ORIGINAL ARTICLE

Are malocclusions more prevalent and severe now? A comparative study of medieval skulls from Norway

Jon Petter Evensen[a] and Bjørn Øgaard[b]
Oslo, Norway

Introduction: The prevalence of malocclusion in modern populations is higher than in excavated samples from ancient times. Presently, more than 30% of children and adolescents in the Scandinavian countries receive orthodontic treatment. The aims of this study were to describe the prevalence and severity of malocclusions in a sample of medieval Norwegians, to evaluate the need for treatment by using the Norwegian need for orthodontic treatment index (NOTI), and to compare these findings with a modern sample already analyzed with the same index. **Methods:** The material consisted of 85 male and 61 female medieval skulls from abandoned and later excavated graveyards of 16th century Oslo that were evaluated with the NOTI. **Results:** Only 36% of the medieval group showed objective assessed needs for orthodontic treatment, compared with 65% of the present-day sample. Among the skulls, the objective needs for treatment were 27% for the males and 49% for the females. No sex differences related to severity or prevalence of malocclusion were found in the modern sample. The medieval sample arranged according to severity was great need (B), 7%; obvious need (C), 29%; and little/no need (D/E), 64%. The findings in the modern sample were B, 20%; C, 44%; and D/E, 35%. The female skulls showed greater severity and prevalence than the male skulls. No skull had very great need (A). **Conclusions:** This study indicates a significant increase in both the prevalence and the severity of malocclusions during the last 400 to 700 years in Oslo, Norway. Furthermore, although no sex differences were found in the modern sample, females had both a higher prevalence of malocclusions and more severe malocclusions than did males in the past. (Am J Orthod Dentofacial Orthop 2007;131:710-6)

The prevalence of malocclusions in modern populations is about 40% to 80%.[1,2] In the Nordic countries, malocclusion frequencies were estimated from 43% to 79%[3-12] and the need for treatment from 30% to 75%.[3,5,7,13,14]

The considerable variations in malocclusion frequency and treatment need relate to different ages, dental ages, genetics, and methods of registrations.

Although malocclusion now generally occurs in much of the population, this was not always the case. Skeletal remains show that malocclusions were relatively unusual before the 19th and 20th centuries.[1] However, malocclusions were not absent, as shown by dental crowding in a Neanderthal specimen estimated to be 100,000 years old, although the Neanderthals had little rotation and displacement of teeth with close approximal contacts.[1] Impacted maxillary canines and congenitally missing third molars were observed in an ancient skull dated about 7250 to 6700 BC.[15]

Several reports found increases in the frequency of malocclusion since medieval times,[16,17] and this was also supported by findings from Scandinavian skull materials.[18-24] Furthermore, the secular increases in malocclusion frequency seem to have accelerated in modern industrialized societies during the last 150 years, after only modest changes for 6000 years.[25-27] Weiland et al[28] studied secular trends in malocclusion among Austrian men and concluded that secular changes with increased prevalence and severity of malocclusion had occurred during the last 100 years.

In ancient materials, it has generally been easier to describe alignment of teeth than occlusal relationships, because the mandible frequently becomes separated from the rest of the skull when long-buried skeletal remains are unearthed. Furthermore, because many anthropologic studies of malocclusion are based on relatively few skulls, we investigated the severity and prevalence of malocclusion in a vast and well-defined Norwegian medieval sample. In a similar study, Helm

From the Department of Orthodontics, Faculty of Dentistry, University of Oslo, Oslo, Norway.
[a]Private practice, Drammen, Norway.
[b]Professor and head.
Reprint requests to: Bjørn Øgaard, Department of Orthodontics, Faculty of Dentistry, University of Oslo, PO Box 1109 Blindern, 0317 Oslo, Norway; e-mail, bogaard@odont.uio.no.
Submitted, April 2005; revised and accepted, August 2005.
0889-5406/$32.00

doi:10.1016/j.ajodo.2005.08.037

and Prydsö[24] used the registration method developed by Björk et al.[29] Their medieval material, however, was neither sex specific nor homogeneous.

Our aims in this study were to describe the prevalence and severity of malocclusions in a sample of medieval Norwegians with the present-day Norwegian need for orthodontic treatment index (NOTI) and to compare these findings with a modern sample already analyzed with the same index.[3]

MATERIAL AND METHODS

The basis for the medieval sample was the Oslo Medieval Material, which is a part of the Schreiner Collection in the Anatomical Institute at the University of Oslo.[30] Skulls from this vast and well-preserved collection, gathered from various abandoned and later excavated graveyards of ancient Oslo, have been used in many previous investigations.[22,31-39] The Schreiner Collection also contains skulls with teeth from as far back as the Stone Age. The Stone Age in Norway began more than 11,000 years ago and lasted for about 7000 years. Chronologically, the Oslo Medieval Material covers the Late Middle Ages; most of the collection is from the 14th to 16th centuries,[32,33,40] and, according to the enumeration of Slagsvold,[33] it consists of 1538 catalogued people of whom 1466 have crania or cranial parts. The medieval material for this study consisted of 146 skulls (85 males, 61 females). The skulls are stored at 21°C and 40% relative humidity.

Sex determination by cranioscopic methods and registration of the skulls were undertaken by Schreiner[31] and Torgersen et al.[32] Slagsvold[33] estimated the error of the method of the cranioscopic technique used for sex determination with a blind test on dissected skulls. He found the sex diagnosis to be correct in 97.8% of the skulls. This minor error of 2.2% established that the sex determination as reliable.

The ethnic background of the Oslo Medieval Material was elucidated by Schreiner[31,41] and found to be homogeneous because of a stable genetic pool with little admixture from without and a rather long time since the last great wave of immigration.

The present-day sample was analyzed by Espeland et al[3] using the NOTI. Their material consisted of 99 children (48 girls, 51 boys), aged 10 to 11 years, attending 3 schools in the city of Drammen (near Oslo) to obtain the socioeconomic spread.

A total of 104 randomly selected families were invited. The modern material included 5 children of non-Nordic origin, but they did not cause significant deviation from the purer Norwegian hereditary part of the sample.

All the medieval skulls were of sex-determined adults with adequate structural preservation so that every measurement could be performed satisfactorily. Both the maxilla and the mandible were present in each skull, and those with teeth lost before or after death were included only if the contralateral tooth of the same jaw was present, with no more than 1 missing tooth per jaw.

Because the preselection showed less than 200 sufficiently reliable skulls, we chose to base this study on the entire reliable part of the medieval material to obtain maximum strength for the investigation. A total of 146 skulls from the catalogued 1466 that included crania or cranial parts was a close to perfect basis for analysis.

The jaws were occluded with the condyles placed in their fossae and with reference to the patterns of attrition of the dentitions; this did not cause any difficulty. Objectively defined treatment need of the skulls was assessed according to the NOTI, introduced in 1990, as used by the Norwegian Health Insurance System for reimbursement of treatment costs (Table I). This index distinguishes between 4 levels of treatment need, comprising various malocclusion traits.

The traits and definitions of cutoff points are based on present scientific evidence and empirical orthodontic norms about the risks for detrimental effects of dentofacial anomalies on dental health, function, and psychosocial well-being. The highest level scored by a trait recorded in 1 skull determined its category.

Based on the measurements, each skull was classified into 1 of the 4 groups defined by the index. Subcategories for rarely occurring deviations were not used. Both close-to-perfect and perfect occlusions were included in group D. Repeated recordings were made by the examiner (J.P.E.) more than a month later to strengthen the validity of the findings. Radiographic examinations of the skulls were not made, but, due to the use of the NOTI, any radiographic findings would only have contributed to reduced prevalence and severity of malocclusion in the medieval sample.

The modern sample was analyzed by Espeland et al,[3] using the NOTI as described for the medieval sample. Dental casts were used for the measurements. Agreement between the examiners on the children's index group was 0.87 expressed by kappa statistics, and the value for intraexaminer agreement was 0.91. Both values were interpreted to represent almost perfect agreement beyond chance.[42]

Statistical analysis

One examinator (J.P.E.) made all analyses in the medieval sample. Group placements relating to sample size were calculated with 95% confidence intervals. The measurements were repeated on all skulls more

Table I. Norwegian NOTI

Category A: very great need
Cleft lip-jaw-palate
Inherited or acquired craniofacial anomalies
Severe anomalies requiring combination of orthodontics and orthognathic surgery
Anomalies of comparable severity
Category B: great need
Overjet ≥9 mm
Unilateral buccal or lingual crossbite on ≥3 pairs of opposing teeth with forced bite or asymmetry
Anterior open bite with occlusal contact on molars only
Impacted incisors and canines when appliance therapy is necessary
Anterior crossbite on all incisors
Anterior teeth missing due to agenesis or tooth loss
Increased overbite (deep bite) with labial or palatinal impingement of soft tissue with ≥2 teeth
Bilateral buccal crossbite (scissors-bite) on ≥2 pairs of opposing teeth
Agenesis of ≥2 teeth in same quadrant (third molars excepted)
Anomalies of comparable severity
Category C: obvious need
Overjet 6-9 mm
Open bite on ≥3 pairs of opposing teeth
Inversion of anterior teeth
Increased overbite (deep bite) without contact on anterior teeth or with contact on gingival ¼ of palatinal surface of maxillary anterior teeth
Agenesis of single teeth in lateral segments
Median diastema of ≥3 mm or pronounced general spacing of anterior segment (≥6 mm per jaw)
Pronounced crowding of anterior teeth (≥3 mm per jaw)
Occlusal disorder combined with strong dysfunction symptoms
Anomalies of comparable severity
Category D: little/no need
Overjet <6 mm
Bilateral crossbite
Anterior and lateral open bites of ≤3 pairs of opposing teeth
Increased overbite (deep bite) with occlusal contact incisal to gingival ¼ of palatal surface of maxillary anterior teeth
Local crossbite and scissors-bite without asymmetry or forced bite
Moderate crowding in anterior and lateral segments
Median diastema <3 mm
Moderate spacing in anterior and lateral segments

than a month after the first registration. Error of the method on choice of index group was then analyzed with kappa statistics. The chi-square test was used to test differences between the sexes in the past, and between past and present samples.[43]

RESULTS

Of the 146 skulls examined, 7% had great need of treatment (group B), with obvious need (group C) recorded in 29% and little/no need (group D) in 64% (Table II). No skull had very great need (group A).

Error of the method on choice of index group was analyzed with kappa statistics, achieving a value of 0.94, which indicated very good strength of agreement beyond chance.[43]

The findings in the modern sample were A, 1%; B, 20%; C, 44%; and D, 35%.[3] Comparing the medieval sample with the present day sample by using the NOTI gave a statistically significant difference at the $P < .001$ level. The present-day sample showed both increased prevalence and severity over the medieval sample.

Thus, only 7% of the medieval skulls had the greatest need of treatment (categories A and B) compared with 21% in the modern sample. A typical example of a skull with the jaws in occlusion and views of both dental arches is shown in Figure 1. Note the well-aligned arches and the broad arch form.

The objective treatment need as calculated from the NOTI is the sum of groups A, B, and C. The objective treatment need were 65% for the modern sample and only 36% for the medieval sample.

Comparing the sexes in the medieval sample, we found a statistically significant difference ($P = .025$) for prevalence and severity of malocclusion (Fig 2).

Of the 61 females, 6 (10%) belonged to group B, and 24 (39%) and 31 (51%) belonged to groups C and D, respectively. Among the 85 men, 4 (5%) belonged to group B, whereas 19 (22%) and 62 (73%) belonged to groups C and D, respectively. The females had both greater prevalence and severity than the male part of the sample.

The objective treatment needs (sum of groups B and C) in the medieval skulls were 49% in the females and 27% in the males. No sex differences were noted in the modern group.[3]

DISCUSSION

Our results and the comparison with modern samples clearly support other findings of increased prevalence and severity of malocclusions over the last centuries. The marked difference between the sexes, on the other hand, is to our knowledge a new observation. It is a fact that women often died during childbirth in medieval times. Thus, their possibly younger mean age at death compared with the men would provide less time for attrition of their dentitions and hence less camouflage of any malocclusion.

The Oslo Medieval Material gives a more homogenous image of fundamental biologic conditions and differences, particularly regarding genetic impact, than the corresponding present-day sample because of increased immigration and emigration of modern societies. Dimensional changes in skeletal samples; alterations in tooth sizes, head shapes, transverse arch dimensions, and arch depths; and comparisons of measurements between natural teeth and casts when access

Table II. Prevalence and severity of medieval sample according to NOTI

Medieval sample NOTI	*A*	*B*	*C*	*D*	*Total*
% (n)	0% (0)	7% (10)	29% (43)	64% (93)	100% (146)
95% confidence interval	—	± 4.1	± 7.4	± 7.8	—

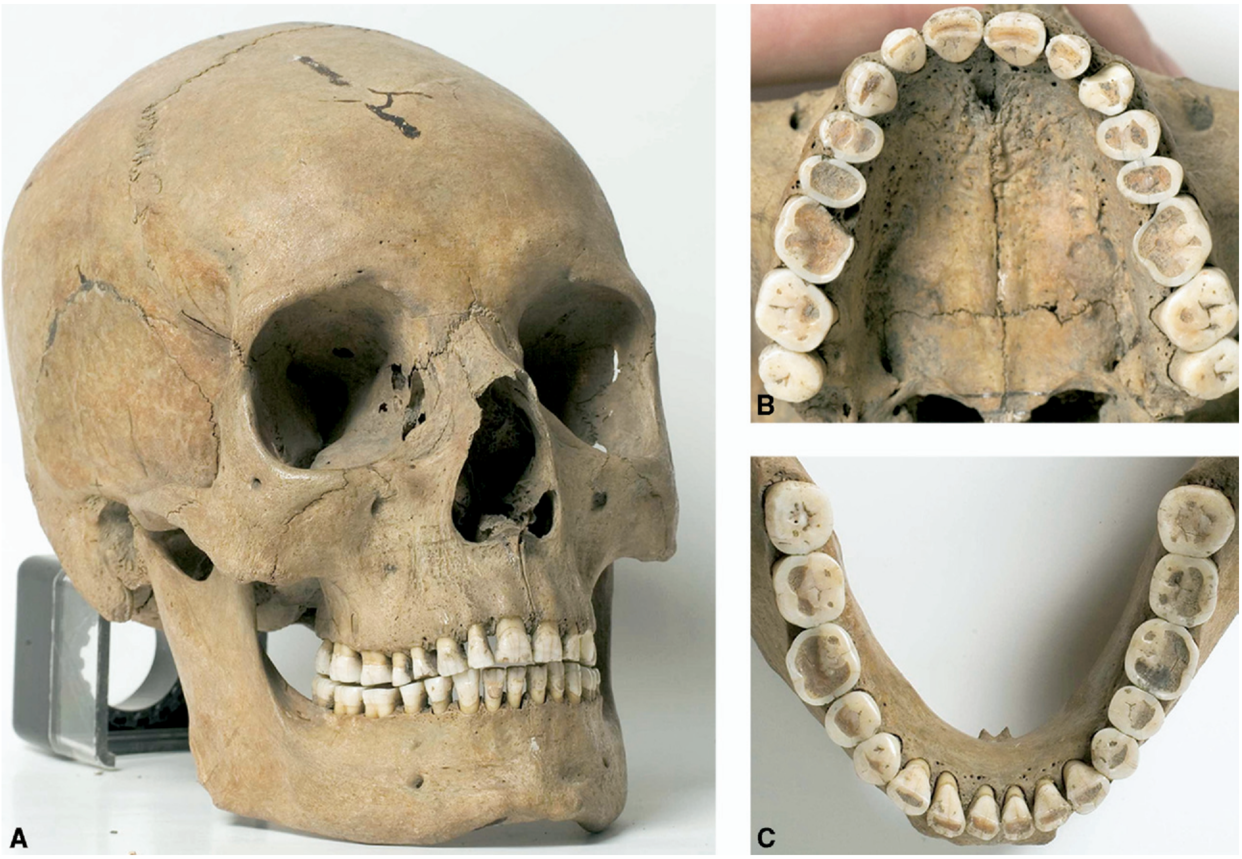

Fig 1. Male skull from 14th century from St Nicolaus church in Oslo. Note broad, well-aligned arches without crowding and severe occlusial attrition into dentin and some approximal attrition. **A,** Skull with jaws in occlusion; **B,** maxillary arch; **C,** mandibular arch.

to teeth and dental arches for measurements are similar were all elucidated by Lindsten,[39] who studied mixed dentitions, and the differences were too small to significantly influence our study in comparing the groups for severity and prevalence of malocclusion.

Even though the 400 to 700 years investigated in this study is a relatively long time compared with a single human life, it is a short time from an evolutionary perspective. Fossil records show evolutionary trends over thousands of years; they document decreases in the sizes of individual teeth, the numbers of teeth, and the sizes of the jaws.[1] Compared with traditional peoples, modern humans have underdeveloped jaws. Obviously, if reduction in jaw size is not well matched to the opposite jaw and to the decreases in tooth sizes and numbers, one might expect greater prevalence of malocclusions.

Although the genetic constitution of a given population might show changes in a relatively short period, these changes play only a minor role in the increasing prevalence of malocclusion.[5,44] The environmental change toward more refined food requiring less powerful masticatory action is thought to be the main reason for the relatively recent increase in malocclusion frequency.[1,36,39,45,46] Most dentoalveolar deviations are attributed to environmental factors,[25,26,47] but several occlusal traits depend on a combination of variations in tooth position and skeletal development; the first is

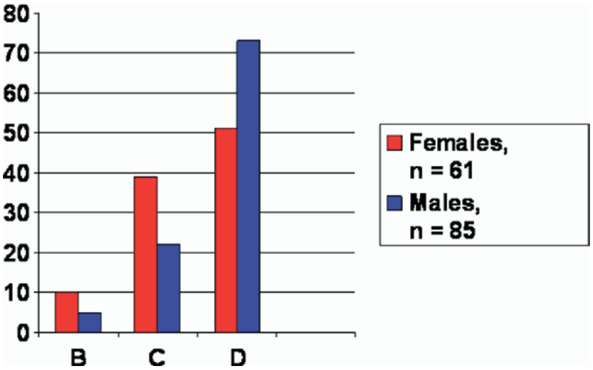

Fig 2. Group placements in percentages of sexes in medieval sample with NOTI (statistically significant different at $P = .025$).

mostly environmentally influenced, and the latter is more genetically determined.[2,47,48]

Investigations of stature indicated an overall decrease of a few centimeters between the 12th and 19th centuries, followed by general increases of 6 cm in women and 11 cm in men over the last 200 years,[39] with the greatest difference occurring in the last century.[1,39] This general increase in stature together with faster growth and earlier maturation during recent decades might have influenced jaw sizes and concomitantly malocclusion frequency.

Changes in malocclusion from adolescence to 35 years of age in orthodontically untreated modern patients were studied by Helm and Petersen[49] and Bondevik,[50,51] who showed generally remarkable stability of the various malocclusion traits. Only deep overbite and mandibular crowding, especially in the incisor segment, tended to increase in frequency.

The difference in malocclusion between juvenile and adult medieval skull samples was assessed by Helm and Prydsö.[24] They found significantly more frequent and pronounced mesial molar occlusion in the adults, whereas the juveniles showed no difference from a modern sample. Furthermore, crossbites were considerably less common in the younger skulls than in modern youths, but a marked increase was observed in the older skulls. No other differences were found. Lindsten et al,[37] investigating and comparing a juvenile skull sample with mixed dentition from the Oslo Medieval Material with a modern sample, however, found more irregularity of the mandibular incisors in the medieval juveniles. Hasund[22] studied the effect of increased approximal attrition in adult skulls from the Oslo Medieval Material. Even though attrition was found to increase with advancing age, this did not improve relative dental arch space in the maxilla and led to only a slight improvement in the mandible.

It seems reasonable that the mandibular incisor crowding found by Lindsten et al[37] in juvenile skulls would have become reduced during adulthood by occlusal and approximal attrition because of vigorous chewing of coarse and tough food, often contaminated by grit and ashes.[45,52] First, because occlusal attrition over time would tend to erase intercuspation and eliminate overbite, the mesial molar occlusion noted by Helm and Prydsö,[24] probably related to late mandibular growth, might have been easily achieved because the 2 jaws would only slightly influence each other. Second, without the juvenile pressure against the maxillary incisors because of occlusal attrition and concomitant edge-to-edge bite, there would be fewer tendencies to crowding of the mandibular incisors. Late mandibular growth is believed to be the main reason for the late anterior crowding found more frequently in modern societies than in medieval times in adult populations.[1]

Comparative studies of past and present samples regarding prevalence of malocclusion are further complicated because both dental caries and periodontal disease—rare with a primitive diet—appear rapidly with modern diet changes, making it difficult to establish what the occlusion might have been like without early loss of teeth and periodontal breakdown. Another complicating factor is the increased frequency of chronic mouth breathing in westernized populations because of nasorespiratory obstructions, which seem to be responsible for the increased tendency toward crossbites and open bites.[2,39] Finally, skulls with more severe malocclusions might be less well preserved from medieval times than those with better occlusions. Nonaligned or protrusive teeth could be at increased risk for postmortem loss during unearthing with concomitant failure to match the inclusion criteria of the studies.

The comparison of an adult medieval sample with a juvenile present-day sample in this study will probably overestimate severity and prevalence of malocclusion in the medieval sample, according to the findings of Helm and Prydsö.[24] Thus, the difference between the medieval and modern samples in this study would likely be even greater if the medieval sample had consisted of juveniles. As an overall judgment of our study, it seems likely that there is a genuine difference in the prevalence and severity of malocclusions between the medieval and the modern findings because major differences were found between the 2 samples.

Objectively assessed treatment need does not necessarily coincide with subjective treatment need,[1] and this also varies with different ages.[53,54] A patient's experience of malocclusion should be considered when assessing treatment need. This was elucidated by Espeland et al[3] for the modern sample used in this study and the applicability of the NOTI. They found that 85% of the patients with orthodontic concerns were objectively determined according to the NOTI to need treatment. However, more than 50% of the subjects allocated to group B (great need) did not experience a need for treatment. Generally, this category does not pose a dilemma for the professional advisor because the potential threat to oral health and function is great, and the future esthetic impairment is often obvious. Thus, after informing and educating patients and parents, treatment will usually be agreed on for the group B patients. According to the NOTI, two thirds of the children were assessed to need treatment. When concern for treatment was taken into account, the treatment need was estimated at about 35%, including all subjects in group B and those in group C who expressed concern; this was only one third of the subjects who were objectively allocated to group C. This 35% frequency was found to correspond fairly well to the proportion of children in Norway who actually received treatment during the last 2 decades.[54]

To better illustrate the difference between the medieval and the modern samples, it is tempting to apply the subjectively corrected objective treatment need findings of Espeland et al[3] to the medieval prevalence and severity of malocclusions. Hypothesizing on what a similar subjectively corrected objective treatment need of the medieval sample's prevalence and severity of malocclusion would be in the modern sample, we could as previously described add 7 (group B) and 10 (one third of group C) and get a frequency of 17%, which is only half of the present-day subjectively corrected objective orthodontic treatment need. In other words, only half of today's children actually undergoing orthodontic treatment in Norway would be undergoing orthodontic treatment if there had not been an increase in the prevalence and severity of malocclusion from medieval times until today. Furthermore, the sex distribution in Figure 1 shows that, under such conditions, twice as many girls as boys would undergo orthodontic treatment.

CONCLUSIONS

This study indicates a significant increase in both prevalence and severity of malocclusions during the last 400 to 700 years in Norway. Furthermore, although no sex differences were found in the present-day sample, females showed both higher prevalences of malocclusions and more severe malocclusions than males in the past. Only 36% of the medieval group had a professionally assessed need for orthodontic treatment, compared with 65% of the modern sample.

We acknowledge Professor Per Holck, Faculty of Medicine, University of Oslo, for giving access to the collection and for valuable advice.

REFERENCES

1. Proffit W, Fields HW Jr. Contemporary orthodontics. 3rd ed. St Louis: Mosby; 2000.
2. Ng'ang'a PM, Ohito F, Øgaard B, Valderhaug J. The prevalence of malocclusion in 13- to 15-year-old children in Nairobi, Kenya. Acta Odontol Scand 1996;54:126-30.
3. Espeland LV, Ivarsson K, Stenvik A. A new Norwegian index of orthodontic treatment need related to orthodontic concern among 11-year-olds and their parents. Community Dent Oral Epidemiol 20;1992:274-9.
4. Thilander B, Myrberg N. The prevalence of malocclusion in Swedish schoolchildren. Scand J Dent Res 1973;81:12-20.
5. Ingervall B, Seemann L, Thilander B. Frequency of malocclusion and need of orthodontic treatment in 10-year old children in Gothenburg. Swed Dent J 1972;65:7-21.
6. Bjørk A, Helm S. Need for orthodontic treatment as reflected in various ethnic groups. Acta Socio Med Scand 1969; 14(suppl):209-14.
7. Helm S. Malocclusion in Danish children with adolescent dentition: an epidemiologic study. Am J Orthod 1968;54:352-65.
8. Grude R. Need for orthodontic treatment in the county of Nordland in northern Norway (Norwegian). Nor Tannlegeforen Tid 1962;72:525-9.
9. Forøy AO. Prevalence of malocclusion and need for treatment among 6-year-olds in the community of Nittedal in Norway (Norwegian). Nor Tannlegeforen Tid 1979;89:538-40.
10. Telle ES. A study of the frequency of malocclusion in the county of Hedmark, Norway. A preliminary report. Trans Eur Orthod Soc 1951;192-8.
11. Rølling S. Registration of occlusion (Danish). Copenhagen: Akademisk Forlag; 1966.
12. Myllärniemi S. Malocclusion in Finnish rural children. An epidemiological study of different stages of dental development. Suom Hammaslääk Toim 1970;66:221-64.
13. Engh O. Prevalence of malocclusion in schoolchildren (Norwegian). Nor Tannlegeforen Tid 1970;80:622-9.
14. Mathiesen A. Malocclusion among 12-year-olds in the county of Finnmar (thesis). Oslo: University of Oslo; 1992.
15. Iseri H, Uzel I. Impaction of maxillary canines and congenitally missing third molars. Description of an ancient skull (7250-6700 BC). Eur J Orthod 1993;15:1-5.
16. Smyth KC. Some notes on the dentitions of Anglo-Saxon skulls from Bidford-on-Avon with special reference to malocclusion. Dent Rec 1934;54:1-28.
17. Brash JC. The aetiology of irregularity and malocclusion of the teeth. London: Dental Board of the United Kingdom; 1956.
18. Mellquist C, Sandberg T. Odontological studies of about 1400 medieval skulls from Halland and Scania in Sweden and from Norse colony in Greenland, and a contribution to the knowledge of their anthropology. Odontol Tidskr 1939, Suppl 38.
19. Lundström A, Lysell L. An anthropological examination of a group of medieval Danish skulls, with particular regard to the jaws and occlusal conditions. Acta Odontol Scand 1953;11: 111-28.
20. Lysell L, Filipsson R. A profile-roentgenologic study of a series of medieval skulls from northern Sweden. Odontol Tidskr 1958;66:161-74.
21. Hasund AP. Attrition and dental arch space. Trans Eur Orthod Soc 1965;41:121-31.

22. Hasund AP. Occlusion and craniofacial morphology in medieval populations in Oslo and Heidal (thesis). Oslo: University of Oslo; 1966.
23. Mohlin B, Sagne S, Thilander B. The frequency of malocclusion and the craniofacial morphology in a medieval population in southern Sweden. Int J Skeletal Res 1978;5:57-84.
24. Helm S, Prydsö U. Prevalence of malocclusion in medieval and modern Danes contrasted. Scand J Dent Res 1979;87:91-7.
25. Andrik P. Die Entwicklung der bissomalien vom neolithikum bis zur gegenwart. Fortschr Kieferorthop 1963;24:12-21.
26. Corruccini RS. An epidemiologic transition in dental occlusion in world populations. Am J Orthod 1984;86:419-26.
27. Vyslozil O, Jonke E. Kieferortopädisch-anthropometrische vergleichsuntersuchung an 100 jahre alten menschlichten schädeln und österreichische bundesheersoldaten. Informationen aus Orthodontie und Kieferorthopädie 1994;26:409-36.
28. Weiland FJ, Jonke E, Bantleon HP. Secular trends in malocclusion in Austrian men. Eur J Orthod 1997;19:355-9.
29. Björk A, Krebs A, Solow B. A method for epidemiological registration of malocclusion. Acta Odontol Scand 1964;22:27-41.
30. Holck P. The Schreiner collection at the Institute of Anatomy, Medical Faculty (Norwegian). Oslo: University of Oslo; 1982.
31. Schreiner KE. Crania Norvegica I. Thesis. Oslo: University of Oslo; 1939.
32. Torgersen J, Getz B, Berle E. Die mittelalterliche bevölkerung von Oslo. Z Morph Anthrop 1964;56:53-9.
33. Slagsvold O. Variations in the transversal dimension of the cranium (thesis). Oslo: University of Oslo; 1969.
34. Howels WW. Cranial variation in man. A study by multivariate analysis of patterns of difference among recent human populations. Cambridge, Mass: Papers of the Peabody Museum of Archaeology and Ethnology, Harvard University; 1973. p. 67.
35. Haugen LK. The human upper and middle face. A morphological investigation in a Norwegian medieval population (thesis). Oslo: University of Oslo; 1976.
36. Larsson E. Malocclusions in a juvenile medieval skull material. Swed Dent J 1983;7:185-90.
37. Lindsten R, Øgaard B, Larsson E. Dental arch space and permanent tooth size in the mixed dentition of a skeletal sample from the 14th to the 19th centuries and 3 contemporary samples. Am J Orthod Dentofacial Orthop 2002;122:48-58.
38. Lindsten R, Øgaard B, Larsson E, Bjerklin K. Transverse dental and arch depth dimensions in the mixed dentition in a skeletal sample from the 14th to the 19th century and Norwegian children and Norwegian Sami children of today. Angle Orthod 2002;72:439-48.
39. Lindsten R. Secular changes in tooth size and dental arch dimensions in the mixed dentition. Swed Dent J Suppl 2003;(157):1-89.
40. Wagner K. Mittelalterknochen aus Oslo. N. Videnskabs-Akad. Skr. 1926; 7. Oslo.
41. Schreiner KE. Crania Norvegica II. Thesis. Oslo: University of Oslo; 1939.
42. Landis JR, Koch GG. The measurement of observer agreement for categorical data. Biometrics 1977;33:159-74.
43. Altman DG. Practical statistics for medical research. London: Chapman & Hall; 1997.
44. Corruccini RS, Sharma K, Potter RHY. Comparative genetic variance and heritability of dental occlusal variables in U.S. and northwest Indian twins. Am J Phys Anthropol 1986;70:293-99.
45. Larsson E, Øgaard B, Lindsten R, Holmgren N, Brattberg M, Brattberg L. Craniofacial and dentofacial development in pigs fed soft and hard diets. Am J Orthod Dentofacial Orthop 2005;128:731-9.
46. Begg PR, Kesling PC. Begg orthodontic theory and technique. Philadelphia: W. B. Saunders; 1977.
47. Harris EF, Johnson MG. Heritability of craniometric and occlusal variables: a longitudinal sib analysis. Am J Orthod Dentofacial Orthop 1991;99:258-68.
48. Mew JRC. The postural basis of malocclusion: a philosophical overview. Am J Orthod Dentofacial Orthop 2004;126:729-38.
49. Helm S, Petersen PE. Individual changes in malocclusion from adolescence to 35 years of age. Acta Odontol Scand 1989;47:211-6.
50. Bondevik O. Growth changes in the cranial base and the face: a longitudinal cephalometric study of linear and angular changes in adult Norwegians. Eur J Orthod 1995;17:525-32.
51. Bondevik O. Changes in occlusion between 23 and 34 years. Angle Orthod 1998;68:75-80.
52. Sobkowiak EM, Berg P, Held M, Schumacher GH. Vergleichende kariesepidemiologische untersuchungen an schädelfunden (aus der eisenzeit, slawenzeit und dem mittelalter) und probanden der gegenwart. Zahn Mund Kieferheilkd Zentralbl 1978;66:359-66.
53. Stenvik A, Espeland L, Berset GP, Eriksen HM, Zachrisson BU. Need and desire for orthodontic (re-) treatment in 35-Year-Old Norwegians. J Orofac Orthop/Fortchr Kieferorthop 1996;57:334-42.
54. Stenvik A, Espeland L, Mathisen A. A longitudinal study on subjective and objective orthodontic treatment need. Eur J Orthod 1997;19:85-92.