ACTA ODONTOLOGICA SCANDINAVICA
2021, VOL. 79, NO. 8, 593–599
https://doi.org/10.1080/00016357.2021.1918348

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ORIGINAL ARTICLE



# Associations between Bolton ratio and overjet deviations in a Finnish adult population

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**ABSTRACT**

**Objective:** To determine the anterior Bolton ratio for a Finnish adult population and to investigate its associations with overjet.

**Material and methods:** This study is part of the Northern Finland Birth Cohort 1966. Clinical oral investigations, including three-dimensional intraoral scanning and registration of occlusion, were performed in connection with the 46-year follow-up for 1,961 subjects. Subjects with normal occlusion ($n = 149$), extreme overjet $\geq$ 8 mm ($n = 49$), large overjet 6–7 mm ($n = 86$), and negative overjet ($n = 16$) and no orthodontic treatment history were selected for further analysis. The mesiodistal widths were measured from canine to canine to evaluate the anterior Bolton ratio.

**Results:** A mean anterior Bolton ratio of 78.6 (SD 3.1) was found for the normal occlusion group. Subjects with extreme overjet had smaller Bolton ratios compared to the normal occlusion group and the negative overjet group ($p = .005$, $p = .019$, respectively). Overjet deviations were associated with upper canine and incisor widths.

**Conclusions:** The mean anterior Bolton ratio in subjects with normal occlusion was larger compared to the original Bolton ratio. Tooth size discrepancy was associated with extreme and negative overjet at population level.

**ARTICLE HISTORY**
Received 9 June 2020
Revised 10 March 2021
Accepted 8 April 2021

**KEYWORDS**
Anterior Bolton ratio; overjet; tooth size

## Introduction

Antero-posterior deviations from normal occlusion are common problems in modern populations. Normal occlusion requires harmony between tooth sizes and dental arches. Disharmony between these factors may lead to various malocclusions, such as sagittal deviations and crowding [1]. Tooth size discrepancy has been suggested to be one factor associated with different malocclusions [1–3].

Bolton analysis [4] is a widely used method for analysing tooth size discrepancies. The anterior Bolton ratio is the percentage of the sum of the mesiodistal widths from canine to canine in the mandible divided by the sum of the mesiodistal widths from canine to canine in the maxilla. Correspondingly, the overall Bolton ratio is the percentage of the sum of the mesiodistal widths from first molar to first molar in the mandible divided by the sum of mesiodistal widths from first molar to first molar in the maxilla. Bolton has determined the ideal anterior ratio as being 77.2% ± 0.26% among subjects with ideal occlusion [4]. According to Bolton, clinical problems can be suggested to arise when discrepancy is greater than ±1 SD. However, most researchers have defined a clinically significant ratio to be larger than 2 SD from Bolton's mean value [5–7].

Previous studies have found association between deviations of Bolton ratio and Angle Class II and Class III malocclusions [8]. Several studies have found that patients with Class III malocclusion have a tendency for larger anterior ratios compared to Class I and II patients [1–3]. Lavelle [1] also reported that subjects with Class III malocclusion had smaller maxillary teeth and larger lower arch compared to the subjects with Class I or Class II molar relationships. Nie and Lin [9] found that anterior Bolton ratios were smaller in Class II patients and larger in Class III patients compared to those with Class I molar relationship. Conversely, Shastri et al. [3] reported that Class II malocclusion was associated with higher anterior ratios in North Indian population. However, some researchers have not found a difference in Bolton ratios between malocclusion groups [10–16]. Alkofide and Hashim [10] did not find a significant difference in the anterior ratios between most of the different malocclusion groups. The only exception was the anterior ratio in Class III malocclusion. In addition, Lopatiene and Dumbravaite [15] did

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not reveal a statistically significant difference in anterior Bolton ratio between Angle Class I, II, and III.

There are only a few studies which have investigated the relationship between Bolton ratio and overjet or overbite [15,17]. Alam and Iida [18] found significant differences in Bolton overall ratios between groups with normal, increased and decreased overjet; decreased overjet was associated with significantly larger overall ratios. Lopatiene and Dumbravaite [15] found a moderate correlation between overall Bolton ratio and overjet. Their study showed that when the overall ratio decreased, overjet increased.

Previous studies concerning sagittal deviations and tooth size discrepancies have mostly studied associations between Angle classifications and Bolton ratio. However, tooth size discrepancy may lead to increased or decreased overjet also in individuals with an acceptable sagittal molar relationship. Therefore, there is a need to understand relationships between tooth size discrepancies and overjet. In addition, there is no previous data on Bolton ratio in Finnish population, although it has been shown that tooth size discrepancies are population-specific [19].

The aim of this study was to determine the anterior Bolton ratio for Finnish adult population and to investigate associations between anterior Bolton ratio and deviations of overjet in adults without orthodontic treatment history. The hypothesis was that increased overjet is associated with lower, and negative overjet with higher anterior Bolton ratios.

## Material and methods

This study is part of the Northern Finland Birth Cohort (NFBC) 1966. These live-born children correspond to 96.3% of all births in the area in 1966 [20] and the subjects have been evaluated regularly. During the years 2012–2013, clinical oral investigations were performed in connection with the 46-year follow-up for 1,964 subjects; of these, 1961 (911 males, 1,050 females) have given consent to data use. Clinical investigations included clinical registration of occlusion and three-dimensional (3D) intraoral scannings. Oral investigations were conducted by six dentists who were trained and calibrated by a golden standard senior dentist before and during the study. Overjet was measured in millimetres with a manual scaler (with 1-mm intervals) horizontally in the maximal intercuspal position from the right central maxillary incisor to the labial surface of the mandibular incisor. The registration of occlusion has been described earlier in more detail [21]. Three-dimensional scannings were done by using 3Shape 3D Scanner (Copenhagen, Denmark).

The subjects with clinically measured normal occlusion were selected for further analysis. Normal occlusion was defined as meeting the following criteria: overjet 2 mm, overbite 2 mm, no cross-bite or scissor-bite ($n = 204$). To exclude the subjects with other deviations from normal occlusion, the 3D scans were scored using the Dental Health Component (DHC) of the Index of Orthodontic Treatment Need (IOTN) [22]. DHC scoring was performed by one author (AS), who was calibrated for the use of IOTN. The DHC scores range from 1 to 5, higher scores indicating greater need of orthodontic treatment. The subjects whose DHC was 3 or more and those with missing teeth from second premolar to second premolar were excluded ($n = 40$) from the normal occlusion group. In addition, the subjects with self-reported orthodontic treatment history ($n = 15$) were excluded from the final analysis. The final normal occlusion group comprised 149 subjects (62 male, 87 female). Digital measurements were performed with Ortho Analyzer$^{TM}$ software (3Shape, Copenhagen, Denmark).

To evaluate the associations between overjet and anterior Bolton ratio, subjects with extreme overjet $\geq$ 8 mm ($n = 49$), large overjet 6–7 mm ($n = 86$), and negative overjet $<$ 0 mm ($n = 16$) were selected for further analysis. Out of total number of subjects in the overjet groups ($n = 197$), 15 were excluded based on missing teeth from canine to canine in the upper or lower arch and 31 were excluded due to self-reported orthodontic treatment history. The gender distributions of overjet groups are presented in Table 1. The formation of normal occlusion and overjet groups is described in Figure 1. The anterior tooth size ratio was counted for each subject as described by Bolton [4]:

$$\frac{\text{Sum of mandibular anterior teeth}}{\text{Sum of maxillary anterior teeth}} \times 100$$

The mesiodistal widths of maxillary and mandibular teeth were measured from canine to canine. The width of each tooth was measured from mesial contact point to distal contact point at the greatest mesiodistal width. Occlusal plane was determined from mesiobuccal cusps of the first molars to the tip of the central incisor separately for maxilla and mandible. Four investigators (HT, MS, JH, PP) were trained for dental measurements. Intra- and inter-examiner errors were measured from twenty randomly selected models and compared using intra-class correlation (ICC). The repeated measurements in 3D models were compared using intraclass correlation. The correlation ranged from 0.741 to 0.899 in intraexaminer error and from 0.889 to 0.966 in inter-examiner error. The intraexaminer and interexaminer error was found to be at a good level.

Data were analysed using SPSS (version 22.0; SPSS, Inc., Chicago, IL, USA). Descriptive statistics, including means, medians, standard deviations, range and 95% CI for mean, were calculated for anterior Bolton ratios as well as for tooth size in both arches for the normal occlusion group and the overjet groups. Analysis of variance (ANOVA) and Games-Howell as a Post Hoc tests were used to compare the mean anterior Bolton ratios and tooth widths between all groups. Discrepancy of ± 2 SD from the mean Bolton ratio of the normal occlusion group was considered a clinically significant deviation from normal Bolton ratio [5–7]. Frequencies of discrepancies ± 2 SD were calculated separately for both normal occlusion and overjet groups. $p$ Value $<.05$ was considered statistically significant.

## Results

A mean anterior Bolton ratio of 78.6 (SD 3.1) was found for the normal occlusion group. No statistically significant

**Table 1.** The mean values, standard deviations and ranges of anterior Bolton ratio for the normal occlusion group and the overjet groups.

| | Normal occlusion $n = 149$ ($m = 62$, $f = 87$) | Extreme overjet Overjet $\geq$ 8mm $n = 49$ ($m = 19$, $f = 30$) | Large overjet Overjet = 6–7mm $n = 86$ ($m = 44$, $f = 42$) | Negative overjet Overjet < 0mm $n = 16$ ($m = 13$, $f = 3$) |
|---|---|---|---|---|
| Mean | 78.6 | 77.1 | 77.8 | 80.0 |
| Median | 78.1 | 76.6 | 77.4 | 80.4 |
| SD | 3.1 | 2.4 | 2.9 | 3.3 |
| Range (min–max) | 72–89 | 72–83 | 71–85 | 75–86 |
| 95% CI for Mean | 78.1–79.0 | 76.4–77.8 | 77.2–78.5 | 78.2–81.8 |

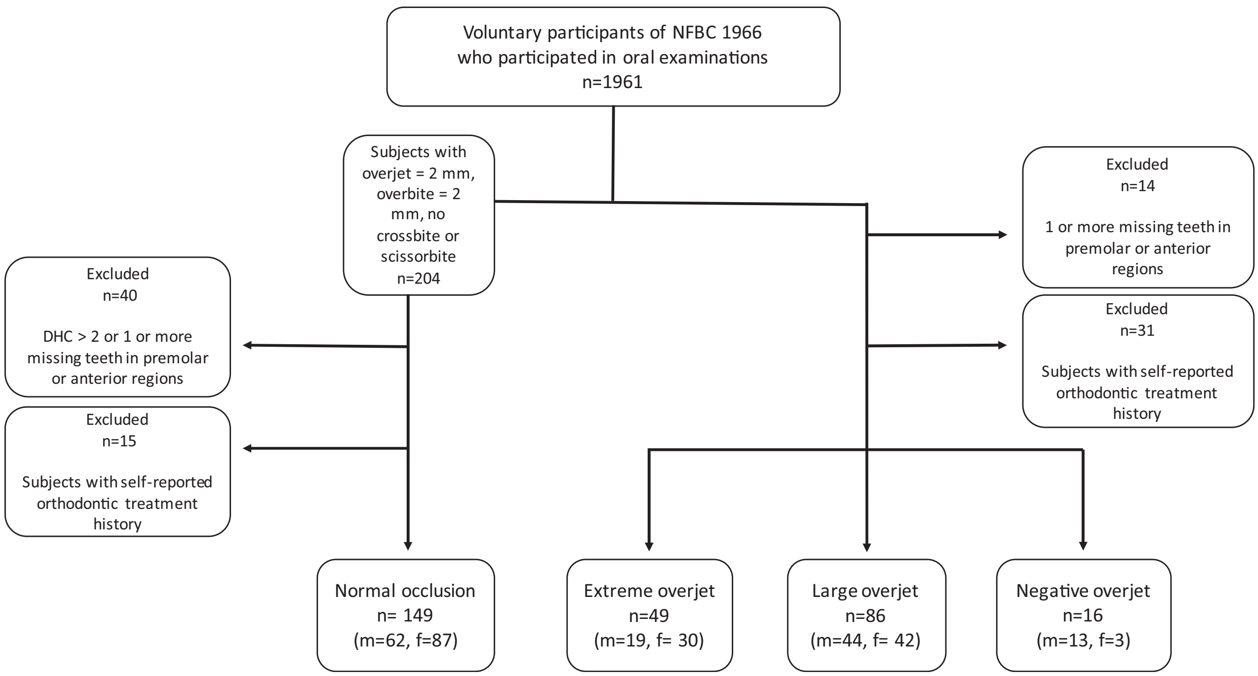



**Figure 1.** The flow of subjects and formation of the normal occlusion group and the overjet groups.

difference between genders was found in the anterior Bolton ratio in subjects with normal occlusion. Mean anterior Bolton ratios for malocclusion groups were: extreme overjet group 77.1 (SD 2.4), large overjet group 77.8 (SD 2.9), and negative overjet group 80.0 (SD 3.3). The mean values and standard deviations for the different malocclusion groups and the normal occlusion group are shown in Table 1.

Statistically significant differences in the anterior Bolton ratio were found between the extreme overjet group (overjet $\geq$ 8 mm) and the normal occlusion group ($p = .005$), as well as between the extreme overjet group and the negative overjet group ($p = .019$) (Figure 2). No other statistically significant differences in the anterior Bolton ratio were found between the groups. The lowest anterior Bolton ratio was found in the extreme overjet group. Conversely, the highest Bolton ratio was calculated for the negative overjet group.

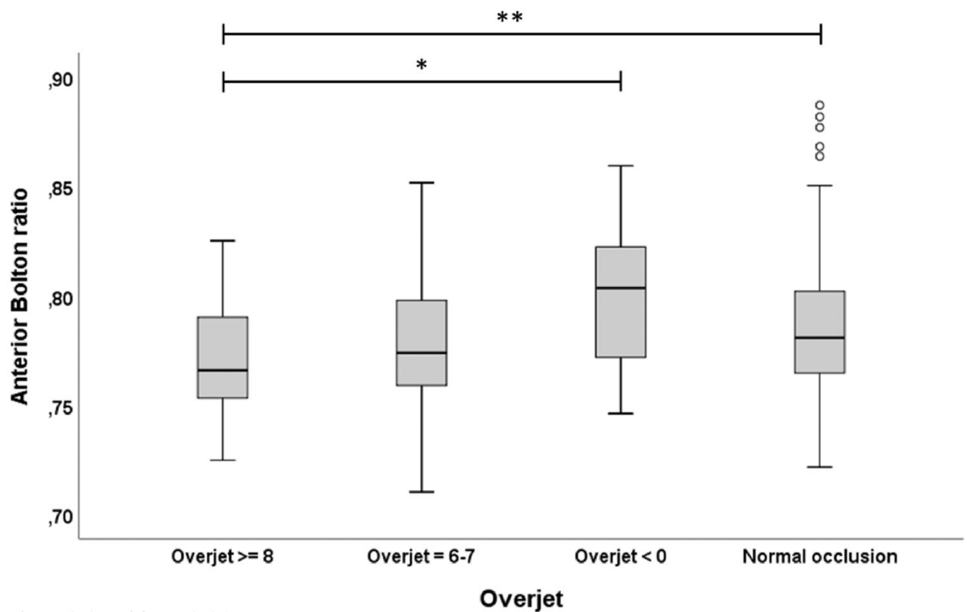
The means and standard deviations of the tooth size distribution in the overjet groups and the normal occlusion group in both arches are summarized in Tables 2 and 3. Subjects with extreme or large overjet had wider upper central incisors compared to the normal occlusion group ($p < .05$). Subjects with negative overjet tended to have smaller upper anterior teeth compared to the other groups, differences being statistically significant in right canines ($p < .01$), in left canines compared to the large overjet group ($p = .049$) and in right central incisors compared to the extreme overjet group ($p = .050$) The widths of lower canines and incisors did not differ between the groups, except wider right canines were found in the large overjet group compared to the normal occlusion group ($p = .003$).

There was a tendency that males had wider teeth compared to females; however, the differences were not statistically significant. None of the subjects had prosthetic restorations in the anterior region, except one subject in the normal occlusion group had a crown in one tooth.

## Discussion

The current study aimed to determine the anterior Bolton ratio in Finnish adults and investigate its associations with overjet deviations. The subjects with extreme overjet had lower anterior Bolton ratio compared to those with normal occlusion or negative overjet. These results support the hypothesis that anterior Bolton ratio is associated with deviations in overjet, not only in some individuals, but also at population level.

When comparing the mean anterior Bolton ratio of the normal occlusion group (78.6) to Bolton's ideal anterior ratio




*$p < 0.05$, **$p < 0.01$

**Figure 2.** Distributions of anterior Bolton ratios in the overjet groups and the normal occlusion group (Boxplot).

**Table 2.** Mean values (mm) and distribution of maxillary teeth in the normal occlusion group and the overjet groups.

| | Maxillary right | | | Maxillary left | | |
|---|---|---|---|---|---|---|
| | Canine | Lateral incisor | Central incisor | Central incisor | Lateral incisor | Canine |
| Normal occlusion | | | | | | |
| Mean | 7.74 | 6.75 | 8.64 | 8.60 | 6.73 | 7.65 |
| Median | 7.67 | 6.74 | 8.59 | 8.59 | 6.71 | 7.63 |
| SD | 0.54 | 0.67 | 0.59 | 0.58 | 0.63 | 0.52 |
| Min | 6.48 | 4.19 | 7.14 | 7.09 | 4.51 | 6.49 |
| Max | 9.06 | 8.43 | 10.89 | 10.55 | 8.66 | 8.94 |
| Range | 2.58 | 4.24 | 3.75 | 3.46 | 4.15 | 2.45 |
| Extreme overjet (Overjet $\geq$ 8 mm) | | | | | | |
| Mean | 7.88 | 6.98 | 8.94 | 8.90 | 6.96 | 7.79 |
| Median | 7.88 | 7.06 | 8.90 | 8.95 | 6.97 | 7.88 |
| SD | 0.54 | 0.81 | 0.64 | 0.69 | 0.63 | 0.59 |
| Min | 6.31 | 3.36 | 7.67 | 7.78 | 5.54 | 5.92 |
| Max | 9.21 | 9.23 | 10.98 | 11.02 | 8.66 | 9.32 |
| Range | 2.90 | 5.87 | 3.31 | 3.24 | 3.12 | 3.40 |
| Large overjet (Overjet = 6–7 mm) | | | | | | |
| Mean | 7.83 | 6.97 | 8.85 | 8.87 | 6.89 | 7.80 |
| Median | 7.82 | 6.93 | 8.81 | 8.95 | 6.84 | 7.81 |
| SD | 0.45 | 0.57 | 0.54 | 0.57 | 0.54 | 0.49 |
| Min | 6.72 | 5.43 | 7.57 | 7.38 | 5.93 | 6.60 |
| Max | 8.91 | 8.30 | 10.12 | 10.05 | 8.24 | 8.95 |
| Range | 2.19 | 2.87 | 2.55 | 2.67 | 2.31 | 2.35 |
| Negative overjet (Overjet < 0 mm) | | | | | | |
| Mean | 7.37 | 6.46 | 8.39 | 8.36 | 6.44 | 7.30 |
| Median | 7.38 | 6.50 | 8.52 | 8.33 | 6.23 | 7.39 |
| SD | 0.36 | 0.77 | 0.71 | 0.71 | 0.76 | 0.68 |
| Min | 6.47 | 4.89 | 7.15 | 7.07 | 5.12 | 5.57 |
| Max | 7.87 | 7.85 | 9.65 | 9.62 | 8.17 | 8.23 |
| Range | 1.40 | 2.96 | 2.50 | 2.55 | 3.05 | 2.66 |
| $p^1$ (normal occlusion vs. extreme overjet) | | | .029* | .037* | | |
| $p^2$ (normal occlusion vs. large overjet) | | .044* | .031* | .004* | | |
| $p^3$ (normal occlusion vs. negative overjet) | .007* | | | | | |
| $p^4$ (extreme overjet vs. negative overjet) | .001* | | .050* | .057 | | .073 |
| $p^5$ (large overjet vs. negative overjet) | .001* | | | .060 | | .049* |

*$p < .05$.

**Table 3.** Mean values (mm) and distribution of mandibular teeth in the normal occlusion and the overjet groups.

| | Mandibular left | | | Mandibular right | | |
|---|---|---|---|---|---|---|
| | Canine | Lateral incisor | Central incisor | Central incisor | Lateral incisor | Canine |
| Normal occlusion | | | | | | |
| Mean | 6.74 | 5.97 | 5.41 | 5.42 | 5.94 | 6.71 |
| Median | 6.76 | 5.95 | 5.40 | 5.42 | 5.91 | 6.71 |
| SD | 0.51 | 0.38 | 0.39 | 0.38 | 0.39 | 0.48 |
| Min | 5.27 | 5.08 | 4.41 | 4.59 | 4.76 | 5.64 |
| Max | 8.14 | 6.95 | 6.59 | 6.41 | 7.04 | 8.14 |
| Range | 2.87 | 1.87 | 2.18 | 1.82 | 2.28 | 2.50 |
| Extreme overjet (Overjet $\geq$ 8 mm) | | | | | | |
| Mean | 6.80 | 6.13 | 5.44 | 5.44 | 6.02 | 6.72 |
| Median | 6.76 | 6.03 | 5.42 | 5.41 | 5.96 | 6.73 |
| SD | 0.53 | 0.60 | 0.40 | 0.38 | 0.46 | 0.49 |
| Min | 5.78 | 5.32 | 4.71 | 4.48 | 5.26 | 5.15 |
| Max | 7.91 | 8.92 | 6.46 | 6.32 | 7.40 | 7.57 |
| Range | 2.13 | 3.60 | 1.75 | 1.84 | 2.14 | 2.42 |
| Large overjet (Overjet = 6–7 mm) | | | | | | |
| Mean | 6.97 | 6.08 | 5.40 | 5.44 | 6.02 | 6.82 |
| Median | 6.97 | 6.14 | 5.43 | 5.45 | 5.99 | 6.81 |
| SD | 0.46 | 0.45 | 0.43 | 0.40 | 0.43 | 0.49 |
| Min | 6.06 | 4.54 | 4.04 | 4.29 | 4.97 | 5.59 |
| Max | 8.24 | 7.44 | 6.35 | 6.23 | 7.06 | 8.24 |
| Range | 2.18 | 2.90 | 2.31 | 1.94 | 2.09 | 2.65 |
| Negative overjet (Overjet < 0 mm) | | | | | | |
| Mean | 6.70 | 5.81 | 5.15 | 5.18 | 5.87 | 6.73 |
| Median | 6.71 | 5.73 | 5.10 | 5.09 | 5.74 | 6.79 |
| SD | 0.48 | 0.57 | 0.57 | 0.52 | 0.60 | 0.55 |
| Min | 5.94 | 4.64 | 3.88 | 4.41 | 5.24 | 5.57 |
| Max | 7.56 | 7.15 | 6.36 | 6.20 | 7.21 | 7.68 |
| Range | 1.62 | 2.51 | 2.48 | 1.79 | 1.97 | 2.11 |
| $p^1$ (normal occlusion vs. large overjet) | .003* | | | | | |

*$p < .05$.

(77.2), the anterior Bolton ratio in a Finnish population sample was larger but still within 2 SD. The anterior Bolton ratio was relatively similar to the previous findings in Swedish, British and Polish populations [9,23,24]. Overall, the majority of studies in different populations have reported larger anterior ratios in subjects with normal occlusion compared to the original anterior ratio presented by Bolton [1,8,18].

Only limited amount of research has been conducted to study the relationship between Bolton ratio and overjet. The present study is in line with Alam and Iida [18], who found statistically significant differences for the overall ratios in groups with normal, increased and decreased overjet. These results reflect those of the studies concerning molar relationships, which have found associations between deviations from Bolton ratio and Angle Class II and Class III malocclusions [3,8]. Taken together, the findings have followed the same order: smaller Bolton ratios are more common in individuals with increased overjet/Class II malocclusion and vice versa. Conversely, some researchers have not found any difference in Bolton ratios between malocclusion groups [10–16].

The results of this study suggest that overjet deviations partly result from variations of teeth width, in particular maxillary anterior teeth widths. The most common sporadic teeth size disharmony is peg-shaped lateral incisor [25]. In the present study, a larger variation of the maxillary right lateral incisor mesiodistal width was found, matching the existence of peg-shaped lateral incisors. It has been suggested that maxillary mesiodistal lateral incisor tooth size is smaller in Angle Class III population, and that partly explains the anterior Bolton tooth size discrepancy [2]. The widths of lower incisors did not differ between the overjet groups, which highlights the importance to evaluate specifically the maxillary incisor and canine widths in clinical practice.

The general goals of orthodontic treatment are a good molar relationship, a good interdigitation, and a normal overjet and overbite. However, tooth size discrepancies or problematic tooth anatomy make it challenging for clinicians to achieve optimal overjet simultaneously with acceptable intercuspation. Wedrychowska-Szulc et al. [8] concluded that Bolton ratios should be calculated in all orthodontic patients, especially in males with a Class II malocclusion. In other European populations, the most common orthodontic problem in molar relationships is Angle II [26–28]. In this study, 'extreme' and 'large' overjet groups represent possible Angle II relationship in Finnish population. The total number of subjects in these groups was manifold compared to the negative overjet group.

The strength of this study is that the sample consists of subjects of a large cohort which represents a normal Finnish middle-aged population. The inter-examiner agreement of six calibrated dentists was tested constantly during the clinical examination against a golden standard senior dentist. We chose to evaluate correlation between Bolton ratio and deviations of overjet instead of Angle classification. Although molar relationship generally reflects deviations in overjet, in cases with tooth size discrepancy these two are not always related. Bolton analysis evaluation in 3D virtual models has previously been found to have equal or better reliability compared with dental casts [29,30]. DHC of the IOTN was selected to sort the subjects for the normal occlusion group, as it is a widely used index and has been shown to be valid and reliable [22]. As DHC score of 1 is extremely exceptional, the threshold of DHC score 2 or less was chosen as inclusion criterion for the normal occlusion group, in addition to defined clinically measured occlusion traits.

The limitation of this study was that previous dental treatment may have had an influence on mesiodistal widths of teeth in the adult population. The subjects with missing teeth from lateral premolar to lateral premolar were excluded as the subjects with missing premolars may had had camouflage treatment. In addition, the subjects with orthodontic treatment history were excluded from the study. The small sample size in the negative overjet group results from the low prevalence of Class III malocclusion in Finnish population. With larger sample size, the association between anterior Bolton ratio and negative overjet could have reached statistical significance. Tooth size discrepancies between males and females were not tested in the overjet groups as the sample size was small in the negative overjet group. As Bolton analyses were performed by four examiners, the examiners were trained before measurements to minimize the inter-examiner error. Intra-examiner correlation was slightly lower than inter-examiner correlation which may be explained by the timing of the repeated measurements: the intra-examiner correlation was calculated before measurements and additional training was done before inter-examiner comparison.

Because there is variation in 'ideal' Bolton ratios in different studies and populations, the Bolton ratio should be used more as a support for clinical treatment plan to estimate the need of approximal grinding or prosthetic restoration. Acceptable skeletal relationship between maxilla and mandible with larger or smaller teeth may lead to malocclusion. Based on the results of this study, especially the maxillary anterior tooth size should be taken into consideration in orthodontic and prosthetic treatment planning. As intraoral cameras are becoming more common and software is continuously evolving, the use of the anterior Bolton ratio will become easier and is likely to become a common diagnostic method in the future.

## Conclusion

- The mean anterior Bolton ratio in Finnish adults with normal occlusion was larger compared to the original Bolton ratio.
- Tooth size discrepancy between upper and lower anterior teeth was related to overjet, especially in subjects with extreme and negative overjet.
- Widths of the maxillary anterior teeth differed between overjet groups

## Disclosure statement

No potential conflict of interest was reported by the author(s).

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