary Investigator
PPI	Papilla Presence Index score
SARME	Surgically Assisted Rapid Maxillary Expansion
SI	Second Investigator
T1	Time point 1
T2	Time point 2
WOHC	Wits Oral Health Centre

Abstract

Introduction: The purpose of this study was to determine the prevalence of open gingival embrasure (OGE) on central incisors among patients after comprehensive orthodontic treatment at the Wits Oral Health Centre.

Methodology: This retrospective study reviewed the intraoral records of patients who began treatment between January 1, 2016, and December 30, 2020, using convenience sampling. Anterior crowding and incisor rotation were measured on pre-treatment study models of patients. Post-treatment OGEs were assessed on frontal intraoral photographs.

Results: In the maxilla, 39% of patients developed OGE post-treatment, and 47% had OGE in the mandible. OGE was present in 32% of individuals under 18 and 50% of those aged 18 and older in the maxillary region. In the mandible, 44% of those under 18 and 50% of older individuals had OGE.

OGE was observed in 41% of central incisor labial rotation corrections and 29% of lingual rotation corrections within the maxilla. In comparison, 50% of labial rotation correction and 38% of lingual rotation correction had OGE in the mandible. In the maxillary region, cases with post-treatment OGE had a median anteroposterior (AP) central incisor crowding of 0.75 mm (range: 0-1.75) and transverse crowding of 0 mm (range: 0-0.25) pre-treatment. In the mandibular region, cases with OGE had a median AP crowding of 1mm (range: 0.5-1), while transverse crowding had a median of 0mm (range: 0-0) pre-treatment.

No statistically significant association was found between pre-treatment crowding, tooth rotation, age, or sex and the occurrence of post-treatment OGE.

Conclusions: OGE frequently developed following orthodontic treatment, with a higher prevalence in the mandible compared to the maxilla.

Keywords: Prevalence, Open gingival embrasure, Orthodontic treatment, Central incisors, Crowding, Rotation.

CHAPTER 1

Introduction and Literature Review

1. Introduction

Open gingival embrasure (OGE), also referred to as a “Black Triangle,” is a common aesthetic problem following orthodontic treatment. OGE is defined as a void triangular space that develops because of the loss of papillae under the interproximal contact of adjoining teeth, and it usually appears between incisors [1]. Orthodontic treatment can lead to OGE, potentially affecting adult patients who have high expectations of aesthetics. OGE may trap food debris and adversely affect periodontal health [2].

The size and dimensions of the papilla may be altered during orthodontic treatment, resulting in an appearance of OGE [3-5]. Tanaka *et al.* (2008) distinguished between a black triangle and a diastema. They described diastema as a complete space between incisors where there is no contact between them. In contrast, a black triangle occurs when there is contact between the teeth, but there is space apical to the contact point [1].

In 1907, Angle stated that the aim of orthodontics is to correct malocclusions of teeth [6]. The negative consequences of orthodontic treatment on periodontal tissues may include bone dehiscence [7], gingival recession, degeneration of soft tissue structure, and the formation of OGE, which greatly impact aesthetic outcomes [8]. Stretching of interdental transseptal gingival fibres during orthodontic treatment has also been implicated as a factor that may contribute to the development of OGE [5]. It is vital to appreciate the sources and development of OGE to develop a suitable treatment plan to reduce the incidence and severity of post-treatment OGE [5].

Studies have reported varying OGE prevalence after orthodontic treatment, with higher rates in mandibular incisors and clear aligner cases than in fixed appliances [5, 9, 10]. Some studies indicate that the likelihood of OGE rises with age and is more prevalent in males [11, 12]. However, Joshi *et al.* (2017) observed that adult females are more susceptible to gingival recession, which results in OGE [13].

2. Literature review

2.1. Open gingival embrasure

OGE develops within the interdental space, the area between adjacent teeth that typically has a pyramidal form. The dimensions of this space are influenced by factors such as tooth morphology and the distance between the alveolar crest and the contact point of neighbouring teeth. Normally, this space is filled by the gingival papilla, a dense tissue covered by oral epithelium [14]. The relationship between the contact point, the apex of the papilla, and the mesial surfaces of adjacent teeth identifies OGE [15-17]. Cohen (1959) described the interdental papilla as the portion of the gingiva that occupies the V-shaped embrasure between two teeth [18].

In the anterior teeth, the contact point follows an apicoincisal orientation and is often referred to interchangeably as the "contact area" [19]. A true contact point is typically seen in younger patients, where adjacent surfaces meet with ideal curvatures, whereas in adults, proximal contact areas (PCA) are more commonly present in the anterior dentition [20]. Kurth and Kokich (2001) reported that in patients with OGE, the PCA was either smaller or positioned approximately one mm more incisally compared to individuals with a normal gingival embrasure. The size of the contact point also plays a role, as larger contact areas reduce the distance between the contact point and the gingival papilla [21]. Gender differences have been noted as well, with males showing higher PCA levels than females, a variation likely linked to crown morphology—males more frequently present squarish crowns, while females tend to have triangular or tapered crowns [22, 23].

2.2. Classification of OGE

Nordland and Tarnow (1998) introduced a classification system to evaluate the severity of OGE (see Table 1 and Figure 1). Their classification was based on the following landmarks: the interproximal contact point, the facial cementoenamel junction (CEJ), and the most interproximal superior level of the CEJ [24]. Uribe *et al*. (2011) added to the above classification a four-point scale for each OGE based on appearance: Unnoticeable, slightly noticeable, moderately apparent, and highly noticeable (Figure 2) [25].

Table 1: Nordland and Tarnow classification system

Normal	Interdental papilla occupies the embrasure space to the apical extent of the interdental contact point or area
Class I	The tip of the interdental papilla is located between the contact point of adjacent teeth and the highest point of the interproximal CEJ (space present but interproximal CEJ not visible)
Class II	The tip of the interdental papilla is positioned at or below the level of the interproximal CEJ but remains above the most apical point of the facial CEJ, and the interproximal CEJ is visible.
Class III	The tip of the interdental papilla is located at or below the level of the facial CEJ.

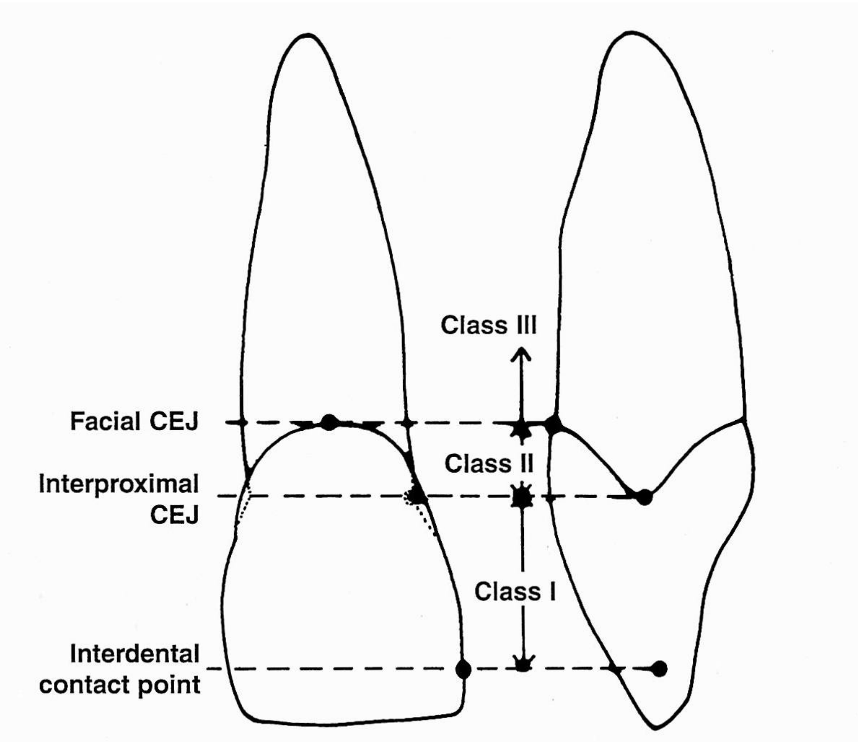

Figure 1: Classification of interdental papilla

Source: [24]

Figure 2: Classification of OGE according to Uribe

A. Unnoticeable, B. Slightly noticeable, C. Moderately apparent, D. Highly noticeable

Source: [25]

Another classification system was developed by Cardaropoli to evaluate interproximal papillary levels according to the positioning of the papilla, CEJ, and neighbouring teeth (Figure 3). He classified interproximal papillary levels as follows [26]:

a. Papilla Presence Index score 1 (PPI 1): The extent of the papilla is coronal and completely fills the interproximal embrasure. The adjacent papillae are at the same level. PPI 1 may be complicated by recession of buccal soft tissue and classified as PPI 1r
b. Papilla Presence Index score 2 (PPI 2): The papilla is positioned below the contact point and not in alignment with the nearby papillae. Although the interproximal CEJ (iCEJ) is not visible, the embrasure is not filled. Buccal recession may contribute to complications in PPI 2 cases, and are classified as PPI 2r
c. Papilla Presence Index score 3 (PPI 3): The papilla is positioned below the iCEJ, and the iCEJ becomes visible. A great amount of soft tissue recession is compatible with PPI 3.
d. Papilla Presence Index score 4 (PPI 4): The position of the papilla is below both iCEJ and the buccal CEJ (bCEJ). There is interproximal and buccal gingival recession. The aesthetics are dramatically compromised.

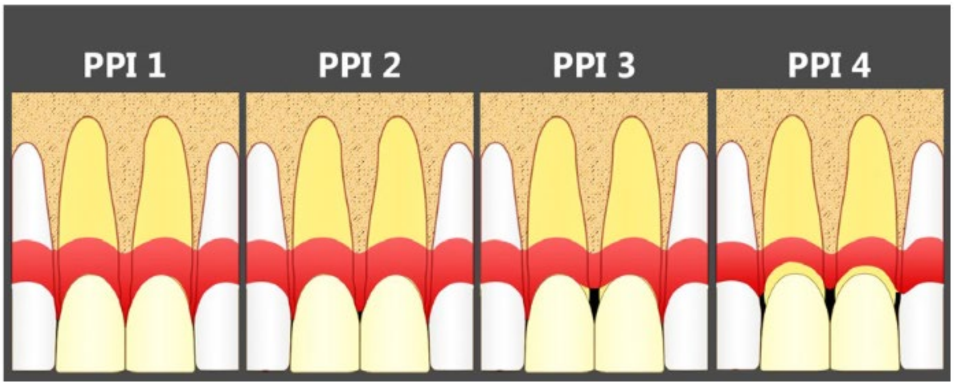

Figure 3: Classification according to Cardaropoli

a. PPI 1 b. PPI 2 c. PPI 3 d. PPI 4

Source: [26]

2.3. Prevalence of OGE

Burke *et al*. (1994) reported the OGE prevalence of 40% in patients who had crowded central incisors pre-orthodontic treatment [3]. This outcome is comparable to the findings of Tanaka *et al.* (2008), who also reported a 40% prevalence [1]. Kurth and Kokich (2001) reported that post-treatment OGE prevalence in the average adult is approximately 38% [2]. Ko-kimura *et al.* (2003) reported that OGE was more common in patients over 20, primarily due to alveolar crest resorption, reporting 44% post-treatment OGEs. In their study, 67% of individuals over 20 were affected, compared to only 18% of those under 20 [27]. Uribe *et al.* (2011) studied the occurrence of OGE in individuals who underwent mandibular incisor extraction, finding that 68% developed noticeable OGE after treatment, with 52% exhibiting moderate to very noticeable OGE [25]. Another study found that females have a higher susceptibility to OGEs, which may be linked to variations in gingival tissue characteristics and hormonal levels [28]. However, a study by An *et al.* (2018) showed that gender is not significantly associated with OGE. Furthermore, their findings indicated that 22% of maxillary and 36% of mandibular central incisors exhibited OGE [5].

2.4. Aetiology of OGE

Research indicates that several factors contribute to the development of OGE. These factors include changes in papilla size through orthodontic treatment, prolonged treatment duration, periodontal attachment loss that can lead to gum recession, excessive space between the crest of alveolar bone and the proximal contact, pre-treatment crowding and rotation, root angulation, age, and the shape of triangular crowns [3, 4, 29-31]. Toothbrush trauma may also contribute to the loss of interdental papillae, which can result in OGE development [1]. It is important to note that one or more aetiological factors may be present in a single patient; therefore, individual assessment and tailored treatment planning are essential [32].

There is contradictory evidence when an association between OGE prevalence and orthodontic treatment is made [27]. Some studies reported that OGE may arise as a consequence of orthodontic therapy [33, 34], while others indicated that orthodontic therapy could promote the growth of the papilla between teeth and consequently result in a decreased incidence of OGE [29, 35]. There are also contradictory findings concerning the duration of treatment. While Sharma and Park (2010) [30] found an association between long-lasting orthodontic treatment and the development of OGE, Ko-Kimura (2003) [27] found that the lengthy duration of orthodontic treatment was not associated to the incidence of OGE.

2.5. Aetiologic factors associated with the appearance of OGE

2.5.1. Orthodontic tooth movement

2.5.1.1. Labial tooth movement

The labiolingual width of the hard and soft tissues plays a role in the occurrence of OGE [36]. Labial movement of teeth, i.e., proclination, results in thinning of the labial surface of the alveolar bone and gum tissues and apical migration of these tissues, causing OGE [37]. Patients scheduled for labial movement of lingually displaced teeth should be counselled beforehand regarding the possible occurrence of OGE and encouraged to follow plaque control practices that are both effective and gentle [2, 38].

An *et al*. (2018) reported that movement along the horizontal plane in the maxillary arch is considered a potential contributor to OGE formation. This is likely because the maxillary labial bone plate is thin, along with the pronounced root prominence of the maxillary teeth [5]. It has been shown that the labial bone plate thickness measures an average of 0.97 mm at maxillary central incisors, 0.78 mm was observed in the lateral incisor area, and 0.95 mm at canines, while the mandibular teeth show thicknesses with corresponding values of 0.86 mm, 0.88 mm, and 1.17 mm [39].

2.5.1.2. Lingual tooth movement

While the tooth is being moved lingually or palatally, there's an increased labio-palatal tissue thickness at the labial side of the tooth and migration of soft tissue in the coronal direction, which often results in a reduced clinical crown [40]. These results were backed by Kandasamy *et al*. (2007), who confirmed that the palatal or lingual movement of teeth that were labially displaced increases the height of the interdental papilla [37]. It has been pointed out that the risk of gingival recession is minimal when a movement of the tooth occurs within the confines of the alveolar housing, irrespective of the quality or dimensions of the gingival tissue [41].

2.5.1.3. Vertical tooth movement

The height of interdental papillae is notably altered following the correction of vertical discrepancies. An increase in interdental papilla height occurs when a tooth is intruded in relation to the adjacent tooth [37]. An *et al*. in 2018 demonstrated that intrusive movement of the incisors causes OGE [5]. This may be attributed to the increased pocket depth with tooth intrusion, which leads to calculus deposition and subsequent alveolar bone damage and a resultant OGE [33]. Extrusive tooth movement typically results in an increase in alveolar bone height, accompanied by a relative increase in the supra-alveolar connective tissue attachment [42]. This finding was supported by a study indicating that the papilla height follows in the direction of tooth movement during extrusion [43].

2.5.1.4. Surgically assisted rapid maxillary expansion (SARME)

In skeletally mature individuals, SARME is recommended to treat transverse maxillary skeletal deficiency [44]. SARME is carried out using distraction osteogenesis by splitting the midpalatal suture. This procedure causes temporary resorption of the bone crest beneath the papilla in the central incisor region. The existence of the interdental papilla is largely influenced by the alveolar bone crest [15]. Recession of the papilla height in the maxillary central incisors was noted in one-third of SARME patients [45].

2.5.1.5. Clear aligners

Clear aligners have gained popularity among adults for orthodontic treatment because they are more aesthetically pleasing than traditional labial fixed appliances [46]. However, a study by Yang *et al*. (2023) found that the incidence of OGEs tends to be higher among individuals treated with aligners, particularly in adults. OGE developed in 26% of maxillary and 40% of mandibular central incisors following clear aligner use [9]. For optimal retention, clear aligners extend well past the contact point, covering the entire dental arch for approximately 22 hours every day, as recommended by most orthodontists and manufacturers. Such gingival extension can extend into the interdental space, displacing the normal gingiva and potentially affecting the remodeling of the gingival papilla. Consequently, both oral hygiene status and altered anatomical structures can elevate the risk of OGEs, especially in adult patients [10].

Some studies have found that clear aligner therapy is associated with a lower incidence of gingival disease than fixed orthodontic treatment [47, 48]. However, with frequent hygiene instructions, no significant difference in periodontal health was found among individuals undergoing fixed orthodontic and clear aligner treatment [49]. The occurrence of OGEs may be due to the mechanical nature of correcting crowding with aligner technology [50]. High initial stress generated by clear aligners is likely to cause injury to periodontal structures and result in OGE [51]. The marginal tissues experience significant active forces and compressive stress during intrusion and tipping movements, which may lead to overall bone reduction and significant gum recession [50].

The thermoforming process of clear aligners has been related to minor cytotoxicity in human gingival fibroblasts [52]. Invisalign appliances were also associated with the protein expression linked to the activation of inflammation in oral epithelial cells. As a result, periodontal inflammatory conditions may ensue, leading to gingival recession and inadequate papilla fill [10]. The accumulation of plaque along the marginal gingiva during clear aligner use can worsen the situation [53].

2.5.1.6. Orthodontic treatment involving extraction

The rate of OGE is greater in individuals who had extractions done than in those who did not. The higher incidence may relate to the more challenging mechanics and greater retraction required in extraction treatments [54]. Specifically, the extraction of permanent lower incisors is associated with a high prevalence of OGE following orthodontic treatment. Evidence suggests that removal of a mandibular lateral or central incisor results in OGE development in 68% of the patients who received orthodontic treatment [25].

Strategies to prevent unfavourable contact point relationships amongst permanent incisors have been employed in the mixed dentition stage. This may involve extracting primary canines early, reducing the contact surfaces of baby teeth, and/or expanding the arch to promote early alignment of permanent incisors. This allows proper development of contact point relationships as incisors have adequate space to align and establish a proper interdental papilla position [55].

2.5.2. Periodontal attachment loss

The interproximal papilla is crucial for shielding periodontal tissues against microbial invasion and mechanical insults, as well as being an essential part of phonetics and aesthetics [56, 57]. The interdental region serves as the principal site of dentogingival diseases, including caries and periodontitis, because it tends to collect and hold microbial deposits [58].

The marginal gingiva is the part of the gingiva that is lacking attachment to the cementum and the connective tissue overlying the alveolar bone. In healthy individuals, this marginal gingiva trails the scalloped outline created by CEJ line of the teeth. The interdental papilla between the facial and lingual gingival surfaces assumes a concave shape apical to the contact area, forming the gingival col [18]. The gingival col is overlaid by a stratified non-keratinised epithelium [59], whereas the interdental papillae is covered by stratified keratinised epithelium [60]. This col is anatomically predisposed to oral microorganism growth and susceptible to inflammation and disease progression because of its non-keratinised epithelium [61].

Orthodontic therapy is usually performed in the adolescent age group, which is mostly associated with gingival disease [62]. Orthodontic appliances may obstruct the effectiveness in carrying out good oral care practices and contribute to the accumulation of plaque [63]. Plaque accumulation may lead to periodontal breakdown with the alveolar bone loss, which leads to the dimensional change of the papilla. Loss of interdental papilla may also be due to iatrogenic procedures, such as surgical interventions, and bad habits that cause trauma to the gingiva [64].

Other conditions that may result in the loss of interdental papilla due to the accumulation of plaque include improper prosthetic restorations, irregular contours of crowns, and trauma [3, 29]. Deficient papillae may worsen among individuals who have a thin periodontal biotype because they are highly prone to loss of attachment and recession [65].

Advanced gingivitis can lead to the destruction of the alveolar bone, creating a greater vertical distance between the crestal bone and the tooth contact points. If the distance between the crestal bone and the tooth contact point exceeds five mm, there is a likelihood of inadequate papilla to fill the embrasure [15]. When the distance measures five mm or less, the papilla is found to be filling the embrasure space in most cases. Changes have been observed where the distance is six mm or more. When the distance measures six mm, the papilla is observed in about half of the subjects. However, if the distance exceeds seven mm, OGEs are observed in the majority of the subjects [66]. Similar results were reported by Chang in 2008 [14]. In a periodontium where the distance is less than five mm and pocket depths of greater than three mm, the chances of plaque retention, inflammation, and gingival recession are increased [64].

2.5.3. Incisor crowding

Incisor crowding is defined as a mismatch between tooth size, measured by the mesiodistal width of each incisor, and jaw size, leading to crowding and rotation [67]. Salzmann's Index scored crowding for each tooth subjectively, as either absent or present, with no scoring of varying amounts of crowding [68]. In cases of crowding, an incisor may be displaced either labially or lingually in relation to the other incisor [67], and are most commonly seen in the anterior region. Terms like crowding, irregularity, and overlap are often used interchangeably in orthodontics [69].

According to Howe *et al.* (1983), three predisposing conditions that may lead to crowding are macrodontia, micrognathia, and a combination of both [67]. However, it has been indicated that incisor crowding is influenced by more than just tooth-arch size discrepancies; it involves multiple contributing factors [70]. These factors include mandibular growth direction [71], oral and perioral musculature, the inclination of incisors and molars [70], and early loss of primary molars [72], leading to a lack of sufficient available space for the incisors and a resultant crowding [67].

OGEs have been reported in patients following orthodontic correction of incisor crowding measuring less than four mm, as well as in cases ranging from four to eight mm. The results suggest that greater crowding severity is linked to an increased likelihood of OGEs following treatment. When incisor crowding was greater than eight mm, OGE occurrence increased by seven per cent (%) [27]. It has been reported that teeth with crowding greater than 3.5 mm of space deficiency may heighten the risk of periodontal disease, which may lead to OGE [73]**.** A study by Burke *et al*. (1994) found post-orthodontic OGE of 42% in patients who had crowding of approximately 1.08 mm [3].

Kurth and Kokich (2001) [2] and Burke *et al.*, (1994) [3] found no statistical association between crowding and rotation of maxillary central incisors before orthodontic treatment and the development of OGEs after orthodontic treatment. Both studies highlighted that the development of OGEs is primarily influenced by various factors that arise after orthodontic treatment, rather than initial crowding or rotation of the maxillary central incisors. Their findings are supported by evidence from casts and CBCT images of maxillary incisors, indicating minimal changes in papilla height after orthodontic treatment [74]. However, An *et al*. (2018) found that crowding of central incisors before orthodontic treatment was significantly associated with the occurrence of OGEs post-orthodontic treatment [5].

2.5.4. Rotation

Tooth rotation is generally defined as any noticeable rotation of at least 20° of mesial or distal displacement in a lingual or buccal direction of a tooth around its longitudinal axis [75]. Saenghirunvattana (2017) described lingual rotation of mesial surfaces of the central incisors as an angle equal to or greater than 180 degrees, while an angle less than 140 degrees was defined as labial rotation [31]. A systematic review study found no satisfactory classification system for assessing anterior teeth rotation [76]. Additionally, Parthiban *et al.* (2024) found that incisors have been noted to exhibit the greatest degree of rotation compared to other teeth due to a combination of anatomical, developmental, and environmental factors [76].

Aetiologic factors of permanent tooth rotations can be classified into two categories [77]:

A. Disturbances occurring before tooth eruption may lead to permanent tooth rotation. These factors may include childhood trauma to the pre-maxillary region that caused displacement and misalignment of the developing tooth germ and pathologies such as a tumour, cyst, odontoma, and supernumerary tooth, which can inhibit tooth eruption [78].

B. Disturbances occurring after tooth eruption include habitual, local, mechanical, and environmental factors [77]. Rotations can occur with crowding as well as in cases of space excess [79]. Some of the environmental factors that cause rotations include the space available for proper alignment of teeth, the eruption pathway, and forces generated by tongue and lip movement [80].

During orthodontic derotation and alignment of the central incisors, the separation of their roots places tension on the gingival papilla, causing it to appear stretched and flattened [81]. This occurs because the gingival embrasure space tends to be larger [3]. When the roots move distally during orthodontic alignment, the interdental gingival fibres are pulled taut yet remain normally attached to the alveolar crest and the teeth. Thus, the tip of the papilla is displaced in an apical direction, and the OGE opens towards the incisal portion of the embrasure space [81, 82]. Root divergence further contributes to a greater distance between the interdental contact point and the crest of the alveolar bone [25, 83].

2.5.5. Roots divergence

A significant link between root divergence and OGE was reported by Kurth and Kokich in 2001. They reported that for every one-degree in root divergence, there is a 14% to 21% chance of OGE development [2]. Root divergence of the central incisors may be caused by improper bracket placement. In patients with central incisors overlapping as well as incisal wear, brackets may be placed inappropriately at an angle that is not at 90 degrees to the long axis of the central incisors. This happens because some clinicians use incisal edges as a reference when placing brackets and do not detect incisal wear. In this case, the roots may diverge distally as the teeth are aligned, resulting in the development of OGE [84].

2.5.6. Crown shape

Three basic types of crown shapes have been detected. Listed in decreasing frequency of prevalence are square, tapered, and ovoid [85]. Incisors with tapered or triangular-shaped crowns usually overlap each other [86]. OGE that was masked by overlapping teeth becomes apparent once the teeth are straightened [30]. In triangular-shaped crowns, the contact area between the central incisors is located in the incisal one mm because the width of the central incisor is greater at the incisal edge than near the cervical region, making them more susceptible to OGE. Normally, the contact areas are two to three mm long [84].

2.5.7. Age

The occurrence of OGE was found to be age-related. From the literature, it is evident that patients above the age of 20 years are more susceptible to OGE [27, 87]. The prevalence of OGE was 67% in the over-20 age group, as compared to 18% in those under 20 [27]. Burke *et al*. (1994) found post-orthodontic OGE of 42% in adolescent patients after orthodontic treatment [3]. However, another study found that post-treatment OGE was uncommon in adolescent patients [31].

The susceptibility of adult patients to OGE can be attributed to the weakening of the oral epithelium, reduction in keratinised gingiva, and a decrease in the height of the papilla due to the ageing process, as compared to younger people who have fewer age-related periodontal issues [4]. Furthermore, age-related increases in OGE have been linked to a decline in healing efficiency, affecting inflammation, tissue proliferation, and bone regeneration [88].

2.6. Impact of embrasure spaces on smile aesthetics.

Among the front teeth, the central incisors in the maxilla are the most noticeable during smiling [89]. A smile that has a two mm OGE was less attractive to orthodontists, while the general dental practitioners and the general population considered an OGE of three mm to be less attractive [90]. Irrespective of the extent of OGE, food can be retained, which negatively affects the periodontium. Furthermore, it can also lead to phonetic problems because of the passage of air through the space [2, 91].

The primary motivation for orthodontic treatment in the early 1980s was correcting malocclusion and restoring functional occlusion [92]. The growth of the economy, paired with transformations in social expectations, has encouraged interest in dental aesthetics among both adolescents and adults [93]. Nowadays, patients are seeking orthodontic treatment to address both functional bite issues and aesthetic concerns [8].

Gingival tissue aesthetic factors include form, contour, colour, height and curvature of the free gingival margins and their zeniths, position of the papilla, inflammation, and recession. Gingival inflammation and irregular free gingival margin levels in the anterior region can significantly affect dental aesthetics. Laypersons often view asymmetrical gingival changes and discoloration from OGE, inflammation, or pigmentation negatively. However, alterations in the gingival shape and zenith tend to have the least influence on the aesthetic opinion of a smile [94].

Research investigating patient views on black triangles revealed that OGE was considered the third most unfavourable aesthetic issue, following caries and crown margins [95]. While Batra *et al*. (2018) reported that during smiling, OGEs were the most negatively rated gingival variations in soft tissue aesthetics by laypeople [94].

2.7. Treatment of OGE

An interdisciplinary treatment is required to restore or improve the gingival curtain, including orthodontics, periodontics, endodontics, prosthodontics, and sometimes oral surgery [94].

2.7.1. Treatment of OGE associated with periodontal disease

In cases of advanced periodontal disease, the alveolar bone crest between the central incisors is destroyed, and the papilla may be absent. In these cases, unesthetic large gaps may be present after orthodontic treatment. Recontouring or reducing the curvature of the proximal surfaces of the incisors to increase the length of the contact area may not eliminate the space, but it may improve the situation substantially [84].

The Periodontist can correct the gingival papillary structure by positioning the papilla incisal to close the OGE [96]. Another procedure that might be beneficial is routine curettage of the interdental papilla to stimulate further papillary generation [97]. Papillary creation by curettage is more suitable in a situation where the papilla was destroyed by a disease such as necrotising ulcerative gingivitis [3]. Reconstruction of the lost interdental papilla is unpredictable and is one of the most challenging procedures. Procedures such coronal repositioning of flaps and connective tissue grafts is considered highly effective for periodontal tissue regeneration; however, they commonly result in more donor site injury, long operative times, and an increased chance of patients opting out [29, 30].

2.7.2. Treatment of OGE associated with divergence of roots

OGE caused by root divergence during derotation of teeth can be corrected by approximating the roots to allow the mesial cementoenamel junction (CEJ) areas to come closer to one another. As the roots come closer to each other, the gingival papilla fills the narrowed embrasure, thereby eliminating OGE. The change results from transseptal fibers losing the tension induced by tooth derotation and alignment, leading to their shortening and relaxation. The aesthetic quality of this treatment is greatly enhanced. Caution should be exercised to prevent root-to-root contact between central incisors, as it may result in the loss of proximal bone and compression of the papilla caused by a lack of embrasure space [3].

The clinician should evaluate a periapical radiograph to identify root divergence. If the roots are diverged, bracket repositioning should be done such that the bracket slots are oriented 90 degree to the long axes of the roots. As the roots align, the contact area lengthens and moves toward the papilla, reducing the OGE. The worn corners of the central incisors will normally move apically. This would reveal the amount of uneven incisal wear that had occurred because of overlapping incisors before orthodontic treatment. These incisal edges can then be restored [84].

2.7.3. Treatment of OGE associated with crown shape

It is recommended to convert the incisal-positioned contact spot into the contact area by recontouring the proximal surfaces of the central incisors to limit the formation of an OGE [30]. The quantity of enamel that must be removed at the mesial surfaces of each incisor is approximately 0.5 to 0.75 mm to the level of the of the papilla tip and should not penetrate the dentin. The space between the centrals will then be consolidated orthodontically. The result will be a longer contact area moved toward the papilla, reducing the OGE [84].

Triangular-shaped crowns are associated with the development of OGE post-orthodontic treatment, and therefore, accurate diagnosis is essential to ensure proper execution of interproximal reduction or restorative procedures [2].
This type of crown shape is also associated with “scalloped-thin” gingiva that encounters greater risk of loss of papilla [98]. The orthodontist should be able to identify and discuss the possibility of post-treatment OGE formation with the patient who has triangular-shaped crowns before commencing treatment [86].

Managing post-orthodontic OGE caused by crown shape may involve placing composite material on the mesial proximal areas of both central incisors [99]. Care must be taken not to over-contour the teeth when restorative procedures are carried out, as it might create harbouring places for plaque, crush the papilla, or create an unesthetic or unhealthy environment [3].

3. Rationale of the study

Orthodontists have a responsibility to recognise and explain the risk of OGEs to patients before initiating therapy [3, 86].

Despite the clinical importance of this condition, no prevalence studies on OGEs have been conducted in South Africa. This research, therefore, addresses a critical gap by investigating the occurrence of OGEs among patients treated at the Wits Oral Health Centre (WOHC), providing locally relevant data that can guide patient counselling, treatment planning, and future research.

4. Research question

What is the prevalence of OGEs on central incisors after comprehensive orthodontic treatment?

5. Aim of the research

To determine the prevalence of OGEs on central incisors among patients after comprehensive orthodontic treatment at the Wits Oral Health Centre (WOHC).

6. Objectives of the study

- To determine the extent of pre-treatment maxillary and mandibular central incisor crowding and rotations
- To determine the prevalence of OGEs in patients upon completion of orthodontic treatment.
- To determine the association of gender and age with pre-treatment crowding and rotation, as well as post-treatment OGEs.
- To determine the association between the extent of incisor rotation and crowding pre-treatment and the extent of OGEs post-treatment.
- To determine the correlation between maxillary and mandibular crowding, rotation, and OGE.

CHAPTER 2

Methodology

2.1. Study design

This was a retrospective study of clinical patient records of those who started orthodontic treatment between 01 January 2016 and 30 December 2020. Clinical records, including pre-treatment study models and post-treatment intraoral frontal photographs of patients who received orthodontic treatment, were obtained from the Department of Orthodontics at Wits Oral Health Centre.

2.2. Intra and inter-examiner reliability

The principal investigator (PI) and second investigator (SI) measured crowding and rotation on the pre-treatment study models. They also observed OGEs in intraoral post-treatment photos at the first time point (T1). The same models and photos were re-evaluated two weeks later at the second time point (T2) by both PI and SI. Intra-examiner ratings of OGEs, crowding and rotation and inter-examiner reliability, were done on 10% of the clinical records using kappa score.

2.3. Inclusion criteria

- Pre-treatment study models and post-treatment frontal intra-oral photographs of patients who underwent fixed comprehensive orthodontic treatment at Wits OHC from 01 January 2016 to 30 December 2020.
- Pre- and post-treatment study models and frontal intra-oral photographs of good diagnostic value
- Participants must be in the permanent dentition stage with no missing central incisor teeth

2.4. Exclusion criteria (pre- and post-treatment)

- Post-treatment diastema between central incisors because diastema is not classified as OGE
- Pre-treatment OGE between central incisors
- Post-treatment intraoral photographs in which the interdental contact and papillary height could not be visualised
- Restorations on the mesial aspects of mandibular and maxillary central incisors
- Damaged or chipped study models

2.5. Sample size

A convenience sampling method was employed, and data from patient pre- and post-treatment records were collected by applying specific exclusion criteria. A sample size estimation was conducted in Raosoft.com. using the following formula: x=Z(c/100)2r(100-r), n=N x/((N-1)E2 + x), E=Sqrt[(N - n)x/n(N-1)]. A total of 156 pre-treatment cases (population size) were available. According to Raosoft.com, the recommended sample size was 112 cases with a 5% margin of error. However, clinical records of only 50 out of 156 patients had post-treatment intraoral frontal photos in the Dolphin software for analysis. Therefore, the sample size available for analysis was 50 patients.

Fifty patients' records were analysed (maxillary and mandibular pre-treatment models and post-treatment frontal photos), resulting in 100 records comprising 50 maxillary and 50 mandibular models and photos. Out of the 100 records, 14 were excluded, leaving 86 records for analysis. The reason for exclusion was that nine maxillary and two mandibular post-treatment photos had a diastema. Additionally, the one mandibular post-treatment photo was unclear, and OGE could not be identified due to poor oral hygiene. Two mandibular pre-treatment models were also excluded due to chipped teeth.

2.6. Data collection and measurement

All data were collected from the Department of Orthodontics at the Wits Oral Health Centre. Pre-treatment data included the patients' study models (maxillary and mandibular casts) and intraoral frontal photographs, while post-treatment data consisted of intraoral frontal photos obtained from Dolphin imaging software. The degree of crowding and rotation of the maxillary and mandibular central incisors was recorded from pre-treatment study models, while post-treatment outcomes were evaluated from intraoral photographs, categorised as either no OGE or noticeable OGE.

2.6.1. Measurements of crowding:

A digital calliper was used to measure the transverse and anteroposterior (AP) distances in order to assess anterior crowding (see Figure 4).

A. Transverse discrepancy B. AP discrepancy

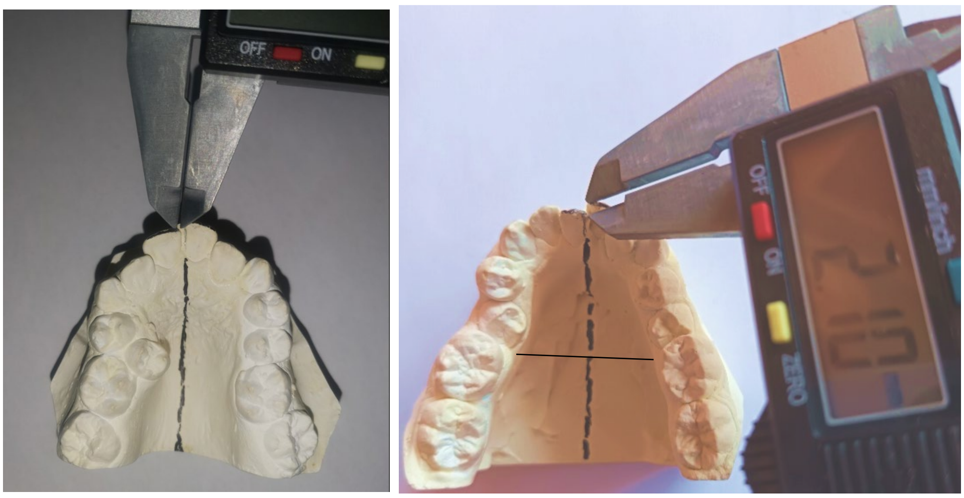

Figure 4: Transverse and AP distance measurements

Central incisor crowding was measured according to the method described by Yang et al. (2023) [10], as detailed below:

The midpalatal raphe served as the reference line in the maxilla. In the mandible, a perpendicular bisector of the line linking the mesial sides of the first permanent molars was used. The transverse distance was determined by measuring between the mesial surfaces of the central incisors perpendicular to the reference line on the study models (Figure 4A), whereas the AP distance was measured between the mesial surfaces in a direction parallel to the reference line (see Figure 4B). Crowding was measured with a digital calliper by aligning its tips on the mesial corners of the central incisors.

2.6.2. Measurement of rotations:

A tracing protractor template was employed to measure the angle that is formed by the lines of mesiodistal edges of the central incisors to evaluate any rotations (Figure 5). A laser beam was utilised to align the zero line on the protractor with the reference line marked on the study models.

Measurement of central incisor rotation was conducted as the angle formed between a line connecting the distal and mesial incisal edges of the central incisors and the reference lines marked on the study models as described by Yang et al. (2023). To establish the total angle between the two central incisors, the individual angles formed by each incisor were added together. If the total angle was less than 180 degrees, this implied a labial rotation of the mesial sides of both central incisors. Conversely, if the angle was 180 degrees or greater, it indicated that mesial sides of both incisors are lingually rotated.

A. Laser beam locating midline   B. Tracing protractor measuring rotation

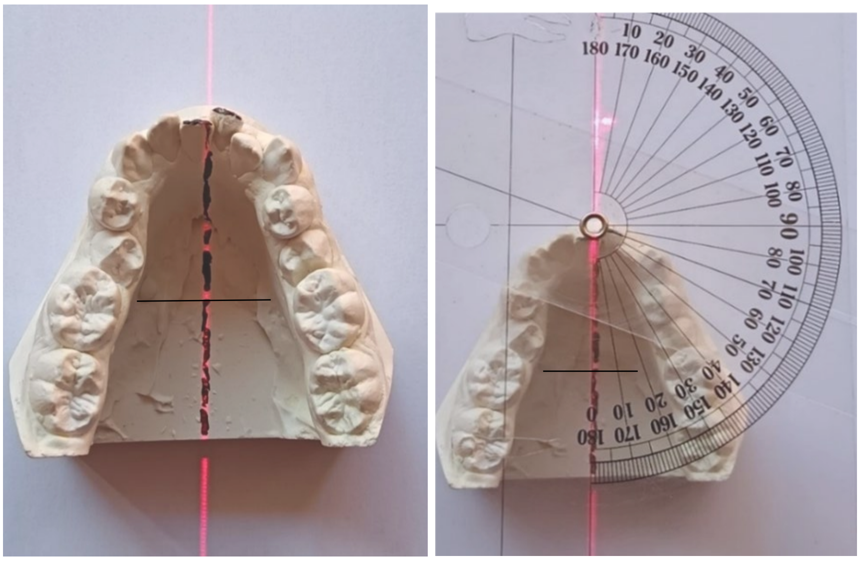

Figure 5: Rotation measurements

2.6.3. Assessment of OGEs:

Pre- and post-treatment intraoral photographs of participants were collected from the Dolphin Imaging Software (Chatsworth, USA) for analysis (Figure 6).

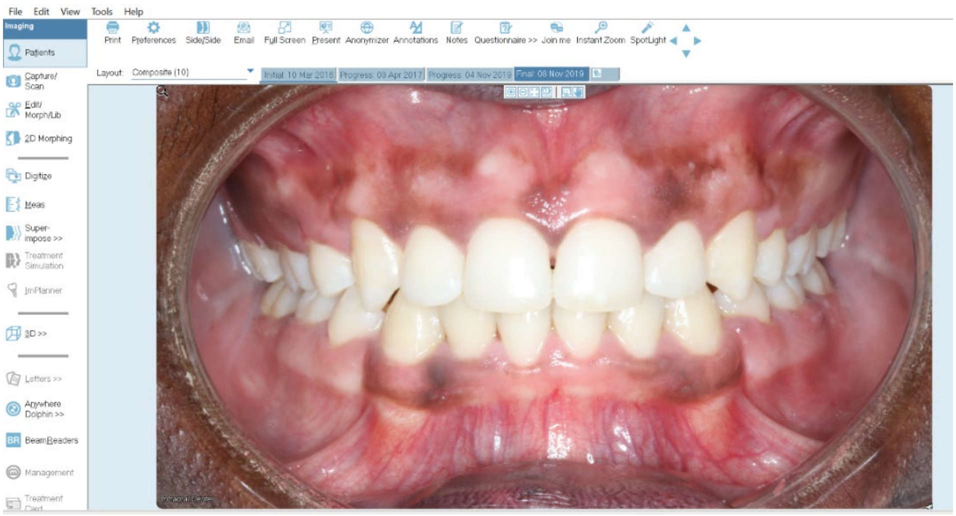

Figure 6: Dolphin Imaging Software

Post-treatment frontal intraoral photographs were utilised to visually evaluate and document the presence of OGE at the post-treatment stage. For this study, Uribe *et al.* (2011)

classification system was considered; however, OGE was recorded simply as either no OGE or OGE noticeable, since Uribe's four categories (A. Unnoticeable, B. Slightly noticeable, C. Moderately apparent, D. Highly noticeable) could not be quantitatively measured.

2.7. Data management and analysis

Data was collected and imported into REDCap, then cleaned, coded, and exported into Stata version 18 for statistical analysis. Frequencies, means, medians, and percentages were used to summarise the continuous and categorical variables. We applied Fisher's exact test, Chi-square test, and logistic regression to identify the associations between crowding, rotations and the occurrence of OGEs. All analyses were conducted at a 5% significance level.

Table 2: Overview of the study objectives and statistical analysis

Objectives	Variables	Statistics
Objective 1 To determine pre-treatment maxillary and mandibular incisor crowding and rotations	Dependent variable(s): - Crowding (distance), Rotation (angle) Independent variable(s): - Site	**Descriptive statistics:** Median and interquartile ranges
Objective 2 To determine the prevalence of OGEs in patients upon completion of orthodontic treatment.	Dependent variable(s): - OGE (post) Independent variable(s): - Site	**Descriptive statistics:** Freq (%)
Objective 3 To determine the association of gender and age with pre-treatment crowding and rotation, as well as post-treatment OGEs.	Dependent variable(s): - OGE (post-treatment) Independent variable(s): - Age, Crowding (pre-treatment), Rotation (pre-treatment), Gender	**Inferential statistics:** Pearson chi-square and Fisher's exact test
Objective 4 To determine the association between the extent of incisor rotation and crowding pre-treatment and the extent of OGEs post-treatment.	Dependent variable(s): - OGE extent (post-treatment) Independent variable(s): - Crowding (pre-treatment), Rotation (pre-treatment)	**Inferential statistics:** Pearson chi-square and Fisher's exact test
Objective 5 To determine the correlation between maxillary and mandibular crowding, rotation and OGE	Dependent variable(s): - Crowding (distance), Rotation (angle), OGE Independent variable(s): - Site	**Inferential statistics:** Correlation coefficient, Pearson chi-square and Fisher's exact test

2.8. Ethical Considerations

The study received ethical clearance from the Human Research Ethics Committee (Medical) at the University of the Witwatersrand (Ethics clearance number: M240138 MED23-08-031) (Appendix 1). Additionally, consent to collect data was granted by the CEO of the Wits Oral Health Centre and the Acting Head of the School of Oral Health Sciences (see Appendix 2). Throughout the study, we maintained confidentiality and anonymity by de-identifying the patients; any information that could identify them was not used. All study models and photos used for analysis were labelled with numbers.

CHAPTER 3

Results

3.1. Intra and inter-examiner reliability

The kappa (κ) score for inter-examiner reliability ranged from 0 to 1.0 at T1 and from 0.4 to 1.0 at T2 across different measurements and time points. Intra-examiner reliability varied from 0 to 1.0 for the investigator PI and from 0.2 to 1.0 for SI (Appendix 4). Table 3 summarises the results of intra- and inter-examiner reliability scores.

Table 3: Intra and inter-examiner reliability

Comparison Type	Maxillary OGE (κ)	Interpretation	Mandibular OGE (κ)	Interpretation
Inter-examiner T1	1.0	Almost perfect agreement	0.8	Substantial agreement
Inter-examiner T2	1.0	Almost perfect agreement	1.0	Almost perfect agreement
Intra-examiner (PI)	1.0	Almost perfect agreement	0.8	Substantial agreement
Intra-examiner (SI)	1.0	Almost perfect agreement	1.0	Almost perfect agreement

Most variables for both inter- and intra-examiner reliability showed strong agreement. McHugh (2012) notes that, according to Cohen, coefficients between 0.4 and 0.6 are considered to show adequate agreement in healthcare research [100].

3.2. Demographics and clinical characteristics

Table 4 below summarises the demographics and clinical characteristics results.

Table 4: Summary of demographics and clinical characteristics

Characteristics	**Levels**	**n (%) or median (Q_1-Q_3)**
Sex	Male	25 (50)
	Female	25 (50)
Age (in years)	Less than 18 years	31 (62)
	18 years and above	19 (38)
Overlap/crowding		
Maxillary		
AP		0.5 (0.0-2.0)
Transverse		0.0 (0.0-0.5)
Mandibular		
AP		0.5 (0.2-1.0)
Transverse		0.0 (0-0)
Rotation		
Maxillary Total: 41	Labial	34 (83)
	Lingual	7 (17)
Mandibular Total: 45	Labial	32 (71)
	Lingual	13 (29)
OGE status		
Maxillary	No OGE noticeable	25 (61)
	OGE noticeable	16 (39)
Mandibular	No OGE noticeable	24 (53)
	OGE noticeable	21 (47)
OGE noticeable (maxilla and mandible)		86 (43)

3.2.1. Demographic characteristics of the total sample

Out of 50 patients, there was an equal gender distribution, with 25 (50%) males and 25 (50%) females. The mean age was 17,3 years, with a minimum age of nine years and a maximum age of 29 years. Overall, the majority (62%) of the sample comprised individuals younger than 18 years, while a smaller proportion (38%) were 18 years or older.

3.2.2. Clinical characteristics of the total sample

3.2.2.1. Pre-treatment crowding of central incisors

For the maxillary AP dimension, the median crowding was 0.5 mm, and the range was between 0.0 and 2.0 mm. Indicating that half of the patients had central incisor AP crowding of less than or equal to 0.5 mm, and the other half had greater than or equal to 0.5 mm. The maxillary transverse dimension had a median of 0.0 mm and an interquartile range of 0.0 to 0.5 mm, indicating that most patients had little to no transverse discrepancy, with only slight variation up to 0.5 mm. For the mandibular AP dimension, the median crowding level was 0.5 mm, and a range of 0.2 to 1.0 mm. The transverse dimension had a median of 0.0 mm with no variation (range 0-0). The mandibular measurements indicated mild AP crowding, while no transverse crowding was observed.

3.2.2.2. Pre-treatment rotations of central incisors

The majority (83%) of the sample demonstrates labial maxillary rotation of central incisors, while a smaller proportion (17%) shows lingual maxillary rotation. This indicates a clear predominance of labial rotation.

In the mandible, a majority (71%) of the sample demonstrates labial mandibular central incisor rotation, while a smaller portion (29%) exhibits lingual mandibular rotation. This indicates a clear predominance of labial rotation among the individuals assessed.

The overall percentage of individuals with labial rotation is approximately 77%, and those with lingual rotation are approximately 23%.

3.2.2.3. Prevalence of OGEs in the maxilla and mandibular central incisors

The total number of patients with and without noticeable OGEs in either maxilla and/or mandible was 50. The prevalence of OGE in the maxilla was 39% (16 cases), whereas the prevalence of OGE in the mandible was 47% (21 cases). 61% (25 cases) and 53% (24 cases) were found to have no OGE in the maxilla and mandible, respectively. The total percentage of noticeable OGE was 43% [37 sites with noticeable OGE identified (16 maxilla and 21 mandible) out of 86 sites. 37/86x100=0.4302 ≈ 43% maxillary and mandibular combined].

3.3. Summary of the association of factors with OGE

Table 5: Summary of the association of factors with OGE

Characteristics	**Levels**	**Maxillary**			**Mandibular**		
		No OGE	OGE noticeable	p-value	No OGE	OGE noticeable	p-value
		n (%) or median (Q_1-Q_3)	n (%) or median (Q_1-Q_3)		n (%) or median (Q_1-Q_3)	n (%) or median (Q_1-Q_3)	
Gender	Male	12 (57)	9 (43)	0.606	14 (61)	9 (39)	0.300
	Female	13 (65)	7 (35)		10 (45)	12 (55)	
Age (in years)	Less than 18 years	17 (68)	8 (32)	0.249	15 (56)	12 (44)	0.714
	18 years and above	8 (50)	8 (50)		9 (50)	9 (50)	
Overlap/crowding							
Maxillary							
Anteroposterior		0.5 (0.5-2)	0.75 (0-1.75)	0.247	0.5 (0-1.5)	1 (0.5-1)	0.834
Transverse		0 (0-1)	0 (0-0.25)	0.549	0 (0-0)	0 (0-0)	0.641
Mandibular							
Anteroposterior		0.75 (0-2)	0.75 (0-2)	0.217	0.5 (0-1)	1 (0.5-1)	0.164
Transverse		0 (0-1)	0 (0-0.5)	0.656	0 (0-0)	0 (0-0)	0.345
Rotation							
Maxillary	Labial	20 (59)	14 (41)	0.534	15 (52)	14 (48)	0.999
	Lingual	5 (71)	2 (29)		3 (43)	4 (57)	
Mandibular	Labial	14 (56)	11 (44)	0.729	16 (50)	16 (50)	0.482
	Lingual	7 (64)	4 (36)		8 (62)	5 (38)	

3.4. Association of gender and age with pre-treatment crowding and rotation, as well as post-treatment OGEs

The table below shows the association of gender with OGE, as well as age with OGE, using the Pearson chi-square test.

Table 6: Association of gender with OGE, and age with OGE.

Characteristic	Group	Noticeable OGE n (%)	p-value
Gender	**Maxillary region**		
	Males	9 (43)	0.606
	Females	7 (35)	
	Mandibular region		
	Males	9 (39)	0.300
	Females	12 (55)	
Age	**Maxillary region**		
	< 18 years	8 (32)	0.249
	≥18 years	8 (50)	
	Mandibular region		
	< 18 years	12 (44)	0.714
	≥18 years	9 (50)	

3.5.1. Association of gender with post-treatment OGE

In the maxillary region, 43% of males and 35% of females had noticeable OGE, and the p-value of 0.606 indicates no significant association between gender and OGE.
In the mandibular region, 39% of males and 55% of females had noticeable OGE, with a p-value of 0.300 also suggesting no significant association between gender and OGE.

3.5.2. Association of age with post-treatment OGE

In the maxillary region, 32% of individuals under 18 years had post-treatment OGE, while 50% of those aged 18 and older exhibited post-treatment OGE. The p-value of 0.249 suggests that there is no significant association between age and OGE.
In the mandibular region, noticeable OGE was observed in 44% of individuals under 18 years, compared to 50% of those aged 18 and older. The p-value of 0.714 does not show a statistically significant association between age and OGE in this region.

3.5.3. Association of gender and age with OGE

The table below shows the association of gender and age with OGE.

Table 7: Comparison between gender and age with OGE

Region	**Gender**	**Age group**	**Post-treatment OGE (%)**	**p-value**
Maxilla	Male	≥18 years	67%	0.056
		<18 years	25%	
	Female	≥18 years	29%	0.658
		<18 years	38%	
Mandible	Male	≥18 years	38%	0.907
		<18 years	40%	
	Female	≥18 years	60%	0.639
		<18 years	50%	

In males, post-treatment OGE in the maxilla was more common in those aged ≥18 years (67%) compared to those <18 years (25%). However, the association between age and post-treatment OGE was marginal and not statistically significant ($p = 0.056$).
In females, noticeable OGE was slightly more frequent in those <18 years (38%) compared to those ≥18 years (29%), but the difference was minimal and not statistically significant ($p = 0.658$).

Overall, although males in the maxilla show a tendency for higher OGE prevalence in individuals aged 18 and older, no significant association was evident for females.

Among males, the prevalence of post-treatment mandibular OGE was comparable between participants aged ≥18 years (38%) and those <18 years (40%), with no significant relationship between age and OGE presence ($p = 0.907$).

Among females, post-treatment OGE was slightly more prevalent in those aged 18 years and older (60%) compared to those under 18 years (50%), but this difference was not statistically significant ($p = 0.639$).
Overall, no significant relationship was found between age and the likelihood of noticeable OGE in the mandible for either gender.

3.5.4. Association of rotation with OGE

The table below shows the association of rotation with OGE.

Table 8: Association of rotation type with OGE

Rotation type	**Maxillary rotation**		**Mandibular rotation**	
	OGE Noticeable n (%)	p-value	OGE Noticeable n (%)	p-value
Labial	14 (41)	0.534	16 (50)	0.482
Lingual	2 (29)		5 (38)	

In the maxilla, 41% of individuals with labial rotation had noticeable OGE, compared to 29% with lingual rotation. In the mandible, 50% of those with labial rotation had noticeable OGE, versus 38% with lingual rotation. The p-values for both maxillary (0.534) and mandibular (0.482) comparisons are above 0.05, indicating that rotation type does not appear to be associated with the presence of noticeable OGE in this sample.

3.5.5. Association of crowding with OGE

The table below summarises the association of crowding with OGE.

Table 9: Association of crowding with OGE

Discrepancy	Maxilla		Mandible	
	OGE Noticeable median (IQR)	**p-value**	**OGE Noticeable median (IQR)**	**p-value**
AP	0.75 (0-1.75)	0.247	1 (0.5-1)	0.164
Transverse	0 (0-0.25)	0.549	0 (0-0)	0.345

In the maxilla, patients with noticeable OGE had a median AP crowding of 0.75 mm (IQR: 0–1.75 mm), with no statistically significant association observed (p = 0.247). The median transverse crowding was 0.0 mm (IQR: 0–0.25 mm), which also showed no significant relationship with OGE (p = 0.549).

In the mandible, the median AP crowding among patients with noticeable OGE was 1.0 mm (IQR: 0.5–1.0 mm), with no significant association detected (p = 0.164). Similarly, the median transverse crowding was 0.0 mm (IQR: 0–0.0 mm), with no significant link to OGE (p = 0.345).

3.5. Association between the extent of incisor rotation and crowding pre-treatment and the extent of OGEs post-treatment

The table below shows the extent to which crowding and rotation are predictive of OGE occurrence using a Logistic regression test.

Table 10: Crowding, rotation versus extent of OGE

Variable	Odds Ratio	p-value
Maxillary AP Dimension	0.728	0.201
Maxillary Transverse Dimension	0.623	0.385
Mandibular AP Dimension	1.277	0.551
Mandibular Transverse Dimension	1.292	0.731
Maxillary lingual rotation	0.571	0.537
Mandibular lingual rotation	0.625	0.484

3.6.1. Maxillary crowding and OGE extent

The odds ratio was 0.728, suggesting that as the maxillary AP dimension increases, the odds of having noticeable OGE in the maxilla decrease slightly. This means that for a one-unit increase in maxillary AP discrepancy, the odds of the OGE outcome decreased by approximately 27%. However, the likelihood ratio (LR) Chi-Square test ($p = 0.201$) indicates that the overall model is not significant, meaning the maxillary AP dimension does not significantly predict noticeable OGE in the maxilla.

With maxillary transverse dimensions, an odds ratio of 0.623 means that for every one-unit increase in maxillary transverse discrepancy, the odds of OGE development decreased by 38%, assuming no other factors change. However, the chi-square statistic ($p = 0.385$) indicates that the overall model is not significant. Meaning that maxillary transverse dimensions do not significantly predict noticeable OGE in the maxilla.

3.6.2. Mandibular crowding and OGE extent

The odds ratio for mandibular AP dimension was 1.277, which suggests that for each unit increase in the mandibular AP, the odds of having noticeable OGE in the mandible increase by about 28%. However, the result was not statistically significant (LR Chi-Square test: $p = 0.551$).

The odds ratio for mandibular transverse dimension was 1.292. This suggests that for each unit increase in the mandibular transverse dimension, the odds of noticeable OGE in the mandible increase by about 29%. However, the finding is not statistically significant ($p = 0.731$), indicating that the observed effect is likely due to chance.

3.6.3. Maxillary rotation and OGE extent

The odds ratio for maxillary lingual rotation was 0.571, indicating that participants in the lingual category had approximately 43% lower chances of exhibiting noticeable OGE in the maxilla. However, this result is not statistically significant ($p = 0.537$).

3.6.4. Mandibular rotation and OGE extent

The odds ratio for mandibular lingual rotation was 0.625. This suggests that participants with the lingual rotation had 63% lower odds of having noticeable OGE in the mandible. However, this result is not statistically significant ($p = 0.484$), meaning the observed effect is likely due to random chance.

3.6. Correlation between maxillary and mandibular crowding, rotation, and OGE.

A pairwise correlation matrix was used to analyse the relationship between maxillary and mandibular AP and transverse overlap/crowding, as these are continuous variables (Table 10). Rotations and OGE were presented as associations between the maxilla and mandible due to their categorical nature (Table 11).

3.6.1. Correlation between maxillary and mandibular crowding

Table 11: Correlation between maxillary and mandibular crowding

Variables	**Correlation Coefficient**	**p-value**
Maxillary and Mandibular AP discrepancy	0.1898	0.2676
Maxillary and Mandibular transverse discrepancy	0.1165	0.4987

The correlation coefficient between maxillary and mandibular AP overlap/crowding was 0.1898, indicating a weak positive correlation between these two variables. The p-value associated with this correlation was 0.2676, suggesting that the correlation between maxillary and mandibular AP is not statistically significant. This implies that changes in maxillary AP overlap/crowding do not have a strong or reliable association with changes in mandibular AP overlap/crowding in this dataset.

The correlation coefficient between maxillary and mandibular transverse overlap/crowding was 0.1165, indicating a very weak positive correlation between the two variables. The p-value for this correlation is 0.4987, suggesting that the correlation between maxillary and mandibular transverse discrepancy was not statistically significant. Therefore, transverse overlap/crowding in the maxilla does not have a meaningful or consistent association with transverse overlap/crowding in the mandible in this sample.

3.6.2. Association between maxillary rotation and mandibular rotation

The table below displays the association between maxillary rotation and mandibular rotation. Since rotations are categorical variables, their relationships between the maxilla and mandible were examined as associations rather than correlations.

Table 12: Association between maxillary rotation and mandibular rotation

Rotation Type	**Maxillary Rotation Observations**	**Mandibular Rotation Observations**	**(%) of Maxillary Rotation with Mandibular Rotation**	**Fisher's Exact Test p-value**
Maxillary Labial & Mandibular Labial	22	20	(76)	0.167
Maxillary Lingual & Mandibular Lingual	3	4	(57)	0.167

The participants with maxillary labial rotation were 22, while the mandible had 20 observations. The results showed that 76% of individuals with maxillary labial rotation also have mandibular labial rotation. While there is a moderate association between maxillary labial rotation and mandibular labial rotation, the relationship is not statistically significant (Fisher's Exact test was 0.167).

There were three observations with maxillary lingual rotation, while mandibular lingual rotation had four observations. 57% of individuals with maxillary lingual rotation also had mandibular lingual rotation. While there is a tendency for maxillary lingual rotation to be associated with mandibular lingual rotation, Fisher's Exact test p-value of 0.167 indicates that the association between maxillary lingual rotation and mandibular lingual rotation is not statistically significant.

3.6.3. Association between OGE presence in the maxilla and the mandible.

The table below examines the association between OGE presence in the maxilla and OGE presence in the mandible. Since OGE are categorical variables, their relationships between the maxilla and mandible were examined as associations rather than correlations.

Table 13: Association between OGE presence in the maxilla and the mandible.

Maxilla OGE status (n)	Mandible OGE status (n)	Percentage (%)	Chi-square test
No OGE (21 total)	No OGE (13)	(62)	-
	Noticeable OGE (8)	(38)	-
Noticeable OGE (15 total)	No OGE (5)	(33)	-
	Noticeable OGE (10)	(67)	0.091

Among participants without OGE in the maxilla (a total of 21 cases), 13 also did not have OGE in the mandible, while eight displayed noticeable OGE in the mandible. In contrast, among participants with noticeable OGE in the maxilla (15 cases), five did not have OGE in the mandible, and 10 had noticeable OGE in the mandible.

For those without OGE in the maxilla, 62% also had no OGE in the mandible, whereas 38% showed noticeable OGE. For participants with noticeable OGE in the maxilla, 33% had no OGE in the mandible, and 67% had noticeable OGE in the mandible.

A higher proportion of maxillary OGE cases also have mandibular OGE (67%). This suggests a potential association between OGE presence in the maxilla and mandible. However, statistical tests (Chi-square with a p-value of 0.091) indicate that this relationship is not statistically significant.

CHAPTER 4
Discussion

4.1. Pre-treatment maxillary and mandibular central incisor crowding and rotations

An average central incisor crowding of 1.08 mm ± 0.94 has been reported before orthodontic treatment [3]. Yang in 2023 analysed crowding in both the AP and transverse dimensions, finding an average AP overlap of 0.37 ± 0.57 mm in the maxilla and 0.39 ± 0.52 mm in the mandible before fixed orthodontics. In the transverse dimension, the average crowding was 0.10 ± 0.20 mm in the maxilla and 0.13 ± 0.21 mm in the mandible [10]. In comparison, our study found a similar pattern, with a median AP crowding of 0.5 mm for both the maxilla and mandible but observed much lower transverse dimension crowding with a median value of 0.0 mm for both jaws. Additional research exploring the reasons why lower transverse crowding occurs more frequently than AP incisor crowding could be valuable.

Our results revealed that labial rotation is much more common than lingual rotation in both maxillary (83%) and mandibular (71%) rotations pre-treatment. Burke (1994) reported similar findings, noting a higher percentage of labially rotated central incisors (23%) compared to lingually rotated ones (8%) [3]. In contrast, Saenghirunvattana (2017) found that lingually rotated central incisors (11%) were more common than labially rotated incisors (6%) [31]. These differences in findings may be explained by the fact that tooth rotation direction is influenced by genetic, developmental, environmental, and occlusal factors, each playing a role in producing different rotational patterns [101].

4.2. Prevalence of OGEs upon completion of orthodontic treatment.

Zhang *et al.* (2023) reported an OGE prevalence of 26% for maxillary central incisors and 40% for mandibular central incisors following comprehensive orthodontic treatment [9]. Similarly, Yang (2023) reported prevalence rates of 35% in maxillary central incisors and 38% in the mandible among patients treated with clear aligners. Additionally, Yang compared clear aligners with fixed appliances, reporting an OGE incidence of 18% in the maxillary and 24% in the mandibular central incisors after fixed appliances [10]. Another study by An *et al.* (2018)

observed OGE rates of 22% in maxillary and 36% in mandibular central incisors after comprehensive orthodontic treatment [5]. Our study observed a prevalence of post-treatment OGE of 39% in the maxillary central incisors and 47% in the mandibular central incisors after fixed orthodontic treatment, which were slightly higher than those reported in previous studies. Our study's higher OGE prevalence compared to other reports may be explained by the small sample size, variations in age distribution, diagnostic criteria, or treatment methods, as well as differences in assessment techniques and the severity of initial malocclusion. Tian *et al.* (2025) reported a lower prevalence rate of 4% in maxillary central incisors, while the prevalence in the mandibular incisor area was 25% [28].

The overall prevalence of posttreatment OGE in our study was approximately 43%, which aligns closely with findings from previous studies: Burke *et al*. (1994) [3] reported a 42% prevalence, Ko-Kimura *et al*. (2003) [27] found 44%, and Abdelhafez *et al*. (2022) [8] reported 43%. An *et al.* (2018) observed a slightly higher OGE rate of 58% [5]. Overall, our study supports the general trend that post-treatment OGE affects roughly 40–45% of patients. However, An et al. (2018) reported a higher prevalence of 58%, indicating that certain factors, such as differences in study design, population characteristics, or evaluation methods, may account for the variation.

4.3. Associations of OGE with gender, age, central incisor crowding, and rotation.

4.3.1. Association of OGE with gender

In our study, post-treatment OGE of the maxillary central incisors was more frequent in males (43%) than in females (35%). In contrast, females had a higher prevalence of noticeable OGE in the mandible (55%) compared to males (39%). However, the results of our study revealed no statistically significant association between gender and OGE status in the maxillary or mandibular central incisors. Similarly, Uribe *et al*. (2011) [25], An *et al.* (2018) [5], and Yang (2023) [10] also found that gender had no significant impact on the occurrence of OGE. Tian *et al.* (2025) found that female patients exhibited a higher rate of OGEs in the maxilla and mandible, with an overall rate of 80% among females compared to 20% among males [28]. The variation across studies highlights that while gender-related differences may appear in specific populations, overall, gender is unlikely to be a consistent determinant of OGE occurrence.

4.3.2. Association of OGE with gender and age

In South Africa, the Children's Act, Act No. 38 of 2005, defines a "child" as a person under the age of 18 and an adult as anyone 18 years or older. Our study observed a trend of increased post-treatment OGE with age, indicating that individuals aged 18 and older are more likely to exhibit OGE in both the maxilla and mandible than those under 18. However, this difference was not statistically significant. Uribe (2011) also found no correlation between age and the presence of OGE [25]. On the contrary, Ko-Kimura *et al.* (2003) [27] and Tian *et al.* (2025) [28] found that OGE was significantly associated with adult patients.

Our findings suggest age- and gender-related patterns in OGE distribution: maxillary OGEs were more frequent in adult males compared to females, while mandibular OGEs were more common in adult females than in males. This points to potential arch-specific differences in how gender and age interact with OGE prevalence. However, these patterns are not consistent with existing literature. Tian et *al.* (2025) reported that females are more susceptible to OGEs in both the maxillary and mandibular central incisor regions in both young and adult populations [28]. In contrast, a study by An *et al.* (2018) did not find a significant association between gender and the occurrence of OGEs [5]. Overall, these discrepancies in the findings indicate that gender and age may affect OGE patterns, but the relationship is inconsistent and likely influenced by other factors.

4.3.3. Association of OGE with pre-treatment crowding of central incisors

Burke *et al.* (1994) reported a post-treatment OGE rate of approximately 42% in patients with an average of 1.08 mm crowding [3]. In our study, we found an overall prevalence of approximately 43%. The average AP overlaps were 0.75 mm for the maxilla and one mm for the mandible. OGE was present in 39% of maxillary central incisors and 47% of mandibular central incisors. However, no statistical associations between crowding and OGE were found in this study. Similarly, Kurth and Kokich (2001) [2] and Ko-Kimura *et al*. (2003) [27] found no statistical association between the crowding of central incisors before treatment and the development of OGEs post-treatment. In contrast, An *et al.* (2018) found that crowding of the central incisors in the maxilla before treatment was significantly linked to the occurrence of OGEs after treatment. They reported an occurrence rate of 22% in the maxilla, where the average AP overlap was 0.91 mm, and 36% in the mandible, with an average AP overlap of 0.3 mm [5]. These differences suggest that while some studies indicate crowding as a predictor of OGE, our findings support the view that crowding alone may not be a consistent determinant, and other factors likely contribute to OGE development.

4.3.4. Association of OGE with pre-treatment rotation of central incisors

Our study observed a higher occurrence of OGE in the maxilla following labial rotation correction (41%) compared to correction of lingual rotation (29%). Similarly, in the mandible, labial rotation correction led to more OGEs (50%) than lingual rotation correction (38%). Despite this trend, the associations between rotation type and OGE were not statistically significant in our study. Kurt and Kokich (2001) also reported no link between the rotation of central incisors and post-treatment OGEs [2]. In contrast, Saenghirunvattana (2017) found a strong, statistically significant relationship between lingual rotation of central incisors and post-treatment OGEs (24%), while labial rotation showed no significant association with OGEs (7%) [31]. Overall, while rotation type may influence OGE occurrence in some populations, our findings suggest that it is not a consistent predictor of post-treatment OGEs.

4.4. Association between the extent of incisor rotation and crowding pre-treatment and the extent of OGEs post-treatment.

In 2017, Saenghirunvattana found that overlapped incisors are associated with a 91% increase in the likelihood of post-treatment OGE development as compared to non-overlapped incisors, which was statistically significant [31]. These findings align with the trend observed by Burke *et al.* (1994), indicating that OGEs are more commonly seen following the alignment of crowded maxillary central incisors [3]. Our study found that for each additional one mm of crowding in the mandible, there was a 27% increase in the likelihood of developing post-treatment OGE. Conversely, in the maxilla, each one mm of crowding increase was associated with a 28% decrease in the likelihood of post-treatment OGE. However, these changes were not statistically significant. The transverse overlap exhibited similar patterns in both the mandible and maxilla. An *et al.* (2018) reported that the likelihood of post-treatment OGE increases 2.2 times for every one mm increase in AP overlap in both the maxilla and mandible, while the transverse overlap showed a similar but lesser extent [5].

The likelihood of OGE development after correction of labial rotation of central incisors was found to be 36% lower than correction of lingual rotation. Correction of lingual rotation was associated with a 3.5-fold increase in the likelihood of OGE development, and this finding was statistically significant [31]. Our study observed a reduced likelihood of post-treatment OGE following the correction of lingual rotations, with a 43% reduction in the maxilla and a 63% reduction in the mandible compared to corrections involving labial rotations. However, the results were not statistically significant. Possible reasons for the differences observed in our study could include variations in sample size, initial severity of rotation, and tissue response to orthodontic movement. Additionally, differences in measurement methods and biological factors such as gingival thickness, papilla morphology, or alveolar bone support may have influenced the outcomes.

4.5. Correlation and association between maxillary and mandibular crowding, rotation, and OGE

Our study found no relationship between maxillary and mandibular AP crowding. Likewise, transverse crowding in the maxilla did not predict transverse overlap in the mandible. This lack of association may be explained by anatomical and functional differences between the arches: mandibular incisors are typically positioned in tighter contact with one another, providing variations in crowding, whereas maxillary incisors tend to be more naturally aligned or exhibit slight spacing, providing less crowding [102]. These inherent differences in arch form and tooth positioning could contribute to the independent patterns of crowding observed in each arch.

In our study, participants with maxillary labial rotation were also more likely to have mandibular labial rotation, while those with maxillary lingual rotation also showed corresponding mandibular lingual rotation, but to a lesser extent. Shared genetic, developmental, or occlusal factors may have an influence on tooth positioning across both arches [103]. However, the lack of statistical significance in our study indicates that this relationship is weak or inconsistent. No studies investigating the correlation between rotations of the maxilla and those of the mandible could be found in the literature; therefore, further studies are recommended.

Mandibular post-treatment OGE was observed more frequently when maxillary OGE was present between the central incisors, but this association lacked statistical significance in our findings. While studies such as those by An *et al.* (2018) [5], Zhang *et al*. (2023) [9], and Yang *et al*. (2023) [10] have documented OGEs in both the maxilla and mandible following treatment, none have specifically analysed the relationship between OGEs in these two regions.

4.6. Limitations of the study

This study used a sample of convenience methodology. Hence a 156 pre-treatment models were found while undertaking the study, and only 50 cases had post-treatment frontal intraoral photos available in Dolphin software. The limited sample size could have impacted the statistical power of the results.
Some photographs could have been taken after an interproximal reduction procedure to reduce OGE. This may have limited the number of post-treatment OGEs, affecting the prevalence of OGEs.

4.7. Recommendations

Since this study assessed OGEs using frontal intraoral photographs, quantifying their exact size was not feasible. Future research on OGE dimensions would require intraoral scanners of healthy gums to obtain precise numerical measurements.
Current and future cohorts of students are encouraged to maintain thorough pre- and post-treatment records to help gather a larger sample size for future OGE studies.
This study focused on the period pre- and post-comprehensive orthodontic treatment. Further studies can be conducted to better understand the OGEs development during the retention phase.
No studies have been found in the literature investigating the correlation between maxillary and mandibular rotations as well as post-treatment OGEs, highlighting the need for further research.

4.8. Conclusions

This study was conducted to assess the prevalence of OGEs after comprehensive orthodontic treatment at the Wits Oral Health Centre. The findings of the study are as follows:

1. The prevalence of OGE was 39% in the maxillary central incisors and 47% in the mandibular central incisors after fixed orthodontic treatment. The overall post-treatment OGE was approximately 43%.
2. There was no statistical association between pre-treatment crowding and post-treatment OGE.
3. Pre-treatment rotations were not statistically linked to the occurrence of post-treatment OGEs. However, correcting labial rotations tended to result in a higher prevalence of OGEs compared to correcting lingual rotations.
4. There was no statistical association between post-treatment OGEs and age or sex. However, maxillary OGE tended to increase with age in males, whereas in females, mandibular OGE showed a similar age-related increase.
5. Individuals with noticeable post-treatment OGE in the maxillary incisors were somewhat more likely to also display OGE in the mandibular incisors. However, the relationship was not statistically significant.

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1. Appendix 1: Ethics clearance certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R14/49 Dr Mashudu Muthavhine M240138 MED23-08-031

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M240138 MED23-08-031

NAME: (Principal Investigator)	Dr Mashudu Muthavhine
STUDENT/STAFF NO:	2294141
DEGREE:	MDent (Orthodontics)
DEPARTMENT:	School of Oral Health Sciences Orthodontics
PROJECT TITLE:	Prevalence of open ginfival embrasures after comprehensive orthodontic treatment at the Wits Oral Health Centre
DATE CONSIDERED:	11/01/2024
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Mosidi Makofane
APPROVED BY:	Paul Ruff Prof P Ruff, Chair, HREC (Medical)
DATE OF APPROVAL:	23/04/2024 **EXPIRY DATE:** 23/04/2029

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated, from the research protocol as approved, I/we undertake to resubmit the application to Committee. **I agree to submit a yearly progress report** in July each year until study is closed. Failure to submit annual report will result in ethics clearance certificate suspension. The date for annual re-certification will be one year after the date of convened meeting wh ere the study was initially reviewed. In this case, the study was initially reviewed in January and will therefore be due in the month of January each year. Unreported changes to the application invalidate the clearance given by the HREC (Medical). Email signed copy of this ethics clearance certificate prior to commencing with the study hrec-medical.researchoffice@wits.ac.za

Principal Investigator Signature

15/07/2024
Date

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES

2. Appendix 2: Permission to access Records/ Files/Database at Wits Oral Health Centre

GAUTENG PROVINCE
HEALTH
REPUBLIC OF SOUTH AFRICA

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

School of Oral Health Science

Department of Oral Biological Sciences – Research Unit, 7 York Road, Parktown, 2193. Tel: 011 717 2110
Email: Mpho.Molete@wits.ac.za

16 October 2023

Dr M. Muthavhine
Orthodontics Department
Faculty of Health Sciences
University of the Witwatersrand
Johannesburg

RE: PERMISSION TO CONDUCT RESEARCH

Your request for permission to conduct a research has been provisionally approved by the Committee.

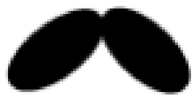
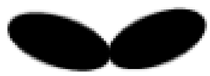
Final approval will be granted after submission of the following information and documents:

1. A list of patient's records needed for the study should be submitted to Patient Administration Manager Mr Ramoleta.
2. Ethics Clearance Certificate

Regards,

Dr S A Matjila
CEO - WOHC
Date: 16/10/2023

3. Appendix 3: DATA collection sheet

Study number and age				
Measurements	Definitions			Findings
OGE	A condition whereby the interdental papilla is shorter than normal leaving an open embrasure space cervical to the contact area of adjacent teeth. Measured between maxillary and mandibular central incisors.			
Gender	Male			
	Female			
Magnitude of OGE	A. No OGE			
	B. Noticeable OGE			
Central incisor alignment	Normal	Central incisors contact without a space or an overlap		
	Overlapped Incisors/crowding	Central incisor overlaps the other central incisor partially		
	Labial Rotation of Mesial Aspects of Both Central Incisors	Central incisal edges form an angle less than 140 degrees		
	Lingual Rotation of mesial aspects of both central incisors	Central incisal edges form an angle greater than or equal to 180 degrees		

4. Appendix 4: Intra- and inter-examiner reliability

Investigators and variables	Agreement (kappa statistics)	Interpretation
Principal and second investigator		
Interrater first time (T1)		
Maxillary AP discrepancy	0.2	Slight agreement (0.01–0.20)
Maxillary transverse discrepancy	1.0	Almost perfect agreement (0.81–1)
Mandibular AP discrepancy	0.4	Fair agreement (0.21–0.40)
Mandibular transverse discrepancy	too few rating categories	Agreement could not be established
Maxillary rotation	0.2	Slight agreement (0.01–0.20)
Mandibular rotation	0	Poor agreement (0)
Maxillary OGE	1.0	Almost perfect agreement (0.81–1)
Mandibular OGE	0.8	Substantial agreement (0.61–0.80)
Interrater second time (T2)		
Maxillary AP discrepancy	0.4	Fair agreement (0.21–0.40)
Maxillary transverse discrepancy	0.8	Substantial agreement (0.61–0.80)
Mandibular AP discrepancy	0.6	Moderate agreement (0.41–0.60)
Mandibular transverse discrepancy	0.8	Substantial agreement (0.61–0.80)
Maxillary rotation	0.6	Moderate agreement (0.41–0.60)
Mandibular rotation	0.4	Fair agreement (0.21–0.40)
Maxillary OGE	1.0	Almost perfect agreement (0.81–1)
Mandibular OGE	1.0	Almost perfect agreement (0.81–1)
Principal investigator: first and second time (T1-T2)		

Intra rater		
Maxillary AP discrepancy	0.4	Fair agreement (0.21–0.40)
Maxillary transverse discrepancy	0.8	Substantial agreement (0.61–0.80)
Mandibular AP discrepancy	0.2	Slight agreement (0.01–0.20)
Mandibular transverse discrepancy	0.8	Substantial agreement (0.61–0.80)
Maxillary rotation	0.2	Slight agreement (0.01–0.20)
Mandibular rotation	0	Poor agreement (0)
Maxillary OGE	1.0	Almost perfect agreement (0.81–1)
Mandibular OGE	0.8	Substantial agreement (0.61–0.80)
Second investigator: first and second time (T1-T2)		
Intra rater		
Maxillary AP discrepancy	0.8	Substantial agreement (0.61–0.80)
Maxillary transverse discrepancy	1.0	Almost perfect agreement (0.81–1)
Mandibular AP discrepancy	0.2	Slight agreement (0.01–0.20)
Mandibular transverse discrepancy	too few rating categories	Agreement could not be established
Maxillary rotation	0.2	Slight agreement (0.01–0.20)
Mandibular rotation	0.2	Slight agreement (0.01–0.20)
Maxillary OGE	1.0	Almost perfect agreement (0.81–1)
Mandibular OGE	1.0	Almost perfect agreement (0.81–1)

5. Appendix 5: Turnitin report

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