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Original Article

Changes in incisor relationship over the life course - Findings from a cohort study

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ABSTRACT

Objective: The aim of this longitudinal cohort study was to investigate the changes in incisor relationship over three decades from adolescence to mid-adulthood.

Materials and Methods: The sample included 1,037 children (48.4% female) born between April 1972 and March 1973 from the longitudinal birth cohort Dunedin Multidisciplinary Health and Development Study. Overjet and overbite values were assessed at age 15 and 45 years and entered in a regression model as outcome variables. Baseline occlusal variables, sex, history of orthodontic treatment, periodontal data recorded at age 38, and self-reported oral parafunction and orthodontic treatment history recorded at age 45 were entered as covariates in the regression analysis.

Results: Regression modelling showed that overjet/overbite category (high or low) at age 15 tends to predict overjet/overbite category at age 45, with overjet become slightly larger (around +0.5 mm) and overbite slightly lower (-0.5 mm) over time. Study members with self-reported tooth clenching had a slighter greater overbite (+0.3 mm) at age 45 than those who did not. Additionally, those with signs of periodontal disease at age 38 had a slightly larger overjet (+0.5 mm) at age 45 than those without disease. Sex differences were demonstrated with females having 0.6 mm larger overjet, and 0.4 mm overbite at age 45.

Conclusions: Overall, overjet values tend to be higher during mid-adulthood than during adolescence, while the converse is true for overbite. There appears to be a degree of sexual dimorphism in overjet and overbite values later in life.

Clinical Significance: Incisor relationships change during the life course and are related to ageing, sex, periodontal health, and parafunctional habits. Clinicians and educators should be aware of these changes when making treatment decisions that alter incisor relationship.

1. Introduction

The unpredictable nature of occlusal changes over time remains a challenge to orthodontists. Many studies have focused on dentoalveolar changes only during adolescence, whereas relatively less is known about changes that occur over the life course. The US NHANES survey has estimated that around one-third of the US population have an ideal horizontal relationship (overjet), and around half have the ideal vertical incisor relationship (overbite)[1]. In orthodontics, incisor positions are key to cephalometric analysis and treatment planning, and are also determinants of overall facial aesthetics [2]. Functionally, the maxillary incisors play an important role in providing anterior guidance for mandibular movements [3]. Furthermore, ideal incisor relationships are thought to enhance stability of orthodontic correction, since it has been postulated that incisors will continue to erupt until there is a stable contact that balances the forces of eruption [4, 5]. Because of this, it has been suggested that, for the long-term stability of orthodontic treatment, overjet and overbite values should embody the ideal Class I relationship [6], apparent when the lower incisor edges occlude with or lie immediately below the cingulum plateau of the upper incisors [7].

Although there has been much research describing incisor relationship changes in the primary and permanent dentitions, there are fewer

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reports of changes occurring into mid-adulthood. Reasons of convenience have meant that most research has focused on data from historical growth studies [8–11]. A more recent study using a small untreated Swedish sample ($n = 18$) showed no changes in overjet or overbite from ages 23 to 61 years [12]. Despite findings from studies based mainly on historical growth records indicating relative stability of overjet and overbite values into the fifth and sixth decades of life, samples have been small and contain a mixture of malocclusion types which have the potential to complicate the interpretation of finding. For this reason, other researchers have investigated dentoalveolar changes that occur in individuals with untreated 'normal' occlusions into the fourth decade and beyond. A wide variety of findings have been reported for incisor relationship changes in these studies. These include: decreases in overjet and no change in overbite [13]; decreases in both overjet and overbite [14]; no changes in overjet but decreases in overbite [15]; and no overjet changes but overbite increases in females only [16].

Other investigations have focused on how untreated malocclusion types (particularly Class II Division 1) change with time, although these have limited follow-up to the late teenage years only [17–22].

Findings on long-term changes of orthodontically untreated 'normal' occlusions seem to be inconsistent, and there is limited information on changes that occur to those with abnormal incisor relationships (both high and low ranges) beyond adolescence and into adulthood. The paucity of long-term data on various untreated malocclusion types may be due to ethical reasons, greater recent uptake of orthodontic treatment, and the logistical and financial challenges of longitudinal research. Reasons for inconsistencies in previous findings could be their small sample sizes, use of historical growth controls, errors in cephalometric measurements, the complex nature of dentoalveolar development, and the inability to control for influences that become increasingly prevalent in adulthood (such as tooth wear and periodontal disease). Changes in incisor relationship (if present) are relevant to clinicians and patients alike, as increasing numbers of adults seek orthodontic treatment, and the interest in orthognathic surgery grows [14].

The aim of this study was to investigate changes in the incisor relationship (overjet and overbite) from ages 15 to age 45, in a birth cohort of New Zealanders. We hypothesised that the incisor relationship (as represented by overbite and overjet during adolescence) will deteriorate in individuals with overbite and overjet values outside the normal range.

2. Materials and methods

2.1. Sample

Participants were members of the Dunedin Multidisciplinary Health and Development Study, a longitudinal investigation of health and behaviour in a cohort born in Dunedin, New Zealand. Between 1/4/1972 and 31/3/1973, 1037 (91% of eligible births; 52% male) participated in the first follow-up at age 3 years; these constituted the base sample for the remainder of the study. Cohort families represented the full range of socioeconomic status in New Zealand's South Island. Over 90% of cohort members identified as New Zealand European or "white", while 7.5% self-identify as being Māori. This matches the ethnic distribution of the South Island of New Zealand. Follow-ups were done at ages 5, 7, 9, 11, 13, 15, 18, 21, 26, 32, 38, and 45 years, when we assessed 94% of the surviving 1007 study members. This study used data collected from ages 15, 38 and 45. The …… Ethics Committee…….., granted ethics approval for each assessment phase. Study members gave informed consent before participating [23].

2.2. Incisor relationships and error study

At ages 15, dental data (including overjet and overbite measures) were collected clinically by trained and calibrated clinicians. All DMHDS dental examinations have employed methods in accordance with World Health Organisation methods [24]. At age 45, Study members had their dentitions digitally scanned using Trios™ (3Shape, Copenhagen, Denmark). The three-dimensional scans were then exported to OrthoAnalyzer™ software (3Shape, Copenhagen, Denmark), where they were trimmed and orientated before a digital orthodontic model base was added.

Prior to examining the digital models, a separate calibration sample ($n = 16$) was recruited for staff calibration and testing of methods. Clinical DAI measurement was completed using a dental mirror and a PCP-2 periodontal probe. Virtual dental arches and bite registration were exported to 3Shape OrthoAnalyzer™, where they were modified into digital models and analysed. The digital DAI scores were analysed against the clinical DAI scores. Orthodontic measurements of these digital scans were repeated for each participant on three separate occasions by two examiners. Subsequently, eight participants were randomly selected to repeat the above steps so that intra-examiner reliability could be evaluated for both methods. Each participant was given a numerical code to blind the examiner, and subsequent rounds of examinations were at least one week apart to minimise recollection of cases. Intra- and inter-examiner reliability scores were calculated as excellent (individual ICC = 0.98, average ICC = 0.99) and bias was not detected for the digital method relative to the clinical method. It was concluded that measurements derived from digital models using OrthoAnalyzer™ software were comparable to the traditional clinical measurements taken in earlier assessment phases. Orthodontic measurements of the digital models of Study members were completed by two examiners using the same guidelines as previous assessments. overjet and overbite values were categorised as: 'low' ($\leq$ 1 mm); 'normal' (2 to 4 mm); or 'large' ($\geq$ 5 mm). These categories were used because they have been previously used in research and cited in dental texts [25–29].

2.3. Orthodontic treatment history

The Orthodontic treatment history information was collected using the age 45 dental questionnaire. Study members were asked "Have you ever had orthodontic treatment (teeth straightening)?". The responses were categorised as 'No self-reported history of orthodontic treatment at age 45′ or 'Any form of self-reported orthodontic treatment at age 45′. Any form of orthodontic treatment (including removable or fixed appliances, extractions, and orthognathic surgery) was considered to be a history of orthodontic treatment for the purposes of this study.

2.4. Molar relationship

Angle's molar classification was also recorded at age 15. The left and right sides were assessed with the teeth in occlusion, and only the largest deviation from the normal molar relationship was recorded. If the assessment could not be based on the first molars, the relationship of the permanent canines or premolars was assessed. The categories of molar relationship were classified as 'normal' (Class I molar relationship), a half cusp distal (tending Class II), a full cusp distal (Class II), a half cusp mesial (tending Class III), and a full cusp mesial (Class III).

2.5. Parafunctional habits

Self-reported data on parafunctional habits were gathered in the age 45 dental questionnaire. Study members were asked about day-time clenching ("During the past 12 months, how often did you clench your teeth during waking hours?" which could be answered: 'None of the time', 'A little of the time', 'Some of the time', 'Most of the time' or 'All of the time'). Anyone who self-reported 'Some of the time', 'Most of the time' or 'All of the time' was considered a case of day-time clenching. Study members were also asked about night-time clenching/grinding ("During the past 12 months, how often did you clench or grind your teeth (based on any information you may have, for example, a partner or room-mate)?" with response options: 'None of the time', 'Less than 1 night per month, '1–3 nights per month', '1–3 nights per week' or '4–7 nights per week'. Anyone who self-reported more than 1–3 nights per month was considered a case of night-time clenching/grinding.

2.6. Periodontal disease

This study used clinical periodontal data recorded at the age 38 dental examination. This involved the measurement of three sites (mesiobuccal, buccal and distolingual) per tooth. A National Institute of Dental Research (NIDR) probe (manufactured by Hu-Friedy, Chicago, IL, USA) was used which has 6 alternating 2 mm bands and a rounded tip. Two measures were recorded: gingival recession (GR; the distance in millimetres from the gingival margin to the cementoenamel junction); and probing depth (PD; the distance from the gingival margin to the tip of the probe). Measurements were rounded down to the nearest whole millimetre at the time of recording. The attachment loss for each site was calculated at the analysis stage by summing the GR and PD measurements. A case of periodontal disease was defined in this study as the presence of one or more sites with 5+ mm of attachment loss.

2.7. Statistical analysis

To investigate changes in overjet and overbite by categories from age 15 to age 45, a two-sided *t*-test was used. Then, age 45 overjet and overbite were entered as dependant variables in a multiple linear regression model with age 15 overjet and overbite (low and large/high), one or more sites with 5+ mm of periodontal attachment loss at age 38 (dichotomous variable), self-reported history of orthodontic treatment by age 45 (dichotomous variable), female sex, self-reported history of day-time clenching (dichotomous variable), self-reported history of night-time clenching/grinding (dichotomous variable). A small number of participants ($n = 7$) had a fixed wire retainer bonded to the lower anterior teeth at age 45 years; owing to this being a small number we did not control for the presence of fixed retainers as a potential confounder. The reference category was a normal overjet/overbite range of 2–4 mm, and all regression coefficients were adjusted for confounding variables. Adjusted regression coefficients were estimated, along with their 95% confidence intervals.

All statistical analyses used STATA 15.1 SE (StataCorp, Texas, USA), with the significance level set at 0.05.

3. Results

Study members who had occlusal data collected at both ages 15 and age 45 were included in the analysis ($n = 661$), although two individuals were missing overbite measures at age 45 ($n = 659$). At age 15, 89 (13.5% per cent) of Study members were categorised as low overjet; 485 (73.4%) had normal overjet, and 87 (13.2%) had large overjet. 101 (15.3%) study members were categorised as low overbite; 407 (61.6%) had normal overbite, and 153 (23.2%) had high overbite.

Mean values of overjet and overbite by categories at age 15 and 45 are presented in Table 1. overjet at age 45 was overall 0.5 mm larger than at age 15, and this was the case for those who did not report orthodontic treatment and those who did. For those in the low overjet category at age 15, overjet was overall 1.2 mm larger at age 45. Self-reported history of orthodontic treatment led to 1.6 mm larger overjet at age 45 for those in this category, than 1.0 mm in those who did not self-report orthodontic treatment. The corresponding overbite changes in the low overjet category were not significant. Those with normal overjet had overall 0.6 mm less ($p < 0.001$) overjet at age 45, and orthodontic treatment had little influence on this age 15 overjet category. For those with large overjet at age 15, overjet was overall 0.5 mm less at age 45. If orthodontic treatment was self-reported, overjet was 1.4 mm

Table 1
Mean overjet and overbite (in mm) at age 15 and 45 by age 15 category and history of orthodontic treatment by age 45 (SD).

	Overjet at 15Overjet at 45Difference	Overjet at 15Overjet at 45Difference	Overjet at 15Overjet at 45Difference	Overbite at 15Overbite at 45Difference	Overbite at 15Overbite at 45Difference	Overbite at 15Overbite at 45Difference	N included (col%)
	No orthodontic history	History of orthodontics	All	No orthodontic history	History of orthodontics	All	
Overjet at 15							
Low (≤1 mm)	0.7 (0.5)	0.9 (0.4)	0.7 (0.4)	2.2 (2.0)	2.0 (1.9)	2.1 (2.0)	89 (13.5)
	1.7 (1.1)	2.4 (1.2)	1.9 (1.2)	2.0 (1.8)	1.7 (1.6)	1.9 (1.7)	
	1.0 (1.1)[c]	**1.6 (1.3)**[c]	**1.2 (1.2)**[c]	**−0.2 (1.4)**	**−0.3 (2.0)**	**−0.3 (1.6)**	
Normal (2–4 mm)	2.8 (0.8)	2.7 (0.8)	2.7 (0.8)	3.6 (1.6)	3.2 (1.5)	3.5 (1.6)	485 (73.4)
	3.3 (1.2)	3.3 (1.5)	3.3 (1.3)	2.9 (1.6)	2.8 (1.6)	2.9 (1.6)	
	0.5 (1.1)[c]	**0.6 (1.5)**[c]	**0.6 (2.2)**[c]	**−0.7 (1.3)**[c]	**−0.5 (1.5)**[c]	**−0.6 (1.4)**[c]	
Large (≥5 mm)	6.1 (1.4)	6.2 (1.8)	6.1 (1.6)	4.1 (1.9)	3.0 (1.7)	3.8 (1.9)	87 (13.2)
	6.0 (2.0)	4.9 (2.1)	5.6 (2.1)	3.4 (2.1)	3.2 (2.6)	3.3 (2.0)	
	−0.1 (2.0)	**−1.4 (3.0)**[a]	**−0.5 (2.2)**[a]	**−0.7 (1.6)**[b]	**0.2 (1.8)**	**−0.4 (1.7)**[a]	
Overbite at 15							
Low (≤1 mm)	2.2 (2.0)	2.3 (1.9)	2.2 (2.0)	0.5 (0.5)	0.7 (0.5)	0.6 (0.5)	99 (15.0)
	2.6 (2.0)	3.1 (1.7)	2.7 (1.9)	0.8 (1.2)	1.7 (1.4)	1.1 (1.3)	
	0.3 (1.1)[a]	**0.8 (2.5)**[a]	**0.5 (1.7)**[b]	**0.3 (1.3)**	**1.0 (1.3)**[c]	**0.5 (1.3)**[c]	
Normal (2–4 mm)	2.9 (1.3)	2.9 (1.6)	2.9 (1.4)	3.2 (0.8)	2.9 (0.8)	3.1 (0.8)	407 (61.8)
	3.4 (1.6)	3.4 (1.7)	3.4 (1.6)	2.7 (1.3)	2.6 (1.6)	2.7 (1.4)	
	0.5 (1.2)[c]	**0.5 (1.7)**[c]	**0.5 (1.4)**[c]	**−0.5 (1.2)**[c]	**−0.4 (1.5)**[b]	**−0.5 (1.3)**[c]	
High (≥5 mm)	3.5 (1.8)	3.2 (2.1)	3.4 (1.9)	5.6 (0.9)	5.6 (0.9)	5.6 (0.9)	153 (23.2)
	4.0 (1.8)	3.4 (1.7)	3.9 (1.8)	4.3 (1.5)	4.1 (1.6)	4.2 (1.6)	
	0.5 (1.1)[c]	**0.3 (2.4)**	**0.4 (1.8)**[b]	**−1.3 (1.3)**[c]	**−1.5 (1.7)**[c]	**−1.4 (1.4)**[c]	
Overall	2.9 (1.6)	2.9 (1.8)	2.9 (1.7)	3.5 (1.8)	3.0 (1.6)	3.3 (1.7)	661
	3.4 (1.7)	3.4 (1.7)	3.4 (1.7)	2.9 (1.7)	2.7 (1.7)	2.8 (1.7)	
	0.5 (1.2)[c]	**0.5 (1.9)**[c]	**0.5 (1.5)**[c]	**−0.6 (1.3)**[c]	**−0.3 (1.7)**[b]	**−0.5 (1.5)**[c]	
Column N	437	219	661	436	218	659[d]	

Two-sided paired *t*-test;.

[a] $p < 0.05$;.

[b] $p < 0.01$;.

[c] $p < 0.001$;.

[d] two individuals excluded from measures of overbite.

less at age 45, and not significantly difference if no orthodontic treatment was self-reported. The corresponding overbite changes in the large overjet category were 0.7 mm less overbite without orthodontic treatment, and no significant overbite change if orthodontic treatment was self-reported.

Overall overbite at age 45 was 0.5 mm less than at age 15. Self-reported history of orthodontic treatment resulted in 0.6 mm less overbite, while it was 0.3 mm less without orthodontic treatment. For those in the low overbite category at age 15, overbite was 0.5 mm higher at age 45 overall. Self-reported orthodontic treatment was associated with a 1.0 mm higher overbite, and 0.8 mm overjet at 45. amongst those with normal overbite at age 15, overbite was overall 0.5 mm less at age 45 and was not associated with history of orthodontic treatment. For those in the high overbite category, overall overbite was 1.4 mm less at age 45, with self-reported orthodontic treatment having little effect on this category.

Orthodontic characteristics at age 45 are summarised in Table 2. 227 (34.5%) of Study members had an Angle Class I molar relationship. 135 (20.5%) had half Class II molar relationships and 91 (13.8%) full unit Class II molar relationships. Half unit Class III molar relationships were identified in 181 (27.5%) of Study members, and 24 (3.7%) had full unit Class III molar relationships. At age 38, 164 (20.7%) of Study members had one or more teeth with 5+ mm periodontal pocketing. Self-reported day-time tooth clenching at age 45 was described (at least some of the time) by 119 (14.7%), while tooth clenching/grinding while sleeping (more than 1–3 nights per month or more) was described by 119 (14.9%). Approximately half (407 or 49.5%) of the Study members were female, and a self-reported history of orthodontic treatment by age 45 was described by 275 (33.7%) of them.

Table 2
Orthodontic characteristics at age 45 by molar relationship at age 15, periodontal disease, parafunctional habits, history of orthodontics and sex.

	Mean overjet at 45 (SD)	Mean overbite at 45 (SD)	N (Col %)
Angle molar relationship at age 15 [$n = 658$]			
Class I	3.2 (1.4)	2.8 (1.4)	227 (34.5)
½ Class II	3.8 (1.7)	3.1 (1.9)	135 (20.5)
Class II	4.5 (2.3)	3.5 (1.9)	91 (13.8)
½ Class III	3.0 (1.5)	2.3 (1.6)	181 (27.5)
Class III	2.1 (1.3)	1.4 (1.6)	24 (3.7)
Periodontal disease at age 38 [$n = 794$]			
1+ sites with 5+ mm of attachment loss	3.8 (2.0)	2.7 (1.8)	164 (20.7)
0 sites with 5+ mm of attachment loss	3.3 (1.6)	2.8 (1.7)	630 (79.4)
Parafunction – clenching at age 45 [$n = 811$]			
At least some of the time	3.5 (1.7)	2.9 (1.8)	119 (14.7)
A little or none of the time	3.4 (1.7)	2.8 (1.7)	692 (85.3)
Parafunction – grinding at age 45 [$n = 801$]			
At least some of the time	3.7 (1.9)	2.8 (1.7)	119 (14.9)
A little or none of the time	3.4 (1.7)	2.8 (1.7)	682 (85.1)
History of orthodontic treatment by age 45 [$n = 816$]			
Yes	3.5 (1.8)	2.7 (1.7)	275 (33.7)
No	3.4 (1.7)	2.9 (1.7)	541 (66.3)
Sex [$n = 823$]			
Female	3.6 (1.7)	2.9 (1.6)	407 (49.5)
Male	3.3 (1.7)	2.7 (1.8)	416 (50.5)
Overall	3.4 (1.7)	2.8 (1.7)	823

The regression model for overjet and overbite at age 45 (adjusted and unadjusted) is presented in Table 3. Compared to normal, those with low overjet at 15 had 1.1 mm less overjet at age 45, and those with large overjet at 15 had 2.2 mm more overjet at age 45. Similar findings were seen for overbite when compared to normal, those with low overbite at 15 had 1.4 mm less overbite at age 45, and those with high overbite had 1.6 mm more overbite at age 45. Compared to those with Class I molar relationships at age 15, those with half unit Class II molar relationships had 0.4 mm more overjet at age 45, and those with full unit Class II molar relationships had 0.8 mm more overjet at age 45. Age 45 overjet and overbite outcomes were not associated with Class III molar relationships (full or half unit). Having one more 5+ mm sites at age 38 was associated with 0.5 mm more overjet at age 45 than those without periodontal disease. A self-reported history of day-time tooth clenching at age 45 predicted greater overbite (0.3 mm), whereas a history of night-time clenching/grinding was not. A self-reported history of orthodontic treatment by age 45 was not associated with overjet or overbite at age 45. Females had larger overjet (+0.6 mm) and overbite (+0.4 mm) at age 45 than males.

4. Discussion

This study reports original data on changes in incisor relationships from adolescence to mid-adulthood. Only a handful of studies have documented incisor relationships into the fifth decade of life [9-12, 15, 16] and those are almost exclusively based on small samples derived from historical growth study records. The strengths of the current study include the large generalisable sample [30], high retention rate and the use of multivariate statistics. This work also utilises clinical or digital dental measures of overjet and overbite rather than those derived from lateral cephalograms; the latter can be prone to measurement error [31, 32].

The study limitations should also be considered. Although participation in the age 45 dental examination/questionnaire involved around 90% of the original cohort, complete overjet and overbite data at ages 15 and 45 were available for only 659 Study members. This lower cohort size arose from the relatively low participation in the age-15 dental examinations. Additionally, an earlier timepoint for assessing the full permanent dentition (excluding third molars) may have been more suitable than age 15, because some Study members were currently undergoing treatment or had already completed orthodontic treatment by age 15. This has the potential to bias the findings towards the null hypothesis. However, this was not possible because there was no earlier assessment phase that included a comprehensive dental examination of the permanent dentition. Furthermore, detailed information on the type of orthodontic treatment (or whether the treatment was undertaken by a general dental practitioner or specialist) was not available at age 45. The self-reported history of orthodontic treatment may have included removable or fixed appliances, extractions, or orthognathic surgery and perhaps a more specific question would have been more appropriate. Accordingly, there is a possibility that the observed associations between self-reported orthodontic treatment and age 45 overjet / overbite could have been influenced by treatment bias. In addition, the assessment of clenching and grinding in the previous 12 months were based on self-report. Although more accurate forms of assessment (such as electromyographic monitoring) are considered the gold standard, this was not practical or feasible for such a large cohort. Despite this, orthodontic treatment (albeit self-reported) appeared to be effective in the age 15 low overjet (1.6 mm higher at 45), high overjet (1.4 mm lower at 45) and low overbite (1.0 mm higher at 45) groups.

Some of the most notable findings pertain to those who had not had orthodontic treatment. Their findings are meaningful because there is no

Table 3
Regression model for overjet and overbite at age 45. *(N in final model = 620)*.

	Overjet: Unadjusted coefficient (95% CI)	Overjet: Adjusted coefficient, (95% CI)	Overbite: Unadjusted coefficient, (95% CI)	Overbite: Adjusted coefficient, (95% CI)
Overjet at age 15				
Low (≤1 mm)	**−1.3 (−1.6, −1.0)**	**−1.1 (−1.5, −0.8)**	**−1.0 (−1.4, −0.6)**	−0.2 (−0.6, 0.1)
Normal (2–4 mm) [ref]	.	.	.	.
High (≥5 mm)	**2.3 (2.0, 2.7)**	**2.2 (1.9, 2.5)**	**0.5 (0.1, 0.9)**	0.2 (−0.1, 0.6)
Overbite at age 15				
Low (≤1 mm)	**−0.5 (−0.9, −0.1)**	−0.1 (−0.5, 0.2)	**−1.5 (−1.8, −1.2)**	**−1.4 (−1.7, −1.0)**
Normal (2–4 mm) [ref]	.	.	.	.
High (≥5 mm)	**0.5 (0.2, 0.8)**	0.2 (−0.0, 0.5)	**1.6 (1.3, 1.9)**	**1.6 (1.3, 1.8)**
Molar relationship				
Class 1 [ref]	.	.	.	.
½ Class II	**0.6 (0.3, 1.0)**	**0.4 (0.1, 0.7)**	0.2 (−0.1, 0.6)	0.2 (−0.1, 0.6)
Class II	**1.2 (0.8, 1.6)**	**0.8 (0.5, 1.2)**	**0.7 (0.3, 1.1)**	**0.4 (0.0, 0.7)**
½ Class III	−0.2 (−0.5, 0.2)	0.1 (−0.2, 0.4)	−0.5 (−0.8, −0.2)	−0.3 (−0.5, 0.0)
Class III	**−1.1 (−1.8, −0.4)**	−0.2 (−0.8, 0.5)	−1.4 (−2.1, −0.7)	−0.2 (−0.9, 0.4)
Periodontal disease at age 38				
1+ sites with 5+ mm of attachment loss	**0.5 (0.1, 0.8)**	**0.5 (0.3, 0.8)**	−0.1 (−0.5, 0.2)	0.1 (−0.2, 0.3)
0 sites with 5+ mm of attachment loss [ref]	.	.	.	.
Parafunction – clenching at age 45				
At least some of the time	−0.0 (−0.4, 0.4)	−0.0 (−0.3, 0.3)	0.2 (−0.2, 0.6)	**0.3 (0.0, 0.7)**
A little or none of the time [ref]	.	.	.	.
Parafunction – clenching/ grinding at age 45				
At least some of the time	0.2 (−0.1, 0.6)	−0.1 (−0.4, 0.3)	0.0 (−0.4, 0.4)	−0.3 (−0.6, 0.0)
A little or none of the time [ref]	.	.	.	.
History of orthodontic treatment by age 45				
Yes	−0.1 (−0.4, 0.2)	−0.1 (−0.3, 0.1)	−0.2 (−0.5, 0.0)	−0.1 (−0.3, 0.2)
No [ref]	.	.	.	.
Sex				
Female	**0.4 (0.1, 0.6)**	**0.6 (0.4, 0.8)**	0.2 (−0.0, 0.5)	**0.4 (0.2, 0.6)**
Male [ref]	.	.	.	.

orthodontic treatment to masque the natural history of how incisor relationships change with time and their data also allows comparison with previous growth studies [8–10]. For example, amongst orthodontically-untreated participants who had low overjet at age 15, overjet increased significantly by age 45 (1.0 mm increase, closer to ideal values), even in the absence of orthodontic treatment. Furthermore, amongst orthodontically-untreated participants with high overbite at age 15, overbite decreased significantly by age 45 (1.3 mm decrease, closer to ideal values), again despite never having had orthodontic treatment. It may be that there is a type of "regression towards the mean" effect, whereby 'improvements' are seen over time. However, for those with orthodontically untreated high overjet and low overbite at age 15, no significant differences were seen, indicating that these characteristics tend to persist and have limited capacity to self-correct. Consequently, this highlights two common clinical situations where orthodontic treatment may be of benefit, preventing trauma to protruding incisors [33] and preventing possible periodontal damage from a deep bite [34]. Interestingly, nearly two decades ago, the acceptable long-term outcomes of orthodontic treatment in the Dunedin cohort *vis-à-vis* equity, efficacy, effectiveness, and safety has also been reported [35].

Among orthodontically untreated Study members, the mean overjet at age 45 was 0.5 mm higher than at age 15. This is in contrast to many other studies of untreated individuals which have indicated relative stability of overjet during adulthood [8–12]. However, the current study's sample size is considerably larger (by at least seven times) than those of any other investigations describing overjet changes into adulthood. Reasons for the higher overjet later in life could be due to more pronounced decreases in mandibular inter-canine widths and arch length, relative to the maxillary arch [8, 12, 36-39]. Such changes have been shown to lead to mandibular arch forms becoming shorter and broader overall [9]. It was noteworthy that those who had orthodontically untreated large overjet age 15 had a significantly lower overbite by age 45. This slight improvement in overbite was unexpected, because such cases are thought to be at risk of continued incisor eruption due to the lack of vertical limit [40]. This finding may assist clinical decision making in cases where orthognathic surgical correction is contraindicated (skeletal Class II, for example) or where the planned movement of the maxillary incisors would adversely affect upper lip support. Currently, permanent bonded retainers are recommended for stabilising these cases, although there is limited evidence to support this practice [40].

After controlling for other factors, females had 0.6 mm higher overjet at age 45 than males. This is not the first time that marked sex differences in overjet beyond adolescence have been described [36]. Sexual dimorphism in overjet into mid-adulthood could be a result of residual mandibular growth subsequent to age 15 in males, or greater decreases in mandibular arch dimension in females [37].

Regardless of age 15 overbite category, the mean overbite values were 0.5 mm lower at age 45 than at age 15. Lower overbite later in life could be due to dentoalveolar/skeletal change, or attrition of incisal edges, which would affect overbite. Decreases in overbite values in orthodontically untreated samples have been observed from age 12 to 20 years [41, 42], into mid-adulthood [14, 43] and into late adulthood [15]. On the other hand, authors have also reported overbite remaining invariant [9, 10, 12, 13] and even increasing [8] during adulthood. We also observed sex differences in age 45 overbite, with female Study members having higher overbite values than males by 0.4 mm. Sex differences in overbite have been previously reported [15, 16, 36, 37]. Greater overbite reductions in males during adulthood may be due to physiological process rather than dentoalveolar change *per se* as increased incisal tooth wear [44], and stronger masticatory muscle activity [45] are more prevalent in males. We also observed that a self-reported history of day-time clenching at age 45 was associated with higher overbite at age 45. This could be a result of posterior dental intrusion of the teeth and subsequent auto-rotation of the mandible.

Another possibility is posterior tooth wear amongst these individuals, although this seems less likely, since no association was seen between overbite and self-reported night-time tooth clenching/grinding at age 45.

Study members who had one or more sites with 5+ mm of periodontal attachment loss at age 38 tended to have greater overjet at age 45. This age 38 case definition was used, rather than a more recent diagnosis, to allow time for periodontal disease to manifest, A limitation of this generalised periodontal variable is that there is an assumption that the anterior teeth are also affected by disease. It is accepted that incisors exist in a position of equilibrium between the lips, cheeks and tongue [4], and a loss of periodontal support can negatively change this [46]. The observed 0.5 mm increase in overjet is likely to have arisen from anterior tooth displacement and early pathologic tooth migration (PTM) which is a common complication of moderate-to-severe periodontitis [46]. However, research has shown that the mean attachment loss of a tooth affected by PTM is around 4.8 mm greater than that of control teeth [47]. Perhaps a more severe periodontal case definition may be more useful in future research, along with limiting periodontal disease analysis to the anterior teeth, to place emphasis on the teeth most affected by this phenomenon. Because greater overjet has a negative impact on quality of life in children and adults [48–51], the influence of periodontal disease on long-term incisor stability is of clinical and social significance.

We hypothesised that the incisor relationship (as represented by overbite and overjet during adolescence) will deteriorate amongst those with overbite and overjet values outside normal range. This does not appear to be the case, although orthodontically untreated Study members with high overjet or low overbite remained such later in life. That these occlusal features did not self-correct could mean they would benefit from orthodontic intervention. Comparisons of orthodontically untreated and treated Study members should be interpreted with care for two reasons. First, many Study members had either finished orthodontics or were undergoing orthodontic treatment at the age 15 examinations; second, orthodontic treatment history was self-reported and included any form of treatment by age 45.

Quantifying long-term changes in overjet and overbite presents many challenges. These include factors such as continuous dentoalveolar and skeletal change throughout life, individual variation, physiological tooth wear, measurement error, changes in arch widths/depths with time, crowding, and periodontal disease. More importantly, the clinical significance of difference in the order of fractions of millimetres observed over a 30-year period needs to be considered. Notwithstanding, the study provides valuable information on changes in overjet and overbite that occur in a large cohort using valid measures, from age 15 into mid-adulthood.

5. Conclusions

Overall, overjet tends to be approximately 0.5 mm higher, and overbite tends to be approximately 0.5 mm lower in mid-adulthood than during adolescence. Sex differences were also apparent with females having higher overjet and overbite at 45 than males. A greater overjet at age 45 was found in Study members with loss of periodontal support at age 38. Overjet at age 45 was not associated with self-reported history of day-time tooth clenching, while overbite was higher in members with self-reported history of tooth grinding. A history of orthodontic treatment is associated with overjet and overbite closer to normal range values over long-term. This research opens new questions that merit investigation, including a need for more detailed and high-quality long-term longitudinal research on how occlusion matures and ages.

CRediT authorship contribution statement

Olliver SJ: Investigation, Software, Formal analysis, Funding acquisition, Writing – original draft, Writing – review & editing. **Broadbent JM:** Conceptualization, Project administration, Funding acquisition, Supervision, Methodology, Resources, Formal analysis, Writing – original draft, Writing – review & editing. **Sabarinath Prasad:** Writing – original draft, Writing – review & editing. **Celene Cai:** Investigation, Methodology, Software. **W. Murray Thomson:** Supervision, Resources, Writing – review & editing. **Mauro Farella:** Conceptualization, Methodology, Formal analysis, Funding acquisition, Project administration, Supervision, Visualization, Data curation, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

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