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ORIGINAL ARTICLE

Growth curves for mandibular range of motion and maximum voluntary bite force in healthy children

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Abstract

Mandibular range of motion and bite force are indispensable variables for the evaluation of mandibular function. There are a variety of medical and dental conditions that can negatively affect mandibular function. Values for mandibular range of motion (i.e., active and passive maximum interincisal mouth opening, protrusion, and laterotrusion) and anterior maximum voluntary bite force (AMVBF) in healthy children and adolescents can help in recognizing temporomandibular dysfunction. In this longitudinal study, 169 healthy children aged 6–18 years were included. They were examined at four time points over 1 year. Mixed model analysis was performed to produce growth curves of mandibular range of motion and AMVBF. Average active maximum interincisal mouth opening was significantly higher in boys with 50.0 mm compared to 47.8 mm in girls. Boys also had a significantly higher AMVBF than girls with an average of 169.0 N versus 140.0 N, respectively. Growth curves of active and passive maximum interincisal mouth opening showed an increase with age, albeit levelling off through puberty. The growth curves of AMVBF in girls reach a plateau phase at ages 12–14 years, after which the curve descends; in boys, the AMVBF tended to increase up to 18 years of age, although a slow-down after 14 years of age was noted.

KEYWORDS
growth, juvenile idiopathic arthritis, mastication, mouth, temporomandibular joint

INTRODUCTION

Mandibular function in children, adolescents, and adults can be affected by a variety of specific medical and dental conditions that impact the temporomandibular joints (TMJs) and/or the masticatory muscles. There are several (medical) conditions that can compromise the mandibular range of motion, the bite force, and therefore also the chewing performance [1–5]. A clinically relevant reduction of the mandibular function in terms of mouth opening and bite force was found in Duchenne muscular dystrophy and spinal muscular atrophy [6, 7]. Juvenile idiopathic arthritis is a rheumatic disease with a potentially negative influence on the masticatory system as well [8]. The TMJs can become inflamed, and as a result pain and dysfunction may develop and eventually mandibular growth disturbances can occur [9–11].

Mandibular range of motion outcomes are paramount in the clinical examination of the masticatory system [9, 11, 12]. Several studies show the value of bite force measurements in the assessment of mandibular function [5, 13–16]. Values of range of motion and bite force and their change over time in healthy young children and adolescents might be helpful in the recognition of potential temporomandibular sequelae due to medical and dental conditions [16–22]. In order to appraise these outcome measures in clinical patients, data from non-patient groups of children and adolescents are mandatory. The aim of this study was to construct growth curves based on longitudinal data in healthy children aged 6–18 years (boys and girls) for (i) active maximum interincisal mouth opening (AMIO) and passive maximum interincisal mouth opening (PMIO), (ii) protrusion, (iii) left and right laterotrusion, and (iv) anterior maximum voluntary bite force (AMVBF) [23].

MATERIAL AND METHODS

The study protocol (study ID: NL.METC-17-531/C) was approved by the Ethics Committees of the University Medical Center Utrecht, The Netherlands. This study was carried out between February 2018 and August 2020. Four elementary schools and one high school in the Netherlands were visited. Each school class was visited by experienced examiners (MS, DV, WdS), a short informative presentation was given, and hardcopy information was handed out to the school children. All participants and their parents and/or guardians received written information and provided their oral and signed informed consent. The inclusion criteria for participation were (i) age ≥6 years and ≤18 years at first examination, and (ii) TMJ screening protocol score ≤1 [11]. The exclusion criteria were (i) a history of mandibular trauma, (ii) TMJ screening protocol score >1 (n = 13), (iii) diagnosed with temporomandibular disorder and/or received previous TMJ treatment (such as physical therapy, occlusal splints, intra-articular injections, or maxillofacial surgery), and (iv) incisal dental restoration or non-erupted incisors. The measurements were conducted at the participating schools. The clinical examination took approximately 15 min per individual. The assessments included (i) height and weight, (ii) mandibular range of motion, and (iii) AMVBF. The measurements were conducted at four time points ($T_{1–4}$) over a year. The first three measurements T_1, T_2, and T_3 were carried out every second week. These short time intervals were chosen to enable analysis of reliability of mandibular range of motion and AMVBF measurements, which will be published in an additional paper. The fourth measurement T_4 was carried out 1 year later, allowing for mandibular range of motion and AMVBF growth analysis. Data collection was performed using the good clinical practice compliant electronic data capture system Research Online owned by the Julius Center (UMC Utrecht).

Height and weight

Both height and weight were measured without shoes or heavy clothing to the nearest centimetre and kilogram up to one decimal. Height and weight measurements took place at T_1 and T_4.

Mandibular range of motion

The mandibular range of motion included the measurement of AMIO, PMIO, protrusion, and left and right laterotrusion, followed by measuring the overjet and overbite. Mandibular range of motion measurements were recorded with a metal ruler to the nearest millimetre. The children were encouraged to open their mouth as wide as possible. The PMIO was assessed through the application of gentle stretch by the examiner, with the index finger and thumb on the incisal edges of the upper and lower incisors at the end of the active opening movement to increase the mouth opening. The active and passive maximum interincisal mouth openings were measured between the incisal edges of the upper and lower central incisors.

Protrusion was assessed by requesting the participants to protrude the mandible as far anteriorly as possible. The horizontal distance between the incisal edges of the upper central incisor and the lower central incisor was recorded with a ruler. Adding the overjet to this value produced the range of motion for protrusion.

When measuring left and right laterotrusion, the dental midlines were used as reference points. In case of a midline shift in the intercuspal position, a correction was carried out for the size of this shift (in millimetres) and its direction. The difference between left and right laterotrusion is reported as discrepancy. The overjet and overbite were documented separately; overbite was not included in the assessment of mouth opening.

Anterior maximum voluntary bite force

The AMVBF was measured using a bite force transducer, based on the bite force transducer from the Amsterdam University Medical Center, as further developed by the University Medical Center Utrecht [24]. The bite force gauge is a handheld device with a load cell to measure AMVBF, with a range between 0 and 490 Newton (N) in linear fashion. The device consists of a strain gauge mounted on a mouthpiece of 10 × 15 mm and a thickness of 12 mm. A plastic foil was applied around the mouthpiece for each child to guarantee hygiene. The mouthpiece was placed between the upper and lower central incisors. The bite force measurement consists of clenching, as hard as possible for ten seconds. Three attempts were documented. In between the three attempts, the children themselves indicated when they were ready for the next attempt. All participants were instructed and encouraged in a similar way through a taped voice recording. The highest bite force of the three attempts was defined as the AMVBF.

Statistical analysis

Characteristics of the children at inclusion are presented as numbers and percentages for categorical variables and means and standard deviations for continuous variables. Normality was assessed with plotting graphs (histograms and Q-Q plots). Mixed models were used to model the effect of age and height on AMVBF, AMIO, and PMIO at T_1 to T_4 for boys and girls separately. Age and height were analysed separately, as these variables showed a high degree of collinearity, with a Spearman correlation of 0.90, suggesting the explanatory impact is very similar. As curves of these outcomes for increasing age may level off, we also included age^2 and height^2. We incorporated a random intercept as well as random effects of age/height and (where applicable) a random effect for age^2/height^2. Inclusion of squared terms was based on likelihood ratio (LR) tests for boys and girls. When a squared term was significant, it was incorporated in the analysis for both boys and girls. Results were presented as regression coefficients and estimated values of outcomes by age and height (Table S1 in the Supporting Information). Predicted values were subsequently plotted against age and height with 95% confidence and prediction intervals. As age is more commonly used as the control variable, we present mandibular range of motion and AMVBF growth curves by age. Associations of outcomes by height are presented in Figure S1. A *p*-value of 0.05 or less was accepted as indicating statistical significance. Statistical analyses were performed using SPSS 26 (IBM) and SAS v9.4 software (SAS Institute).

Sample size calculation

Data on the association between bite force and age are scarce. We based our sample size estimation on a correlation between age and bite force in healthy children of 0.36 or higher, and alpha of 0.05 and power of 0.80. This results in a sample size of at least 46 children. We included at least 10 children per year class (total of 100 children) to accommodate enough girls and boys for separate analyses with sufficient power. This sample size will provide sufficient statistical power to detect an intraclass correlation (ICC) of 0.275 or higher for the measurement reliability analysis, where an ICC of at least 0.70 is expected. Sample size calculations were performed with SAS v9.4 software (SAS Institute), while the statistical power for intraclass coefficients was estimated in R (The R Project for Statistical Computing) using the ICC.Sample.Size package.

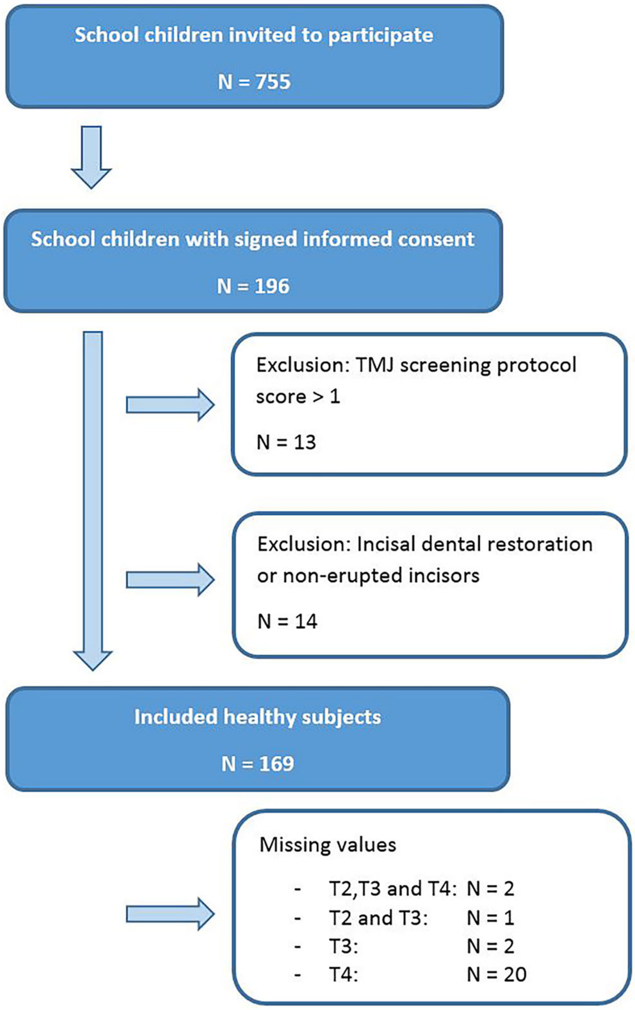

FIGURE 1 Flow chart of the selection process for included subjects. The missing values were attributable to children not being present on the day of our visit ($n = 17$) and/or them having switched schools ($n = 8$)

RESULTS

A total of 169 healthy children participated in this study and 88 (52.1%) were boys. A flow chart of the selection process is presented in Figure 1. Boys had a mean age of 11.6 years; girls had a mean age of 11.3 years. There were 17 subjects with dental braces (10.1%) with a mean age of 13.8 years. The demographic characteristics of the participants are presented in Table 1 along with the mean mandibular range of motion

TABLE 1 Clinical characteristics, mandibular range of motion, and anterior maximum voluntary bite force in children aged 6–18 years (T_1)

	Boys (*n* = 88) Mean (SD)	Girls (*n* = 81) Mean (SD)	Total (*n* = 169) Mean (SD)
Age (years)	11.6 (3.5)	11.3 (3.6)	11.5 (3.5)
Weight (kg)	47.2 (17.1)	46.5 (17.5)	46.9 (17.3)
Height (cm)	155.5 (21.7)	150.1 (19.8)	153.0 (20.9)
AMIO (mm)	50.0 (6.3)	47.8 (5.7)	49.0 (6.1)
PMIO (mm)	51.2 (6.4)	49.5 (5.5)	50.4 (6.1)
Protrusion (mm)	8.7 (2.0)	8.3 (2.2)	8.5 (2.1)
Laterotrusion left (mm)	9.6 (1.5)	9.8 (1.7)	9.7 (1.6)
Laterotrusion right (mm)	9.7 (1.6)	9.8 (1.7)	9.7 (1.6)
Discrepancy (mm)	0.2 (0.4)	0.3 (0.6)	0.3 (0.5)
Overbite (mm)	2.2 (1.7)	2.3 (1.2)	2.3 (1.5)
Overjet (mm)	3.0 (1.5)	2.9 (1.3)	2.9 (1.4)
AMVBF (N)	169.0 (75.2)	140.0 (56.9)	155.0 (68.7)

Abbreviations: AMIO, active maximum interincisal mouth opening; AMVBF, anterior maximum voluntary bite force; N, Newton; PMIO, passive maximum interincisal mouth opening; SD, standard deviation; Discrepancy, the difference between left and right laterotrusion.

and AMVBF values recorded at the first time point (T_1).

AMVBF, protrusion, AMIO, and PMIO showed a non-linear flattening curvilinear relationship with age. For these outcomes, therefore, we included age^2 in the models. Similarly, a non-linear flattening curvilinear relationship with height was found for AMVBF. For this outcome, therefore, we included height^2 in the models. LR tests showed a significant model improvement for these outcomes (Table S1).

Estimated values for AMIO, PMIO, protrusion, laterotrusion, and AMVBF by gender and age are presented in Table 2. The mean AMIO for 6-year-olds was 45.0 mm for boys and 42.8 mm for girls. At age 18 years the mean AMIO was 55.3 mm and 50.5 mm for boys and girls, respectively. Laterotrusion (left) was 9.2 mm for boys and 9.1 mm for girls at the age of 6 years, and increased to 10.4 mm for boys, and 10.3 mm for girls, at the age of 18 years. The mean AMVBF of 6-year-old was 100.3 N for boys, and 85.0 N for girls. At age 18 years, the mean AMVBF was 227.5 N and 142.0 N for boys and girls, respectively. The growth curves of AMIO, PMIO, protrusion, left and right laterotrusion, and AMVBF by age for boys and girls are presented in Figures 2 and 3.

DISCUSSION

In this study, growth curves for mandibular range of motion and AMVBF were constructed for healthy children aged 6–18 years. For boys, an increase of these curves with age and height was found for AMIO, PMIO, laterotrusion, and AMVBF. Protrusion exhibited a minor decrease after the age of 13 years for boys. In girls, an increase in the growth curves with age and height was found for AMIO, PMIO, protrusion, and laterotrusion. The growth curve for AMVBF in girls reached a plateau phase at the age of 12–14 years, after which the curve descends. In boys, AMVBF increased up to 18 years of age, although the curve ascended more slowly after 14 years of age. The ascending growth curves of AMIO and PMIO by age in girls descended through puberty, while growth curves of boys ascended in a linear trend.

The mandibular range of motion values found here are in line with results reported in the literature [18, 19, 25]. However, the AMIO values reported by Patel et al. [17], 43.5 mm for girls and 44.2 mm for boys, are lower than those values found in our study, 47.8 mm for girls and 50.0 mm for boys. This difference can plausibly be attributed to ethnical differences between included subjects (Caucasian vs. Indian). On average, the Indian population is smaller in height than our Dutch study population [26]. This implies smaller skulls and shorter mandibles, and as a result, smaller mouth openings [27]. In most studies reporting on mouth opening, the results presented regard active mouth opening. In addition to this data, we measured passive mouth opening. Increased or decreased differences between these two variables can differentiate between myogenic or arthrogenic temporomandibular aetiologies [28, 29]. In our studied groups, we found less than 2 mm difference between AMIO and PMIO values. These small differences indicate normal temporomandibular function [29]. A PMIO ≥3 mm higher than AMIO may indicate a possible temporomandibular disorder [30].

The mandibular range of motion values, protrusion and laterotrusion, did not differ between boys and girls. In comparison with the growth of AMIO between ages 6 and 18 years (43.6–54.6 mm), only slight increases in laterotrusion

TABLE 2 Estimated mean AMIO, PMIO, protrusion, laterotrusion, and AMVBF with 95% confidence intervals in children aged 6–18 years ($T_{1–4}$)

Age (years)	6	7	8	9	10	11	12
Boys	***n* = 9**[a] **Mean (CI)**	***n* = 31** **Mean (CI)**	***n* = 29** **Mean (CI)**	***n* = 39** **Mean (CI)**	***n* = 28** **Mean (CI)**	***n* = 25** **Mean (CI)**	***n* = 25** **Mean (CI)**
AMIO (mm)	45.0 (42.0–48.0)	46.0 (43.7–48.2)	46.9 (45.1–48.6)	47.8 (46.4–49.3)	48.7 (47.4–50.0)	49.6 (48.3–50.9)	50.4 (49.2–51.7)
PMIO (mm)	46.9 (43.8–50.0)	47.7 (45.3–50.1)	48.5 (46.6–50.3)	49.3 (47.7–50.8)	50.1 (48.7–51.4)	50.8 (49.5–52.2)	51.7 (50.4–52.9)
Protrusion (mm)	7.5 (6.5–8.6)	8.0 (7.2–8.8)	8.4 (7.8–9.0)	8.8 (8.3–9.2)	9.0 (8.6–9.5)	9.2 (8.8–9.7)	9.4 (8.9–9.8)
Laterotrusion left (mm)	9.2 (8.6–9.8)	9.3 (8.8–9.8)	9.4 (9.0–9.9)	9.5 (9.1–9.9)	9.6 (9.3–9.9)	9.7 (9.4–10.0)	9.8 (9.5–10.1)
Laterotrusion right (mm)	9.1 (8.4–9.7)	9.2 (8.6–9.7)	9.3 (8.8–9.8)	9.4 (9.0–9.8)	9.6 (9.2–9.9)	9.7 (9.4–10.0)	9.8 (9.5–10.1)
AMVBF (N)	100.3 (62.7–137.8	116.5 (88.5–144.4)	131.7 (110.7–152.6)	145.8 (129.1–162.5)	158.9 (143.8–174.1)	171.1 (156.1–186.1)	182.2 (167.0–197.4)
Girls	***n* = 16** **Mean (CI)**	***n* = 47** **Mean (CI)**	***n* = 18** **Mean (CI)**	***n* = 26** **Mean (CI)**	***n* = 39** **Mean (CI)**	***n* = 22** **Mean (CI)**	***n* = 12** **Mean (CI)**
AMIO (mm)	42.8 (40.2–45.4)	44.2 (42.3–46.2)	45.5 (44.0–47.1)	46.7 (45.3–48.0)	47.7 (46.4–49.0)	48.5 (47.2–49.8)	49.2 (47.9–50.6)
PMIO (mm)	45.4 (42.8–48.0)	46.4 (44.4–48.5)	47.4 (45.8–49.1)	48.3 (46.9–49.7)	49.1 (47.8–50.4)	49.8 (48.5–51.1)	50.5 (49.2–51.8)
Protrusion (mm)	7.7 (6.7–8.6)	7.9 (7.2–8.6)	8.1 (7.6–8.6)	8.3 (7.8–8.8)	8.4 (7.9–8.9)	8.5 (8.0–9.1)	8.6 (8.1–9.2)
Laterotrusion left (mm)	9.1 (8.5–9.6)	9.2 8.7–9.7)	9.3 8.9–9.7)	9.4 9.0–9.8)	9.5 9.2–9.8)	9.6 9.3–9.9)	9.7 (9.4–10.0)
Laterotrusion right (mm)	9.0 (8.4–9.6)	9.1 (8.6–9.6)	9.3 (8.8–9.7)	9.4 (9.0–9.8)	9.5 (9.2–9.8)	9.6 (9.3–9.9)	9.8 (9.5–10.1)
AMVBF (N)	85.0 (57.4–112.5)	106.4 (85.9–126.8)	124.7 (108.8–140.7)	140.1 (126.0–154.2)	152.4 (138.3–166.6)	161.7 (147.1–176.3)	168.0 (153.2–182.7)

Age (years)	13	14	15	16	17	18
Boys	***n* = 29** **Mean (CI)**	***n* = 36** **Mean (CI)**	***n* = 28** **Mean (CI)**	***n* = 23** **Mean (CI)**	***n* = 22** **Mean (CI)**	***n* = 15** **Mean (CI)**
AMIO (mm)	51.3 (50.0–52.6)	52.1 (50.8–53.5)	52.9 (51.4–54.4)	53.7 (51.9–55.6)	54.5 (52.2–56.9)	55.3 (52.2–58.4)
PMIO (mm)	52.5 (51.1–53.8)	53.3 (51.9–54.7)	54.1 (52.5–55.7)	54.9 (53.0–56.9)	55.8 (53.3–58.2)	56.6 (53.4–59.8)
Protrusion (mm)	9.4 (9.0–9.9)	9.4 (9.0–9.9)	9.4 (8.9–9.9)	9.3 (8.6–9.8)	9.0 (8.2–9.8)	8.8 (7.7–9.9)
Laterotrusion left (mm)	9.9 (9.6–10.2)	10.0 (9.7–10.3)	10.1 (9.7–10.5)	10.2 (9.7–10.6)	10.3 (9.8–10.8)	10.4 (9.8–11.0)
Laterotrusion right (mm)	9.9 (9.6–10.2)	10.0 (9.7–10.4)	10.1 (9.7–10.6)	10.3 (9.8–10.7)	10.4 (9.8–10.9)	10.5 (9.9–11.1)
AMVBF (N)	192.3 (177.0–207.6)	201.3 (185.7–217.0)	209.4 (192.1–226.7)	216.4 (195.0–237.9)	222.5 (194.1–250.8)	227.5 (189.6–265.3)
Girls	***n* = 8** **Mean (CI)**	***n* = 32** **Mean (CI)**	***n* = 34** **Mean (CI)**	***n* = 25** **Mean (CI)**	***n* = 23** **Mean (CI)**	***n* = 4** **Mean (CI)**
AMIO (mm)	49.8 (48.5–51.1)	50.2 (48.9–51.6)	50.5 (49.1–52.0)	50.7 (48.9–52.5)	50.7 (48.4–53.0)	50.5 (47.5–53.6)
PMIO (mm)	51.0 (49.7–52.3)	51.5 (50.1–52.9)	51.9 (50.4–53.4)	52.2 (50.4–54.1)	52.5 (50.1–54.8)	52.6 (49.6–55.7)

(Continues)

TABLE 2 (Continued)

Girls	*n* = 8 Mean (CI)	*n* = 32 Mean (CI)	*n* = 34 Mean (CI)	*n* = 25 Mean (CI)	*n* = 23 Mean (CI)	*n* = 4 Mean (CI)
Protrusion (mm)	8.7 (8.2–9.2)	8.8 (8.3–9.2)	8.8 (8.3–9.3)	8.7 (8.1–9.4)	8.7 (7.9–9.6)	8.6 (7.5–9.8)
Laterotrusion left (mm)	9.8 (9.5–10.1)	9.9 (9.5–10.3)	10.0 (9.6–10.4)	10.1 (9.7–10.6)	10.2 (9.7–10.8)	10.3 (9.7–11.0)
Laterotrusion right (mm)	9.9 (9.6–10.2)	10.0 (9.7–10.4)	10.1 (9.7–10.5)	10.3 (9.8–10.7)	10.4 (9.8–10.9)	10.5 (9.9–11.1)
AMVBF (N)	171.2 (156.7–185.7)	171.4 (157.1–185.7)	168.6 (153.3–183.9)	162.7 (144.1–181.4)	153.9 (129.1–178.6)	142.0 (108.8–175.2)

Abbreviations: AMIO, active maximum interincisal opening; AMVBF, anterior maximum voluntary bite force; N, Newton; PMIO, passive maximum interincisal opening; CI, 95% confidence interval.

[a]Number represents the number of observations, each participating child was measured four times ($T_{1–4}$). The total accumulated *n* in Table 2, therefore, exceeds 169 included children. Missing values on individual measurements are not represented in this table.

(8.9–10.5 mm) and protrusion (7.5–8.7 mm) were found. Two different studies reported small differences between left and right laterotrusion (10.2 mm vs. 10.6 mm and 11.5 mm vs. 12.1 mm) [19, 31]. In the present study no laterotrusion discrepancy was found (9.7 mm vs. 9.7 mm).

Clinical evaluation of the masticatory system in children usually does not include bite force measurements. However, multiple studies have stressed the role of bite force as an indicator for masticatory function [4, 32–34]. Bite force measurements are typically performed in the molar and incisor region (AMVBF). The authors of this study deliberately chose to measure anterior bite force instead of molar bite force. Measuring bite force in the incisal region loads the temporomandibular system symmetrically. Molar bite force measurement (left or right) leads to an asymmetric loading of the masticatory system, with less reliable outcomes. Secondly, placing a mouthpiece between the molar teeth requires a wider gape thus stretching the chewing muscles more extensively compared to placement of the mouthpiece between the incisor teeth, especially in younger children [16]. Moreover, higher reliability for interincisal bite force assessment when compared to molar bite force has been reported [13].

In our group of healthy children, AMVBF increased with age and height and was significantly higher in boys than in girls. These gender and age differences are in accordance with the results of multiple other studies that have reported on this topic [5, 16, 34, 35]. Interestingly, the pattern of growth of AMVBF is different for boys and girls. Mild flattening of the AMVBF growth curve is visible for boys through their late teens. In comparison, the growth curve for girls shows a plateau phase reached at age 12–14 years, after which a slight decrease of AMVBF is noted. Several other studies have also reported girls reaching a plateau phase or slight decrease of maximum bite force around 15 years of age [16, 36–38]. In these studies, no explanations for the decrease of AMVBF in older girls were given. However, in a study of handgrip strength, a similar finding was reported. A possible explanation is the difference between chronological age and biological age. In particular, during the adolescent growth spurt the variability in somatic and biological maturity is large in children with the same chronological age [39]. In the study measuring hand grip strength, the biological age seems to be more correlated with grip strength changes than chronological age; a stronger flattening of the curve for hand grip strength in girls was found for chronological age as compared to this curve for biological age [40]. Hormonal changes (i.e., puberty and/or the use of oral contraceptives) are also more influential for biological age than chronological age [41, 42]. Interestingly, another study of grip strength in Dutch children also noted a decrease of the grip strength curve of girls weighing 65 kg or more. The authors state that overweight and obesity might negatively affect grip strength, as long as the weight increase is not correlated with an increase of age or height [43]. Our AMVBF curve by weight showed a similar pattern (Figure S2). Overall, our data show that higher age, height, and weight are associated with a decrease of AMVBF in girls. Another possible explanation for the decrease of AMVBF in girls older than 14 years could be due to sampling bias, that is, too few participants in certain female age groups resulting in higher overall standard deviation (Table 2). In future studies it is advised to include more girls (in all age groups) and to create new AMVBF growth curves. If these curves show similar trends, this would strengthen the present findings. Additionally, since we did not include participants older than 18 years, it is unclear how long AMVBF growth continues in boys. In upcoming studies, it is also advised to expand the age group to the early and mid-twenties to get more insight into the timing of the plateau phase for AMVBF in boys.

Population-based data may be helpful for the medical and dental professional in early recognition of potential temporomandibular sequelae in children and adolescents. Maximum mouth opening has already proven to be a strong indicator

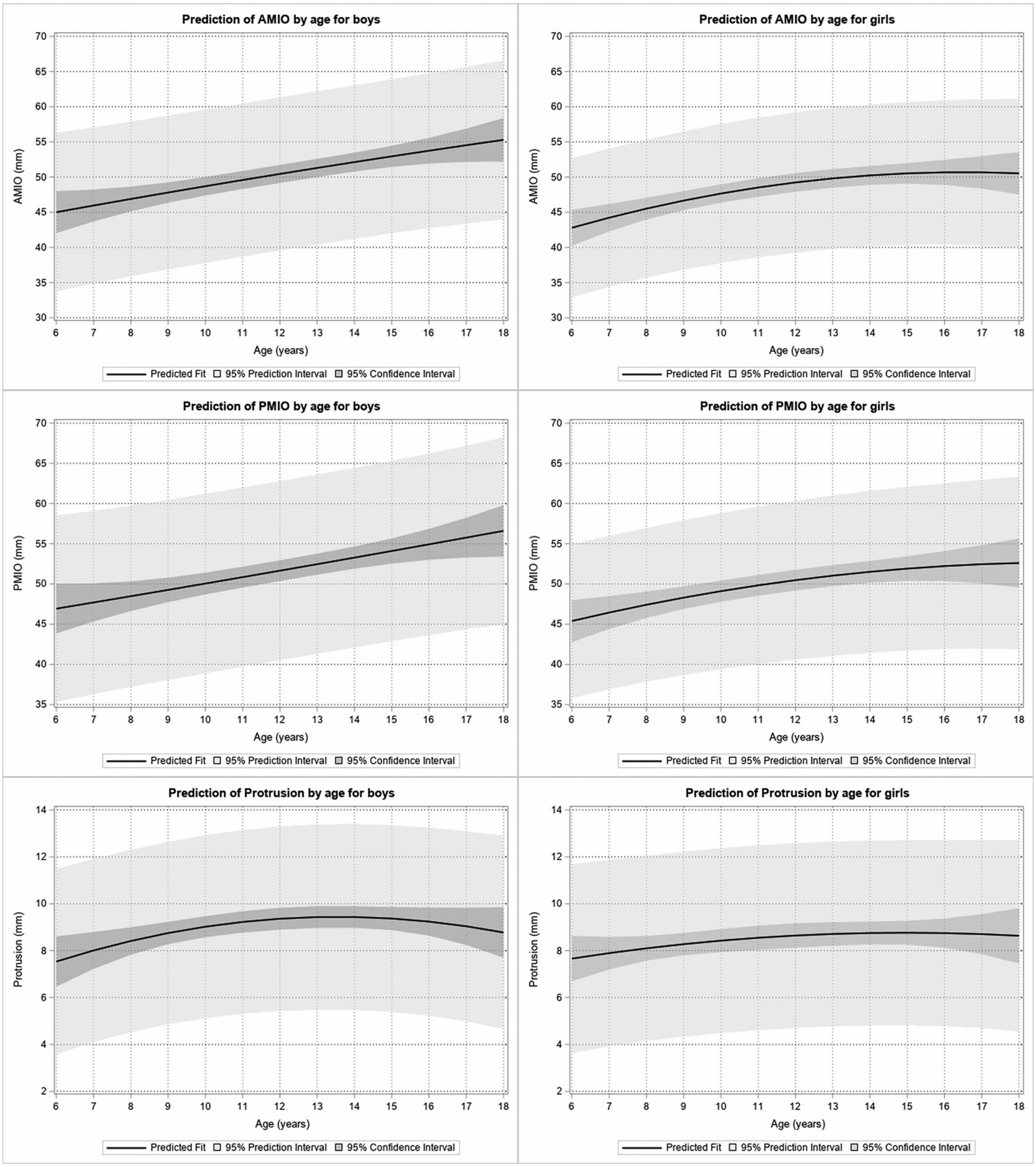

FIGURE 2 Growth curves for AMIO, PMIO, and protrusion by age for boys and girls. The growth curves (predicted fit) show 95% prediction and 95% confidence intervals for AMIO, PMIO, and protrusion in boys and girls. AMIO, active maximum interincisal mouth opening; PMIO, passive maximum interincisal mouth opening

for evaluation of mandibular function in a clinical setting [21, 44–47]. Children with equal age show a wide range of maximum interincisal mouth opening values [18]. Therefore, it is the authors' opinion that changes over time of these values, and differences between assisted and unassisted mouth opening, in individual children are clinically more relevant than comparing absolute values with age class group means. Children with underlying disorders possibly affecting the TMJs, such as juvenile idiopathic arthritis, more often have deviating differences between AMIO and PMIO [29, 48]. Additionally, measuring AMIO opening is quick and easy for medical doctors without expertise in the orofacial area.

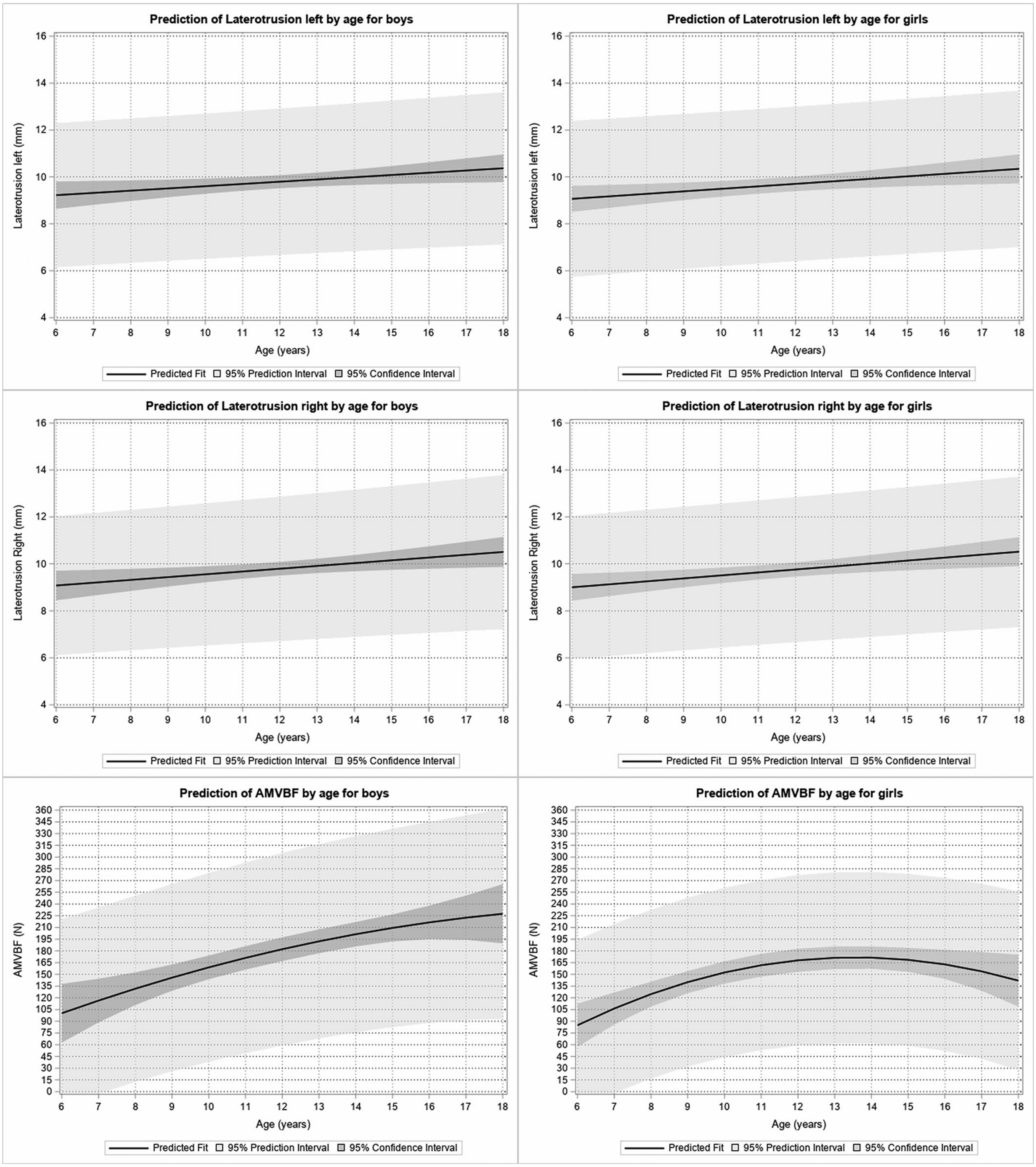

FIGURE 3 Growth curves for left and right laterotrusion and AMVBF by age for boys and girls. The growth curves (predicted fit) show 95% prediction and 95% confidence intervals for left and right laterotrusion and AMVBF in boys and girls. AMVBF, anterior maximum voluntary bite force; N, Newton

Healthcare professionals treating children for conditions that could possibly also affect the masticatory system are advised to measure AMIO during routine check-ups. This means that a healthcare professional could play an important role fulfilling the signalling role of early recognition of potential temporomandibular conditions, by measuring AMIO during routine (dental) checks in growing children. Protrusion and laterotrusion measurements are more difficult to carry out for non-dental/oral health care professionals, and hence more time consuming and less reliable. Additionally, younger children may also find the execution of laterotrusion and protrusion difficult, resulting in missing values [49]. In our cohort 16 missing values were noted for laterotrusion and two missing values for protrusion, in a total of 649 measurements (T_1–T_4).

In two previously published papers it has been suggested that documenting 'sudden' changes over time in AMIO, and possibly in AMVBF, can help to recognize potential temporomandibular conditions, such as temporomandibular involvement in juvenile idiopathic arthritis [11, 48]. For AMIO this might be appropriate, while the growth curve for AMVBF in girls is not supportive of this train of thought. This underpins the need for regular AMIO (and AMVBF) measurements. If these values are not available, our growth curves and the prediction intervals in healthy children aged 6–18 years offer such information.

Most studies on the topic of mandibular range of motion and bite force in children are cross-sectional or retrospective in character, and measure subjects at only one point in time [17, 18, 20, 50]. The longitudinal aspect of this study strengthens our results because growth curves incorporated individual growth over 1 year. Nevertheless, this study has several limitations. For one, in certain specific age groups (per gender) only a few participants were observed. Prediction intervals of mandibular range of motion and AMVBF for these specific groups may be wider than desirable, with the lower limit of some intervals straying below 0. Additionally, the growth curves presented in this paper may provide medical and dental clinicians with an indication of normal AMIO, PMIO, laterotrusion, and AMVBF in growing children. However, caution is needed with clinical implementation, as these curves were developed on data from five Dutch schools. This brings a risk of selection bias, and these curves may not be representative for children in other countries. Similar growth curves developed on data from different countries will be needed to corroborate our findings.

The analysis was performed with squared terms for age and length where applicable. This approach was chosen to allow curves to flatten at higher values of age and height compared to models that included restrictive cubic splines, an approach to known to be more flexible (see for example Harrell [51]). However, comparison of methods showed similar results. Additionally, we chose to model the outcomes with age and height separately. Age and height are highly correlated in children aged 6–18 years, thus introducing collinearity in the analysis. Additionally, the main aim of the study was to construct easy-to-use figures that represent the progression of the outcomes for children and adolescents during growth. Nevertheless, figures based on models that include both age and height may provide slightly more reliable estimates of the outcomes given specific age and height. Over 85% of children in this study were willing to participate in all measurements. Of the remaining children, 4% were unavailable as they changed schools between the third and fourth measurement, and 9% were absent for unknown reasons when measurements were performed with only two children refusing further participation after the first measurement (Figure 1). Even though random effect models are known to be robust to missing follow-up measurements under an assumption of missing-at-random, a bias in the results cannot fully be excluded [52].

The AMVBF curve for girls showed some unexpected results, for which a clear explanation is lacking. However, an extension of the follow-up period might further reinforce our outcomes, and a longer follow-up period would make possible a detailed longitudinal analysis of individual growth curves, specifically AMVBF in girls.

In conclusion, this study showed that AMIO, PMIO, protrusion, laterotrusion, and AMVBF increase with age in healthy children. Boys have a larger AMIO and AMVBF than girls. A plateau phase and the subsequent descending of the AMVBF growth curve in girls occurs at age 12–14 years. Growth curves of AMIO, PMIO, protrusion, laterotrusion, and AMVBF of healthy children are presented to provide an indication of normal values. These values may be helpful for medical and dental professionals in early recognition of potential temporomandibular sequelae in young children and adolescents.

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CONFLICTS OF INTEREST STATEMENT

There are no conflicts of interest.

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