Association between coronal caries and malocclusion in an adult population

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Abstract

Purpose Only a few but conflicting results have been reported on the association between malocclusions and caries. We investigated this association using data from the population-based cross-sectional Study of Health in Pomerania (SHIP).

Methods Sagittal, vertical and transversal intermaxillary relationship, space conditions and sociodemographic parameters of 1210 dentate subjects (median age 30 years, interquartile range 25–35 years) were collected. Caries was assessed with the Decayed-Missing-Filled Surfaces index but analyzed as ordered outcome (four levels: sound, enamel caries, caries, tooth loss) in ordinal multilevel models, taking into account subject, jaw, and tooth level simultaneously.

Results Anterior open bite ≤3 mm (odds ratio [OR] = 2.08, 95% confidence interval [CI]: 1.19–3.61), increased sagittal overjet of 4–6 mm (OR = 1.31, CI: 1.05–1.64), distal occlusion of ½ premolar width (OR = 1.27, CI: 1.05–1.53) and distal 1 premolar width (OR = 1.31, CI: 1.06–1.63) were associated with adjusted increased odds for a higher outcome level (caries). Anterior spacing (OR = 0.24, CI: 0.17–0.33), posterior spacing, (OR = 0.69, CI: 0.50–0.95), posterior crowding (OR = 0.57, CI: 0.49–0.66) and buccal nonocclusion (OR = 0.54, CI: 0.33–0.87) were associated with a lower outcome level (caries).

Conclusion The results from this population-based study suggest that a connection between caries and malocclusion exists to a limited extent in young adults. The associations with caries are contradictory for several malocclusion variables. Distal occlusion (OR = 1.31, CI: 1.06–1.63) and related skeletal anomalies displayed positive associations with caries whereas crowding did not. Orthodontic treatment of anterior crowding would probably not interfere with caries experience. These aspects should be considered for patient information and in treatment decisions.

Keywords Dental occlusion · Orthodontics · Caries risk assessment · Epidemiology · Multilevel analysis

Availability of data and material All variables and data of the Study of Health in Pomerania (SHIP) can be requested under: https://www.fvcm.med.uni-greifswald.de/dd_service/data_use_intro.php.

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Zusammenhang zwischen Kronenkaries und Malokklusionen in einer Erwachsenenpopulation

Zusammenfassung

Ziel Da über den Zusammenhang zwischen Malokklusionen und Karies bislang nur wenige und widersprüchliche Ergebnisse bekannt sind, haben wir diese Fragestellung anhand von Daten aus der bevölkerungsbezogenen Querschnittsstudie „Study of Health in Pomerania“ (SHIP) untersucht.

Methoden Die sagittale intermaxilläre Kieferrelation, Variablen der Malokklusion und soziodemographische Parameter von 1210 Probanden (Durchschnittsalter 30 Jahre, Interquartilbereich 25–35) wurden in die Analyse einbezogen. Karies wurde mit dem DMFS(„Decayed-Missing-Filled Surfaces“)-Index erfasst und als geordnetes Ereignis (4 Stufen: gesund, Schmelzkaries, Karies, Zahnverlust) in ordinalen Mehrebenenmodellen unter gleichzeitiger Berücksichtigung von Personen-, Kiefer- und Zahnebene analysiert.

Ergebnisse Anterior offener Biss ≤3 mm (Odds Ratio [OR] = 2,08, 95 %-Konfidenzintervall [KI]: 1,19–3,61), vergrößerte sagittale Stufe von 4–6 mm (OR = 1,31, KI: 1,05–1,64), distale Okklusion von einer halben Prämolarenbreite (OR = 1,27, KI: 1,05–1,53) und distale Okklusion von 1 Prämolarenbreite (OR = 1,31, KI: 1,06–1,63) waren mit einem erhöhten Risiko für Karies assoziiert. Lückige Zahnstellung in der Front (OR = 0,24, KI: 0,17–0,33), lückige Zahnstellung im posterioren Bereich (OR = 0,69, KI: 0,5–0,95), Engstand im posterioren Bereich (OR = 0,57, KI: 0,49–0,66) und bukkale Non-Okklusion (OR = 0,54, KI: 0,33–0,87) waren mit einem geringeren Risiko für Karies assoziiert.

Schlussfolgerungen Die Ergebnisse dieser bevölkerungsbezogenen Studie legen nahe, dass bei jungen Erwachsenen in begrenztem Umfang ein Zusammenhang zwischen Karies und Malokklusion besteht. Die Assoziationen mit Karies sind bei den einzelnen Malokklusionsvariablen nicht gleichgerichtet. Die distale Okklusion (OR = 1,31, KI: 1,06–1,63) und verwandte skelettale Anomalien zeigten positive Assoziationen mit Karies, während dies beim Engstand nicht der Fall war. Eine kieferorthopädische Behandlung des frontalen Engstandes würde das Kariesrisiko wahrscheinlich nicht beeinflussen. Diese Aspekte sollten bei der Patienteninformation und bei Behandlungsentscheidungen berücksichtigt werden.

Schlüsselwörter Okklusion · Kieferorthopädie · Kariesrisikobewertung · Epidemiologie · Mehrebenenanalyse

Introduction

Proper alignment and function of teeth as well as neutral occlusion are primary goals of orthodontic treatment. This should lead to an appealing aesthetic appearance, ensure chewing efficiency and last but not least, has been proposed to be associated with periodontal and dental health [3]. There has been a long-lasting debate about the impact of malocclusion on the progression of caries and periodontal disease [23, 24]. Although an association between malocclusion and periodontitis was established and does not seem to be negligible [4], periodontal health after orthodontic treatment does not seem to improve [6]. Regarding caries, the association with malocclusion seems to be even smaller [12].

Conflicting data have been reported in the past as to whether dental crowding increases caries scores [20]. Some studies reported higher interproximal caries prevalence, whereas others did not. Most of the studies focused on anterior teeth [2]. Differences in caries risk were also found between the upper and lower jaws [20]. Regarding caries, results from intervention studies are also heterogeneous [5, 12]. A recent publication on caries prevalence and former orthodontic treatment on 448 Australians at the age of 30 years did not provide any measurable benefits from orthodontic treatment with respect to improved dental health later in life [12]. No distinction was made in that study, however, for different forms of malocclusion, which was established with the Dental Aesthetic Index and orthodontic treatment had been performed mainly to resolve aesthetic problems [12]. In a retrospective German evaluation, 75 former Angle class II patients seemed to benefit from orthodontic treatment based on Decayed-Missing-Filled Surfaces (DMFS) values when compared to a population-based age cohort [5].

In contrast to crowding, much less is known about the relationship between overjet, overbite, crossbite, and spacing to caries. Studies in primary and mixed dentitions delivered inconsistent results [15, 19, 35, 40]. In an early study, Helm and Petersen considered different forms of malocclusion but did not find any association with caries prevalence in an adult sample [23].

To the best of our knowledge, there are no epidemiological data on the association between caries and the different forms of malocclusion including sagittal intermaxillary relationships in an adult population. Thus, we aimed to analyze cross-sectional data from the Study of Health of Pomerania (SHIP) to assess the association between caries prevalence and various forms of malocclusion in a statistical model on tooth, jaw and subject levels.
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Materials and methods

Study participants

The aim of the population-based SHIP was to estimate the prevalence of a broad range of diseases, risk factors, and health-related factors for the Northeast German population. The baseline examination SHIP-0, whose sampling method was adopted from the World Health Organization MONICA (Monitoring Trends and Determinants in Cardiovascular Disease) Project in Augsburg, Germany, was approved by the local ethics committee and performed between 1997 and 2001 [28]. The net sample (without migrated or deceased subjects) comprised 6265 subjects with an age range from 20 to 79 years. Finally, 4308 subjects—all were Caucasian—gave written, informed consent and participated in SHIP-0, which corresponded to a response rate of 68.8%. SHIP-0 comprised a medical examination, a clinical dental examination (including periodontal, orthodontic, functional, and cariologic components), an interview, and a questionnaire completed by each participant [26, 28].

Assessment of malocclusion

The occlusal status was assessed according to selected occlusal parameters including the sagittal intermaxillary relationship in the canine region. This relationship was registered separately for the right and left canine regions and determined as neutral, distal by the width of ½ premolar and 1 premolar, and mesial by at least a ½ premolar width [25]. The following signs were recorded as being either present or absent: frontal and lateral crowding, ectopic position of canines, widely spaced teeth without approximal tooth contact, frontal and lateral crossbite, buccal nonocclusion, excessive overjet and overbite, edge-to-edge bite, open bite, negative overjet and retruded position of maxillary incisors. Orthodontic status was not recordable when in 2 or more sextants of the dentition (2 anterior and 4 posterior tooth regions), 3 or more teeth per sextant were missing, regardless of whether the gaps were restored or not. Third molars were not included in the evaluation.

Dental examination

According to the WHO recommendations [42], coronal caries findings (cavitated carious defects into the enamel and dentine), fillings, secondary caries on the surface level, and missing teeth, were registered by surface with the exception of third molars according to the half-mouth method (quadrants 1 and 4, or quadrants 2 and 3 in alternating sequence) using a periodontal probe (PCP 11, Hu Friedy, Frankfurt am Main, Germany) [26, 39]. Cavitated carious lesions (D component) were subdivided into lesions confined to enamel and those involving dentine. The number of cavitated lesion solely in enamel was absolutely minimal (n = 72). Initial caries lesions without cavitation were not recorded or counted for the caries scores. In detail, caries was defined in the manual of SHIP-0 as follows:

0. Sound: no caries, discoloration without carious defect, wedge-shaped defects, fissure sealings, tooth brushing defects
1. Enamel caries or carious defect into the enamel: visible or detectable defects of the enamel; if enamel caries is in doubt, do not opt for it
2. Dentine caries ≤3 mm: the defect into the dentin does not exceed 3 mm in length and width measured with the periodontal probe PCP11
3. Dentine caries >3 mm: the defect into the dentin exceeds 3 mm in length and width measured with the periodontal probe PCP11
4. Filling: filled surfaces of teeth (without secondary caries) and crowns
5. Secondary caries: visible or detectable caries at the margin of fillings
6. Missing: all missing teeth except third molars
7. Others: missing anterior teeth due to trauma, missing premolars due to orthodontic treatment, crowns due to trauma (proband were ask for the reason of tooth loss), persistent teeth of the first dentition

This was the basis for the calculation of the DMFS index to characterize the SHIP sample in Tables 1 and 2, and to analyze the data using four ordered outcome levels on tooth level as described in more detail in the statistical analyses section.

Visual inspection and probing with the dental probe PCP11 determined the presence or absence of plaque and calculus on test teeth 1, 3, and 6 in the selected quadrants, and the proportion of sites with plaque was calculated per participant. If a test tooth was missing, the distal adjacent tooth was examined instead. Each of these teeth was scored at four sites: distobuccal, midbuccal, mesiobuccal, midlingual.

Quality control

Eight experienced and calibrated dentists performed the dental examinations. Training of examiners and consensus discussions were carried out before the study started and training/calibration sessions were repeated twice yearly while the study was ongoing. Orthodontic calibration of the examiners was based on the examination of 30 pairs of casts showing complex symptoms of malocclusion, examination was repeated after several days. Intra- and interexaminer agreement were measured by Cohen’s kappa (κ) [25, 26].
Table 1 Demographic characteristics of participants aged 20–39 years of the Study of Health in Pomerania (SHIP), 1997–2001, n = 1210

| Variable                        | n   | DMFS (half mouth) | n   | Plaque (%) |
|---------------------------------|-----|-------------------|-----|------------|
|                                 |     | Median (IQR)      |     | Median (IQR) |
| Age group                       |     |                   |     |            |
| 20–24 years                     | 255 | 6 (4–8)           | 254 | 33 (17–63) |
| 25–29 years                     | 305 | 7 (5–9)           | 305 | 38 (17–63) |
| 30–34 years                     | 333 | 8 (6–10)          | 331 | 40 (20–67) |
| 35–39 years                     | 317 | 8 (6–10)          | 316 | 42 (25–67) |
| Gender                          |     |                   |     |            |
| Men                             | 573 | 7 (5–9)           | 572 | 42 (21–67) |
| Women                           | 637 | 8 (6–10)          | 634 | 38 (17–63) |
| School education                |     |                   |     |            |
| <10 years                       | 95  | 7 (5–9)           | 94  | 55 (30–80) |
| 10 years                        | 826 | 8 (6–10)          | 825 | 42 (21–67) |
| >10 years                       | 289 | 7 (4–9)           | 287 | 29 (8–50)  |
| Marital status                  |     |                   |     |            |
| Married                         | 518 | 8 (6–10)          | 517 | 42 (21–63) |
| Married, living separately      | 20  | 9 (6–11)          | 20  | 50 (18–75) |
| Single                          | 614 | 7 (5–9)           | 612 | 36 (17–63) |
| Divorced                        | 55  | 8 (6–10)          | 54  | 46 (29–65) |
| Widowed                         | 3   | 2 (0–4)           | 3   | 33 (29–67) |
| Household income (€/month)      |     |                   |     |            |
| ≤475                            | 224 | 7 (5–9)           | 224 | 45 (21–69) |
| 475 <x ≤700                     | 237 | 7 (5–9)           | 235 | 40 (17–67) |
| 700 <x ≤950                     | 211 | 7 (5–9)           | 211 | 42 (17–63) |
| 950 <x ≤1,250                   | 264 | 8 (6–10)          | 262 | 42 (21–63) |
| >1,250                          | 235 | 8 (6–9)           | 235 | 33 (15–58) |
| Smoking                         |     |                   |     |            |
| Never                           | 376 | 5 (9–4)           | 374 | 33 (15–58) |
| Ex, <1 cig./day                 | 142 | 7 (6–9)           | 142 | 33 (17–60) |
| Ex, 1–14 cig./day               | 64  | 7 (5–9)           | 64  | 29 (8–52)  |
| Ex, ≥15 cig./day                | 85  | 7 (5–9)           | 85  | 42 (25–69) |
| Current, <1 cig./day            | 80  | 7 (5–9)           | 80  | 35 (17–54) |
| Current, 1–14 cig./day          | 214 | 7 (5–9)           | 214 | 42 (21–67) |
| Current, ≥15 cig./day           | 247 | 8 (5–10)          | 245 | 50 (29–75) |
| Orthodontic treatment           |     |                   |     |            |
| Never                           | 837 | 7 (6–9)           | 834 | 40 (20–63) |
| Currently                       | 4   | 7 (5–8)           | 4   | 10 (4–25)  |
| Formerly                        | 360 | 7 (5–9)           | 359 | 38 (17–63) |

**DMFT** Decayed-Missing-Filled Teeth index, **Ex** Former smoker, number of cigarettes (cig.) per day, **IQR** interquartile range

Cohen’s κ values ranged from 0.66–0.81, meaning “good agreement” [41]. The calibration exercises for the caries scores consisted of each examiner performing two examinations on each of 10 and 5 test participants one to two weeks apart. Examiners applied the eight categories for caries as described in the manual for SHIP-0. On surface level, which was the basis for calibration and certification, very good Cohen’s κ values were reached for intra- and interexaminer reliability (0.9–1.0 and 0.93–0.96, respectively [26, 39]). On the tooth level as used herein, good κ values were reached for intra- and interexaminer reliability (0.69–1.0 and 0.70–1.0, respectively).

**Statistical analyses**

To avoid selection bias, subject’s age range was restricted to 20–39 years; older subjects have a higher proportion of missing orthodontic variables due to missing teeth. As shown for the relationship between malocclusion and periodontal disease [4], confounding by tooth type across jaws required modelling on subject, jaw, and tooth levels. As is common in multilevel analyses [16], the outcome (caries) is measured on the tooth level, whereas some covariates are at the subject level, for example gender, and other covariates are at the tooth level, including all malocclusion variables except distal and mesial occlusion [4]. Thus, the 33 malocclusion variables on the subject level were transformed into 18 corresponding variables on the tooth level [4]. Thus, ectopic canines on the tooth level could occur only at 13, 23, 33, or 43 [4]. For crowding (and spacing as well), a single variable instead of two variables for anterior and posterior regions may be desirable. We addressed this coding scheme only in sensitivity analyses because the six joint tests for the global malocclusion conditions, including space conditions in the anterior region and lateral malocclusions, were clearly of clinical and statistical interest. Moreover, crowding was assessed differently in the anterior and posterior regions. The malocclusion variables were simultaneously fitted in ordinal logistic multilevel models using the “meologit” procedure (Stata software, release 14.2; Stata Corporation, College Station, TX, USA). The four ordered outcome levels were (1) sound, (2) carious defects into the enamel, (3) caries (dentine caries ≤3 mm, dentine caries >3 mm, filling, or secondary caries), and (4) tooth loss. Because pitfalls of ignoring the hierarchy in dental research (subject, tooth, surface; subject, jaw, tooth) have been well-known for 20 years [17], multilevel models have been widely used for answering complex research questions, especially when the tooth type is a confounder on a level different from the subject level [4, 18]. Herein, the three hierarchical levels subject, jaw, and tooth were included as random effects [36]; age, gender, school education (3 levels in accordance with the former east German
Table 2  Decayed-Missing-Filled Teeth index (DMFT) and plaque according to malocclusion variables of participants aged 20–39 years of the Study of Health in Pomerania (SHIP), 1997–2001, \( n = 1210 \)

| Variable                                      | \( n \)  | DMFT (half mouth) | Plaque (%), \( n = 1206 \) |
|------------------------------------------------|----------|-------------------|-----------------------------|
| **Space conditions in the anterior region**   |          |                   |                             |
| Anterior crowding, upper arch lack of space   |          |                   |                             |
| No anterior crowding                          | 643      | 8 (5–10)          | 639 42 (20–65)              |
| ≤½ lateral incisor width                     | 483      | 7 (5–9)           | 483 38 (17–63)              |
| ½ < x ≤ 1 lateral incisor width              | 68       | 6 (5–8)           | 68 38 (21–71)               |
| >1 lateral incisor width                     | 6        | 6 (4–8)           | 6 33 (29–38)                |
| Anterior crowding, lower arch lack of space   |          |                   |                             |
| No anterior crowding                          | 444      | 8 (6–10)          | 442 42 (17–63)              |
| ≤½ lateral incisor width                     | 628      | 7 (5–9)           | 626 38 (17–63)              |
| ½ < x ≤ 1 lateral incisor width              | 129      | 8 (6–9)           | 129 46 (20–75)              |
| >1 lateral incisor width                     | 9        | 8 (6–9)           | 9 33 (29–42)                |
| Ectopic canine 13                             |          |                   |                             |
| No                                            | 1089     | 7 (5–9)           | 1085 38 (17–63)             |
| Yes                                           | 120      | 7 (5–9)           | 120 42 (21–70)              |
| Ectopic canine 23                             |          |                   |                             |
| No                                            | 1083     | 7 (5–9)           | 1079 38 (17–63)             |
| Yes                                           | 127      | 7 (4–9)           | 127 38 (21–63)              |
| Ectopic canine 33                             |          |                   |                             |
| No                                            | 1108     | 7 (5–9)           | 1104 38 (17–63)             |
| Yes                                           | 102      | 7 (5–9)           | 102 42 (25–70)              |
| Ectopic canine 43                             |          |                   |                             |
| No                                            | 1090     | 7 (5–9)           | 1086 38 (17–63)             |
| Yes                                           | 120      | 7 (6–9)           | 120 42 (18–75)              |
| Anterior spacing upper arch                   |          |                   |                             |
| No                                            | 1056     | 8 (5–10)          | 1053 38 (17–63)             |
| Yes                                           | 154      | 7 (5–8)           | 153 38 (20–63)              |
| Anterior spacing lower arch                   |          |                   |                             |
| No                                            | 1110     | 7 (5–9)           | 1106 38 (17–63)             |
| Yes                                           | 100      | 8 (6–10)          | 100 42 (20–64)              |
| **Space conditions in the posterior region**  |          |                   |                             |
| Posterior crowding right upper jaw            |          |                   |                             |
| No                                            | 958      | 7 (5–9)           | 954 38 (17–63)              |
| Yes                                           | 252      | 7 (5–9)           | 252 38 (21–58)              |
| Posterior crowding left upper jaw             |          |                   |                             |
| No                                            | 972      | 7 (5–10)          | 968 40 (17–63)              |
| Yes                                           | 236      | 7 (5–9)           | 236 38 (21–58)              |
| Posterior crowding left lower jaw             |          |                   |                             |
| No                                            | 898      | 8 (5–10)          | 894 40 (17–67)              |
| Yes                                           | 312      | 7 (5–9)           | 312 38 (21–58)              |
| Posterior crowding right lower jaw            |          |                   |                             |
| No                                            | 914      | 7 (5–9)           | 911 38 (17–65)              |
| Yes                                           | 296      | 7 (5–9)           | 295 40 (25–60)              |
| Posterior spacing right upper jaw             |          |                   |                             |
| No                                            | 1175     | 7 (5–9)           | 1171 38 (17–63)             |
| Yes                                           | 35       | 6 (4–9)           | 35 30 (10–58)               |
Table 2 (Continued)

| Variable                                      | n  | DMFT (half mouth) Median (IQR) | n  | Plaque (%), n = 1206 Median (IQR) |
|------------------------------------------------|----|---------------------------------|----|-----------------------------------|
| Posterior spacing left upper jaw               |    |                                 |    |                                   |
| No                                            | 1168| 7 (5–9)                         | 1164| 38 (18–63)                        |
| Yes                                           | 42  | 6 (4–8)                         | 42  | 30 (8–50)                         |
| Posterior spacing left lower jaw               |    |                                 |    |                                   |
| No                                            | 1166| 7 (5–9)                         | 1162| 38 (17–63)                        |
| Yes                                           | 44  | 8 (6–10)                        | 44  | 40 (25–63)                        |
| Posterior spacing right lower jaw              |    |                                 |    |                                   |
| No                                            | 1160| 7 (5–9)                         | 1156| 38 (17–63)                        |
| Yes                                           | 50  | 7 (5–9)                         | 50  | 39 (21–60)                        |
| Vertical overbite                              |    |                                 |    |                                   |
| Anterior open bite                             |    |                                 |    |                                   |
| No                                            | 1165| 7 (5–9)                         | 1161| 38 (17–63)                        |
| ≤3 mm                                         | 37  | 7 (6–9)                         | 37  | 38 (21–63)                        |
| >3 mm                                         | 8   | 10 (8–11)                       | 8   | 85 (65–97)                        |
| Anterior edge to edge bite                    |    |                                 |    |                                   |
| No                                            | 1132| 7 (5–9)                         | 1128| 38 (17–63)                        |
| Yes                                           | 78  | 7 (6–9)                         | 78  | 42 (21–69)                        |
| Deep anterior overbite                         |    |                                 |    |                                   |
| No                                            | 912 | 7 (5–9)                         | 909 | 38 (17–63)                        |
| Without gingival contact                       | 211 | 7 (6–9)                         | 210 | 39 (21–63)                        |
| With gingival contact                         | 87  | 8 (5–10)                        | 87  | 38 (17–63)                        |
| Sagittal overjet                               |    |                                 |    |                                   |
| Retroclination/inversion of the upper incisors|    |                                 |    |                                   |
| No                                            | 827 | 7 (5–9)                         | 824 | 42 (21–67)                        |
| Yes                                           | 381 | 7 (5–9)                         | 380 | 33 (17–58)                        |
| Anterior crossbite                             |    |                                 |    |                                   |
| No                                            | 1150| 7 (5–9)                         | 1146| 38 (17–63)                        |
| Yes                                           | 60  | 8 (5–9)                         | 60  | 40 (29–65)                        |
| Negative overjet                               |    |                                 |    |                                   |
| No                                            | 1196| 7 (5–9)                         | 1192| 38 (17–63)                        |
| Yes                                           | 14  | 8 (6–9)                         | 14  | 46 (29–67)                        |
| Increased sagittal overjet                     |    |                                 |    |                                   |
| <4 mm                                         | 807 | 7 (5–9)                         | 803 | 40 (17–65)                        |
| 4–6 mm                                        | 304 | 8 (5–10)                        | 304 | 35 (20–63)                        |
| >6 mm                                         | 97  | 7 (6–9)                         | 97  | 42 (17–70)                        |
| Lateral malocclusion                           |    |                                 |    |                                   |
| Left lateral crossbite                         |    |                                 |    |                                   |
| No                                            | 1036| 7 (5–9)                         | 1033| 38 (17–63)                        |
| Yes                                           | 174 | 8 (6–10)                        | 173 | 42 (25–65)                        |
| Right lateral crossbite                        |    |                                 |    |                                   |
| No                                            | 1035| 7 (5–9)                         | 1031| 38 (17–63)                        |
| Yes                                           | 175 | 8 (6–10)                        | 175 | 46 (25–71)                        |
| Left buccal nonocclusion                       |    |                                 |    |                                   |
| No                                            | 1180| 7 (5–9)                         | 1176| 38 (20–63)                        |
| Yes                                           | 30  | 6 (3–8)                         | 30  | 23 (8–50)                         |
| Right buccal nonocclusion                      |    |                                 |    |                                   |
| No                                            | 1181| 7 (5–9)                         | 1177| 38 (20–63)                        |
| Yes                                           | 29  | 8 (5–9)                         | 29  | 25 (8–54)                         |


Table 2 (Continued)

| Variable                                      | \( n \) | DMFT (half mouth) Median (IQR) | \( n \) | Plaque (%), \( n = 1206 \) Median (IQR) |
|-----------------------------------------------|--------|-------------------------------|--------|------------------------------------------|
| Left lateral open bite                        |        |                               |        |                                          |
| No                                            | 1198   | 7 (5–9)                       | 1194   | 38 (17–63)                               |
| ≤3 mm                                         | 11     | 6 (5–9)                       | 11     | 46 (17–63)                               |
| >3 mm                                         | 1      | 10 (10–10)                    | 1      | 70 (70–70)                               |
| Right lateral open bite                       |        |                               |        |                                          |
| No                                            | 1198   | 7 (5–9)                       | 1195   | 38 (17–63)                               |
| ≤3 mm                                         | 11     | 7 (5–9)                       | 10     | 38 (25–63)                               |
| >3 mm                                         | 1      | 10 (10–10)                    | 1      | 70 (70–70)                               |
| Left lateral edge to edge bite                |        |                               |        |                                          |
| No                                            | 1023   | 7 (5–9)                       | 1019   | 38 (17–63)                               |
| Yes                                           | 187    | 8 (5–10)                      | 187    | 46 (21–67)                               |
| Right lateral edge to edge bite               |        |                               |        |                                          |
| No                                            | 1018   | 7 (5–9)                       | 1015   | 38 (17–63)                               |
| Yes                                           | 192    | 8 (6–10)                      | 191    | 46 (21–71)                               |

Sagittal intermaxillary relationship in the canine region

Occlusion status left canine area

|                                           |        |                               |        |                                          |
|-------------------------------------------|--------|-------------------------------|--------|------------------------------------------|
| Neutral                                   | 713    | 7 (5–9)                       | 709    | 40 (17–65)                               |
| Distal ½ premolar width                   | 276    | 8 (5–10)                      | 276    | 38 (17–63)                               |
| Distal 1 premolar width                   | 152    | 7 (5–9)                       | 152    | 36 (17–58)                               |
| Mesial                                    | 69     | 7 (6–9)                       | 69     | 50 (29–71)                               |
| Occlusion status right canine area         |        |                               |        |                                          |
| Neutral                                   | 747    | 7 (5–9)                       | 743    | 38 (17–63)                               |
| Distal ½ premolar width                   | 246    | 7 (5–10)                      | 246    | 38 (20–63)                               |
| Distal 1 premolar width                   | 139    | 8 (6–10)                      | 139    | 33 (15–55)                               |
| Mesial                                    | 78     | 7 (6–10)                      | 78     | 59 (33–79)                               |
| Asymmetry                                  |        |                               |        |                                          |
| Symmetry                                   | 713    | 7 (5–9)                       | 709    | 38 (17–63)                               |
| Neutral and distal ½                       | 230    | 8 (5–10)                      | 230    | 42 (17–63)                               |
| Neutral and distal 1                       | 94     | 8 (5–9)                       | 94     | 33 (15–50)                               |
| Neutral and mesial                         | 64     | 8 (6–10)                      | 64     | 53 (29–84)                               |
| Distal ½ and distal 1                      | 76     | 7 (5–10)                      | 76     | 33 (17–55)                               |
| Distal ½ and mesial                        | 22     | 7 (5–10)                      | 22     | 63 (33–75)                               |
| Distal 1 and mesial                        | 11     | 7 (6–8)                       | 11     | 63 (29–75)                               |

IQR interquartile range

school system), marital status (5 categories), jaw, tooth type (7 levels), the interaction between jaw and tooth type [21], and monthly household equivalence income (1 € = 1.956 German marks) were included as fixed effects [30]. Restricted cubic splines with three knots were used to allow for departures from linearity for age and income. Income was considered only in additional analyses because, unlike school education, it was linked with adulthood rather than childhood and, therefore, not assumed to be a confounder. As orthodontic treatment is part of the effect to be studied, it was not included into the model because “a confounder must not be an effect of the exposure” [37]. Odds ratios (OR) with 95% confidence intervals (CI) and \( p \)-values are provided. For any cut point of the outcome on four levels, ORs in ordinal logistic regression models can be interpreted as those in binary logistic regression models; note that the ordinal logistic regression model has fewer assumptions than the ordinary least squares regression model [22].

Results

The analysis sample consisted of 1210 participants with a median age of 30 years (interquartile range [IQR] 25–35 years). Of these patients, 30% had previously undergone orthodontic treatment. Four patients (<0.5%) were under treatment at the time of examination. (Fig. 1). The median DMFT half mouth was 7 (IQR 5–9 teeth). Partici-
pants’ general characteristics according to caries (DMFT) and plaque are shown in Table 1. Notably, the difference in plaque was very small comparing never and former orthodontic treatment (median: 40 and 38%, respectively). The orthodontic characteristics are shown in Table 2. The most common malocclusion was anterior crowding of the lower jaw in 766 of the 1210 subjects. Lateral open bite was observed in 12 subjects and was the least common malocclusion. According to intermaxillary relationships in the canine area, 44.3% of the subjects showed a neutral occlusion on both sides. Table 3 displays malocclusion in relation to orthodontic treatment for nontreated participants and participants who had previously undergone orthodontic treatment.

On the tooth level, out of the 16,675 teeth half mouth, 1196 teeth were missing, 7521 displayed caries into the dentin, and 72 revealed clinically detectable enamel caries lesions (7.2, 45.1, and 0.4%, respectively, Fig. 2; Table 4). Caries differs considerably by tooth type and jaw, especially for incisors and canines (Fig. 2).

Caries model

On the tooth level, the following malocclusions were associated with an increased odds ratio for caries, or more exactly, for tooth loss versus no tooth loss; or tooth loss or caries versus no caries; or tooth loss, caries, or enamel caries versus sound (Table 4): anterior open bite ≤3 mm (OR = 2.08, CI: 1.19–3.61, frequency among all incisors 2.9%) and increased sagittal overjet of 4–6 mm (OR = 1.31, CI: 1.05–1.64, frequency among all incisors 25.0%). Increased sagittal overjet of >6 mm (OR = 1.45, CI: 1.00–2.11, frequency among all incisors 8%) displayed a p-value of <0.1. Distal occlusion according to the sagittal intermaxillary relation in the canine region also displayed higher odds for caries with distal ½ premolar width (OR = 1.27, CI: 1.05–1.53, frequency among all teeth 28.9%) and distal 1 premolar width (OR = 1.31, CI: 1.06–1.63, frequency among all teeth 19.4%). For negative overjet, the data are consistent with a true OR between 0.84 and 5.62 (frequency among all incisors 1.1%). Some malocclusions were associated with a significantly reduced odds for caries: anterior spacing (OR = 0.24 CI: 0.17–0.33, frequency among all in-
### Table 3
Malocclusion and orthodontic treatment in participants aged 20–39 years of the Study of Health in Pomerania (SHIP), 1997–2001, \(n=1187\) (4 subjects with current treatment, 9 missing treatment values)

#### Tab. 3 Malokklusionen und kieferorthopädische Behandlung der Probanden im Alter von 20–39 Jahren der “Study of Health in Pomerania” (SHIP), 1997–2001, \(n=1187\) (4 Probanden mit aktueller Behandlung, 9 fehlende Behandlungswerte)

| Variable | No \((n=837)\) | % | Formerly \((n=360)\) | % |
|----------|----------------|---|----------------------|---|
| **Space conditions in the anterior region** | | | | |
| Anterior crowding, upper arch lack of space | | | | |
| No anterior crowding | 478 | 57.7 | 158 | 44.1 |
| \(\leq \frac{1}{2}\) lateral incisor width | 311 | 37.5 | 167 | 46.6 |
| \(\frac{1}{2}<x\leq 1\) lateral incisor width | 37 | 4.5 | 31 | 8.7 |
| >1 lateral incisor width | 3 | 0.4 | 2 | 0.6 |
| Anterior crowding, lower arch lack of space | | | | |
| No anterior crowding | 333 | 39.8 | 107 | 29.7 |
| \(\leq \frac{1}{2}\) lateral incisor width | 425 | 50.8 | 194 | 53.9 |
| \(\frac{1}{2}<x\leq 1\) lateral incisor width | 73 | 8.7 | 56 | 15.6 |
| >1 lateral incisor width | 6 | 0.7 | 3 | 0.8 |
| Ectopic canine 13 | | | | |
| No | 760 | 90.9 | 316 | 87.8 |
| Yes | 76 | 9.1 | 44 | 12.2 |
| Ectopic canine 23 | | | | |
| No | 761 | 90.1 | 309 | 85.8 |
| Yes | 76 | 9.1 | 51 | 14.2 |
| Ectopic canine 33 | | | | |
| No | 779 | 93.1 | 317 | 88.1 |
| Yes | 58 | 6.9 | 43 | 11.9 |
| Ectopic canine 43 | | | | |
| No | 779 | 93.1 | 298 | 82.8 |
| Yes | 58 | 6.9 | 62 | 17.2 |
| Anterior spacing upper arch | | | | |
| No | 726 | 86.7 | 321 | 89.2 |
| Yes | 111 | 13.3 | 39 | 10.8 |
| Anterior spacing lower arch | | | | |
| No | 759 | 90.7 | 339 | 94.2 |
| Yes | 78 | 9.3 | 21 | 5.8 |
| **Space conditions in the posterior region** | | | | |
| Posterior crowding right upper jaw | | | | |
| No | 681 | 81.4 | 267 | 74.2 |
| Yes | 156 | 18.6 | 93 | 25.8 |
| Posterior crowding left upper jaw | | | | |
| No | 681 | 81.5 | 280 | 80.0 |
| Yes | 155 | 18.5 | 79 | 22.0 |
| Posterior crowding left lower jaw | | | | |
| No | 644 | 76.9 | 244 | 67.8 |
| Yes | 193 | 23.1 | 116 | 32.2 |
| Posterior crowding right lower jaw | | | | |
| No | 653 | 78.0 | 250 | 69.4 |
| Yes | 184 | 22.0 | 110 | 30.6 |
| Posterior spacing right upper jaw | | | | |
| No | 812 | 97.0 | 350 | 97.2 |
| Yes | 25 | 3.0 | 10 | 2.8 |
### Table 3 (Continued)

| Variable                                      | No ($n=837$) |            | Formerly ($n=360$) |            |
|-----------------------------------------------|--------------|------------|-------------------|------------|
|                  | $n$  | $\%$ | $n$  | $\%$ |
| Posterior spacing left upper jaw              |              |            |                   |            |
| No                                            | 806         | 96.3      | 349               | 96.9       |
| Yes                                           | 31          | 3.7       | 11                | 3.1        |
| Posterior spacing left lower jaw              |              |            |                   |            |
| No                                            | 806         | 96.3      | 347               | 96.4       |
| Yes                                           | 31          | 3.7       | 13                | 3.6        |
| Posterior spacing right lower jaw             |              |            |                   |            |
| No                                            | 803         | 95.9      | 345               | 95.8       |
| Yes                                           | 34          | 4.1       | 15                | 4.2        |
| Vertical overbite                              |              |            |                   |            |
| Anterior open bite                             |              |            |                   |            |
| No                                            | 815         | 97.4      | 338               | 93.9       |
| $\leq$3 mm                                    | 19          | 2.3       | 17                | 4.7        |
| $>3$ mm                                       | 3           | 0.4       | 5                 | 1.4        |
| Anterior edge to edge bite                    |              |            |                   |            |
| No                                            | 786         | 93.9      | 335               | 93.1       |
| Yes                                           | 51          | 6.1       | 25                | 6.9        |
| Deep anterior overbite                         |              |            |                   |            |
| No                                            | 635         | 75.9      | 267               | 74.2       |
| Without gingival contact                      | 141         | 16.8      | 68                | 18.9       |
| With gingival contact                         | 61          | 7.3       | 25                | 6.9        |
| Sagittal overjet                              |              |            |                   |            |
| Retroclination/inversion of the upper incisors|              |            |                   |            |
| No                                            | 566         | 67.8      | 254               | 70.6       |
| Yes                                           | 269         | 32.2      | 106               | 29.4       |
| Anterior crossbite                             |              |            |                   |            |
| No                                            | 805         | 96.2      | 333               | 92.5       |
| Yes                                           | 32          | 3.8       | 27                | 7.5        |
| Negative overjet                              |              |            |                   |            |
| No                                            | 831         | 99.3      | 352               | 97.8       |
| Yes                                           | 6           | 0.7       | 8                 | 2.2        |
| Increased sagittal overjet                    |              |            |                   |            |
| $<4$ mm                                       | 571         | 68.3      | 228               | 63.5       |
| $4$–$6$ mm                                    | 212         | 25.4      | 89                | 24.8       |
| $>6$ mm                                       | 53          | 6.3       | 42                | 11.7       |
| Lateral malocclusions                          |              |            |                   |            |
| Left lateral crossbite                         |              |            |                   |            |
| No                                            | 727         | 86.9      | 298               | 82.8       |
| Yes                                           | 110         | 13.1      | 62                | 17.2       |
| Right lateral crossbite                        |              |            |                   |            |
| No                                            | 725         | 86.6      | 300               | 83.3       |
| Yes                                           | 112         | 13.4      | 60                | 16.7       |
| Left buccal nonoclusion                       |              |            |                   |            |
| No                                            | 816         | 97.5      | 351               | 97.5       |
| Yes                                           | 21          | 2.5       | 9                 | 2.5        |
| Right buccal nonoclusion                      |              |            |                   |            |
| No                                            | 815         | 97.4      | 353               | 98.1       |
| Yes                                           | 22          | 2.6       | 7                 | 1.9        |
| Variable                                      | No (n = 837) | %  | Formerly (n = 360) | %  |
|----------------------------------------------|--------------|----|-------------------|----|
| **Left lateral open bite**                   |              |    |                   |    |
| No                                           | 832          | 99.4 | 355              | 98.6 |
| ≤3 mm                                        | 5            | 0.6  | 4                 | 1.1  |
| >3 mm                                        | 0            | 0.0  | 1                 | 0.3  |
| **Right lateral open bite**                  |              |    |                   |    |
| No                                           | 830          | 99.2 | 355              | 98.6 |
| ≤3 mm                                        | 7            | 0.8  | 4                 | 1.1  |
| >3 mm                                        | 0            | 0.0  | 1                 | 0.3  |
| **Left lateral edge to edge bite**           |              |    |                   |    |
| No                                           | 708          | 84.6 | 305              | 84.7 |
| Yes                                          | 129          | 15.4 | 55               | 15.3 |
| **Right lateral edge to edge bite**          |              |    |                   |    |
| No                                           | 710          | 84.8 | 299              | 83.1 |
| Yes                                          | 127          | 15.2 | 61               | 16.9 |

**Sagittal intermaxillary relationship in the canine region**

Occlusion status left canine area

|                                      | No (n = 837) | %  | Formerly (n = 360) | %  |
|--------------------------------------|--------------|----|-------------------|----|
| Neutral                              | 500          | 59.7 | 203              | 56.4 |
| Distal ½ premolar width              | 185          | 22.1 | 90               | 25.0 |
| Distal 1 premolar width              | 107          | 12.8 | 44               | 12.2 |
| Mesial                               | 45           | 5.4  | 23               | 6.4  |

Occlusion status right canine area

|                                      | No (n = 837) | %  | Formerly (n = 360) | %  |
|--------------------------------------|--------------|----|-------------------|----|
| Neutral                              | 522          | 62.4 | 216              | 60.0 |
| Distal ½ premolar width              | 167          | 20.0 | 76               | 21.1 |
| Distal 1 premolar width              | 101          | 12.1 | 37               | 10.3 |
| Mesial                               | 47           | 5.6  | 31               | 8.6  |

Asymmetry

|                                      | No (n = 837) | %  | Formerly (n = 360) | %  |
|--------------------------------------|--------------|----|-------------------|----|
| Symmetry                             | 483          | 57.7 | 221              | 61.4 |
| Neutral and distal ½                 | 161          | 19.2 | 68               | 18.9 |
| Neutral and distal 1                 | 77           | 9.2  | 16               | 4.4  |
| Neutral and mesial                   | 38           | 4.5  | 25               | 6.9  |
| Distal ½ and distal 1                | 52           | 6.2  | 23               | 6.4  |
| Distal ½ and mesial                  | 19           | 2.3  | 3                | 0.8  |
| Distal 1 and mesial                  | 7            | 0.8  | 4                | 1.1  |

Joint effects occurred for space conditions in the anterior region ($p<0.0001$ for the global test with 5 degrees of freedom; Table 4), space conditions in the posterior region ($p<0.0001$), vertical overbite ($p=0.0412$), sagittal overjet ($p=0.0325$), lateral malocclusions ($p=0.0051$), and sagittal intermaxillary relationship in the canine region ($p=0.0200$). The joint effect for increased sagittal overjet and distal occlusion, which were correlated, was statistically significant ($p=0.0011$ for the global test with 4 degrees of freedom).

**Sensitivity analyses using a single variable for crowding and spacing, respectively**

Whereas anterior and posterior spacing can be combined into a single spacing variable in a natural way, posterior crowding can be combined with different levels of anterior crowding. Counting posterior crowding as the lowest level of the presence of anterior crowding, the ORs were 0.65 (95% CI: 0.58–0.74; $p<0.0001$), 0.64 (95% CI: 0.43–0.95; $p<0.0255$), and 0.60 (95% CI: 0.17–2.14; $p=0.4348$) from the lowest to the highest crowding level, respectively. The
OR of spacing was 0.38 (95% CI: 0.30–0.48; \( p < 0.0001 \)). Counting posterior crowding as the middle level of anterior crowding, the OR of the middle level was 0.56 (95% CI: 0.49–0.65; \( p < 0.0001 \)). Of note, the 95% CIs for anterior and posterior spacing did not overlap in the main analysis (Table 4).

**Sensitivity analyses including household income**

Including household income did not lead to a change >10% in the ORs of malocclusion variables in the reduced sample of 1171 subjects.

**Discussion**

Capitalizing on a large sample size from the general population, this is the first study to investigate the association between malocclusions and caries on tooth, jaw and subject levels in adults in a single model. The benefit of orthodontic treatment on oral health including caries prevention is a matter of ongoing debate in the literature as well as in political demands for scientific proof [2, 5, 8, 12]. The extensive dataset of SHIP enables analyses with multilevel models that consider the nested character of the data (tooth level under consideration of the jaw and subject level) [36]. Such extensive analyses including all forms of malocclusion have not been possible in the past.

Although a marked decline in caries has been noticed during the last 30 years in Western countries, caries still represents a relevant dental problem [29, 38, 39]. DMFT values of our subsample are not comparable to other population-based surveys due to the selection criteria described above. Caries prevalence of the sample from SHIP, which has been published previously, is higher compared to other nationwide data from Western European countries in the same decade [27, 31, 38, 39]. Higher numbers of filled and missing teeth in seniors compared to Swedish and US surveys may be based on limited caries prevention programs or unavailability of fluoridated tooth paste before 1989 [39]. DMFT values in the comparable age group of the 35–44 year olds are slightly elevated compared to a German nationwide survey, which was conducted in 2005 [39, 43]. The Fourth German Health Study also reported elevated values for the former East Germany [43].

Besides socioeconomic or cohort effects, several local factors such as improper tooth alignment have also been connected to an increased caries prevalence [1]. Although
accumulation in these cases that might lead to higher caries incidence, high plaque scores were found in 12-year-old children with extreme maxillary overjet. The authors assumed that mandibular overjet was associated with higher bite could be established at least for the mixed dentition instance increased sagittal overjet [34]. To avoid this influence, the examination in SHIP 0 did not count traumatic events and tooth loss due to trauma or orthodontic tooth extractions as missing teeth in assessing the DMFS. However, the caries risk was increased in persons with an overjet of more than 6 mm compared to an overjet of 4–6 mm. Furthermore, because periodontal disease that finally leads to tooth loss has been linked with increased sagittal overjet [4], we chose our sample within an age range of 20 to
Table 4  Caries (four ordered levels: sound, enamel caries, caries, tooth loss): ordinal multilevel model on 1210 subjects, 2420 jaws, and 16,675 teeth (4727 incisors, 2410 canines, and 9538 premolars and molars); odds ratios (OR) on tooth level are adjusted for age, gender, school education, marital status, jaw, tooth type, and the interaction between jaw and tooth type, and for the subject and jaw level Tab. 4  Karies (4 geordnete Ebenen: gesund, Schmelzkaries, Karies, Zahnverlust): ordinales Mehrebenenmodell bei 1210 Probanden, 2420 Kiefern und 16.675 Zähnen (4727 Schneidezähne, 2410 Eckzähne und 9538 Prämolaren und Molaren); Chancenverhältnisse (Odds Ratios, OR) auf Zahn­ebene wurden an Alter, Geschlecht, Schulbildung, Familienstand, Kiefer, Zahntyp und die Wechselwirkung zwischen Kiefer und Zahntyp sowie an Personen- und Kieferebene angepasst

| Variable | Teeth | Caries | Relative effect | Related test |
|----------|-------|--------|----------------|--------------|
|          | Frequency | Frequencies for enamel caries; caries; tooth loss | OR (95% CI) | P value (P<sub>trend</sub>) |
| Space conditions in the anterior region | – | – | – | <0.0001 |
| Anterior crowding, lack of space | 14,055 | 61; 6915; 1190 | 1 (reference) | – |
| No anterior crowding | – | – | (0.0350) | |
| ≤½ lateral incisor width | 2202 | 11; 531; 6 | 0.84 (0.68–1.03) | 0.0958 |
| >½ ≤ 1 lateral incisor width | 388 | 0; 69; 0 | 0.68 (0.45–1.03) | 0.0660 |
| >1 lateral incisor width | 30 | 0; 6; 0 | 0.63 (0.18–2.26) | 0.4824 |
| Ectopic canines | 214 | 3; 35; 0 | 1.25 (0.8–1.95) | 0.3229 |
| Anterior spacing | 493 | 3; 85; 5 | 0.24 (0.17–0.33) | <0.0001 |
| Space conditions in the posterior region | – | – | – | <0.0001 |
| Posterior crowding | 2675 | 9; 1418; 115 | 0.57 (0.49–0.66) | <0.0001 |
| Posterior spacing | 444 | 0; 197; 57 | 0.69 (0.5–0.95) | 0.0230 |
| Vertical overbite | – | – | – | 0.0412 |
| Anterior open bite | – | – | (0.0073) | |
| No | 16,507 | 72; 7461; 1193 | 1 (reference) | – |
| ≤3 mm | 136 | 0; 46; 2 | 2.08 (1.19–3.61) | 0.0096 |
| >3 mm | 32 | 0; 14; 1 | 2.19 (0.74–6.51) | 0.1582 |
| Anterior edge to edge bite | 307 | 3; 74; 6 | 0.90 (0.6–1.35) | 0.6272 |
| Deep anterior overbite | – | – | – | (0.0441) |
| No | 15,519 | 64; 7207; 1176 | 1 (reference) | – |
| Without gingival contact | 819 | 7; 217; 15 | 1.23 (0.95–1.60) | 0.1179 |
| With gingival contact | 337 | 1; 97; 5 | 1.39 (0.95–2.04) | 0.0888 |
| Sagittal overjet | – | – | – | 0.0325 |
| Retroclination upper incisors | 734 | 5; 353; 11 | 0.91 (0.71–1.16) | 0.4492 |
| Anterior crossbite | 297 | 3; 67; 4 | 1.05 (0.66–1.69) | 0.8249 |
| Negative overjet | 54 | 0; 18; 2 | 2.17 (0.84–5.62) | 0.1107 |
| Increased sagittal overjet | – | – | – | (0.0090) |
| No | 15,114 | 66; 7073; 1171 | 1 (reference) | – |
| 4–6 mm | 1.182 | 5; 338; 17 | 1.31 (1.05–1.64) | 0.0191 |
| >6 mm | 379 | 1; 110; 8 | 1.45 (1.00–2.11) | 0.0517 |
| Lateral malocclusions | – | – | – | 0.0051 |
| Lateral crossbite | 1670 | 13; 891; 202 | 1.16 (0.94–1.43) | 0.1742 |
| Buccal nonocclusion | 158 | 0; 82; 6 | 0.54 (0.33–0.87) | 0.0116 |
| Lateral open bite | – | – | – | (0.1119) |
| No | 16,559 | 71; 7457; 1183 | 1 (reference) | – |
| ≤3 mm | 106 | 1; 58; 11 | 1.61 (0.77–3.39) | 0.2085 |
| >3 mm | 10 | 0; 6; 2 | 3.47 (0.34–35.3) | 0.2932 |
| Lateral edge to edge bite | 1885 | 11; 997; 238 | 1.21 (0.99–1.47) | 0.0624 |
| Sagittal intermaxillary relationship in the canine region | – | – | – | 0.0200 |
| Distal occlusion | – | – | – | (0.0047) |
| Neutral or mesial occlusion | 8626 | 53; 3813; 556 | 1 (reference) | – |
that associations between caries and malocclusion depend on the kind of malformation. Anterior open bite (OR = 2.08, CI: 1.19–3.61), increased sagittal overjet (OR = 1.31, CI: 1.05–1.64) and distal occlusion (OR = 1.31, CI: 1.06–1.63) were positively associated with caries, whereas spacing, posterior crowding and buccal nonocclusion were negatively associated. Caries and malocclusion, however, were not far reaching associated. Anterior crowding was not associated with caries nor displayed higher plaque scores compared to no crowding. Causality of the detected associations have to be examined in longitudinal analyses.

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Compliance with ethical guidelines

Conflict of interest O. Bernhardt, K.-F. Krey, A. Daboul, H. Völzke, C. Splieth, T. Kocher and C. Schwahn declare that they have no conflict of interest and no competing interest.

Ethical standards All procedures performed in this study were in accordance with the ethical standards of the Medical Ethics Committee, University Medicine Greifswald, and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Approval was granted by the Medical Ethics Committee, University Medicine Greifswald. Written informed consent was obtained from all individual participants included in the study.

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