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Final thesis

Advantages of Orthodontic Treatment

Narrative literature review

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SUMMARY

Orthodontic treatment is mainly financed privately which alters the dynamics of treatment justification. The orthodontic community may directly reach out to each potential patient as each of them may decide freely if they want to be orthodontically treated. The patients are usually not medically educated and therefore, orthodontists may misleadingly claim theories and vague suggestions of treatment advantages as some ultimate truths. This literature review aims to gather, summarize, and criticize relevant and possibly misleading claims of orthodontic treatment advantages – and comes to several conclusions of different degrees of confidence.

Rather confidently, it may be concluded that orthodontic treatment may be advantageous to exponentiate the improvement of localized impaction-related and occlusal-traumatic periodontitis and to normalize several performative aspects of the masticatory system. It may also normalize the sociocultural reception and improve psychosocial well-being. About the oral health-related quality of life, it may be preliminarily concluded that it may indeed be improved by orthodontic treatment, but the concept itself still is so vague that this conclusion should be taken as nothing more than a call for further research.

With lesser confidence, it may preliminarily be concluded that orthodontic treatment may be advantageous to reduce caries risk in certain types of malocclusion. It may also be advantageous to treat and support certain types of malocclusions to treat certain types of temporomandibular disorders. Due to the lack of studies, it remains unclear if the inclusion of orthodontics in the multidisciplinary treatment of speech disorders is always advantageous.

Keywords: Orthodontic treatment, malocclusion, OHRQOL, periodontitis, caries, mastication, speech, psychosocial well-being

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INTRODUCTION

Compared to therapeutic and other dental treatments, orthodontic treatment has relatively low chances of being (fully) compensated by health insurance – if health insurance

by the state or private companies is even available. In Germany, for example, public healthcare ensures every insurant free option for necessary therapeutic, periodontal, and prosthetic treatments. But for orthodontic treatment, even if the healthcare provider rarely acknowledges the medical necessity, the patient still has to pay 20% instead of otherwise the total costs. This restricts access to orthodontic treatment for low-income patients. [1] In France, the public healthcare system covers 70% of any basic therapeutic and periodontal treatment and, for low-income patients, also prosthetic treatment. The field of orthodontics has no strict regulations, allowing orthodontists to not offer low-cost options – while the healthcare provider, irrespectively of the high costs initiated by their non-regulation, will still only reimburse the amount of a low-cost treatment option to the few patients with acknowledged medical necessity. [2] This concept restricts access to orthodontic treatment for low-income patients even more critically than in Germany.

The exact characteristics depend on the local healthcare system, but in general, orthodontic treatment is mainly financed privately, directly by the patient – which alters the dynamics of treatment justification in the following way. When, in other fields of dentistry, the treatment costs are paid rather indirectly by the patient via healthcare taxes – then the collective of all taxpayers decides together which treatments are justified and therefore paid. The creation of such guidelines is commonly conducted by independent experts in the field. Coming to the altered dynamics of treatment justification of orthodontics, we may recognize that there is no inclusion of independent expert opinions as there is no mediating collective that requires their guidelines. The orthodontic community may now directly reach out to each potential patient as each of them may decide freely (as far as they are financially free) if they want to be orthodontically treated. The patients are usually not medically educated and therefore, orthodontists may misleadingly claim theories and vague suggestions of treatment advantages as some ultimate truths.

The goal of this literature review is to clear up the waters by gathering, summarizing, and criticizing the most relevant and possibly misleading claims of orthodontic treatment advantages.

LITERATURE SEARCH STRATEGY

The literature included in this narrative review was not strictly systematically searched for and therefore the integrity relies on the effort and impartiality of the author. For each paragraph, the literature was scoped with initial searches for recent systematic reviews in the databases of PubMed Central and Google Scholar by the following pattern. In PubMed Central, the initial searches were constructed as *((systematic review[Title]) AND (malocclusion[Title] OR orthodontic[Title])) AND (simplified topic of each paragraph[Title])*. In Google Scholar, the initial searches were constructed as *"systematic review" + "malocclusion" + "simplified topic of each paragraph"* and *"systematic review" + "orthodontic" + "simplified topic of each paragraph"*. All initial searches were restricted to ten years but later supplemented by older publications. Further supplementations were taken from the references of previously included studies and the repetition of similar searches after the exclusion of the term *systematic review*. Studies were mostly excluded if the investigated time span was during the treatment instead of pre- to post-treatment. Studies were occasionally excluded when the sample was too small or unrepresentative in other ways.

TREATMENT ADVANTAGES

Improvement of the oral health-related quality of life

The concept

Zhou et al. (2014) observed that the amount of recent literature on oral health-related quality of life (OHRQOL) is growing fast – indicating the growing interest and relevance of this broader concept respecting more dimensions than just the biophysical. [3] The concept is only vaguely defined, combining clinical and patient factors. In a systematic scoping review of different OHRQOL models, *Sekulic et al. (2019)* recaptured that the 13 relevant models were incompatible with each other as they differed immoderately in dimension amount, dimension definitions, data sources, statistically versus theoretically based models, and more. The only

absolute consistency was the concept of oral health as a multidimensional concept. It may still be recognized that most models included four dimensions that (sometimes differently named) were the same ones as described by *John et al. (2014)* in several factor analysis studies. Based on the Oral Health Impact Profile (OHIP) model, these researchers from seven countries observed that oral health mainly consists of a differentiated four-dimensional structure made up of psychosocial impact, oral function, orofacial appearance, orofacial pain – sorted from most to least influential, though nonetheless too influential to be excluded. [4–8] However, also this statistical evidence has to be understood as merely quantitative by artificial categorization while most clinical situations present with mixed categories – possibly leading to the significant dimensional fluctuation in the models that *Sekulic et al. (2019)* had recaptured. [4]

Influence of malocclusion and orthodontic treatment

In a longitudinal study, *Chen et al. (2015)* confirmed the previous observation that malocclusion had a significant negative impact on OHRQOL. [9,10] In systematic reviews and one meta-analysis, *Javidi et al. (2017)* and *Zhou et al. (2014)* recaptured that orthodontic treatment could moderately improve the OHRQOL of children, adolescents, and adults – which was also significant in comparison to untreated controls with malocclusion. [3,11] There had been mentions by *Zhou et al. (2014)* and *Karimi-Afshar et al. (2018)* of studies with opposing observations, but those studies were irrelevant as they either simply described the decreased OHRQOL during the ongoing treatment – or the decreased OHRQOL of one orthodontic option over another. [3,12–15] Of the found studies, the only valid observation of long-term decreased OHRQOL was in the longitudinal study by *Karimi-Afshar et al. (2018)*. [13] But especially in this field of OHRQOL without clearly defined study criteria, the systematic review of all studies with a sufficient level of evidence should be valued higher than single outliers that have no higher levels of evidence than any of the other studies within the consensus.

Conclusion

Due to the lack of a methodological guideline provided by the OHRQOL concept as it contemporarily is commonly used, the following chapters of this review will not be centered around its dimensions, but rather around some of the contemporarily most relevant discussions and claims about the advantages of orthodontic treatment. The results may if preliminarily

found relevant, be targeted again by future research, then categorized into the domains of OHRQOL – according to the suggestions of *John et al. (2014)*.

Improvement of temporomandibular disorders

Temporomandibular disorders (TMDs) may become a more common condition in patients that seek orthodontic treatment as the orthodontic patient age is rising. [16,17] The anatomical and physiological proximity of teeth and the temporomandibular joint (TMJ) and the interest of orthodontists in the following have led to the assumption that malocclusion may be related to TMDs. [18] Logically, if that was the case – orthodontic treatment may be advantageous over some treatment alternatives. [17–19]

The influence of malocclusion

Okeson (2020) recaptured in their textbook that it was merely due to the lack of evidence for each single suggested TMD etiology and dissent between the relevant studies, the contemporarily commonly accepted concept of etiology is multifactorial. But criticizing this unfounded philosophizing did not stop them from participating in it. Specifically, they theorized that occlusal factors may be one of the etiological domains – together with trauma, emotional stress, deep pain input, and parafunction. [20] Such theories may seem like a logical compromise, but the lack of evidence let other investigators suggest that occlusal factors may only by chance coincide with TMDs and should not be considered in the etiological concepts. [18,21,22] *Trivedi et al. (2022)* recaptured in a systemic review and meta-analysis with fair quality evidence that TMDs and associated symptoms were nearly 15 times more prevalent in subjects with malocclusion with or without more associated factors. [23] *Fernández-González et al. (2015)* specified this to be especially true for subjects with an untreated crossbite, crowding, or large overjet which had a higher prevalence of signs and symptoms of TMD – as they recaptured from some of the included studies in a systemic review (and many other studies of lower evidence). [24] *Manfredini et al. (2017)* specified the TMD-associated malocclusion to two specific features which were, firstly, the centric relation maximum intercuspation slide and, secondly, the mediotrusive interferences – as they recaptured from some of the included

studies in a systematic review. [21] Both *Fernández-González et al. (2015)* and *Manfredini et al. (2017)* still concluded that the evidence was insufficient to mark clear associations between specific types of malocclusion and the development of significant signs and symptoms of TMD, but both their systematic reviews are without meta-analysis and older than the previously discussed one by *Trivedi et al. (2022)* which advocated the relevance of the associations between TMD and malocclusion – which was recaptured by all of them to in varying mode and degree. [21,23,24] In a cross-sectional study, *Aboalnaga et al. (2019)* observed that 52.7% of the subjects with TMDs presented with increased overjet (>3mm) with no significant difference among their investigated TMD categories: myalgia, disc displacement with reduction, disc displacement without reduction, degenerative disc disorders, and subluxation. [22] In the following paragraphs, TMDs will be differentiated to understand the logical differences in possible advantages of orthodontic inclusion in the definitive and supportive treatment.

Disc displacement with reduction and with intermittent locking

According to *Okeson (2020)*, disc displacement with reduction (DDWR) and disc displacement with intermittent locking (DDWIL) result from elongation of the capsular and discal ligaments coupled with thinning of the articular disc which is commonly caused by macrotrauma or microtrauma. They claimed an association between, firstly, DDWR and DDWIL and, secondly, class II division 2 malocclusion due to its orthopedic instability – as illustrated and described in figure 1. [20] To support this claim, they referred to studies by *Wright (1986)*, *Seligman & Pullinger (1989)*, *Solberg et al. (1986)*, and *Tsolka et al. (1995)*, but none of these studies precisely suggested that. *Wright (1986)* found an association with class II division 1 (not division 2) but reported that no precise subdivision between division 1 and 2 of class II malocclusion was possible. [25] According to *Tsolka et al. (1995)*, *Seligman & Pullinger (1989)* also found this association but questioned the significance of their finding due to the small sample size. [26,27] *Solberg et al. (1986)* reported that their sample was too small for making proper subdivisions into divisions 1 and 2 of class II malocclusion. Even precise super-categorization was not possible because the cephalometric assessment was impossible. [28] *Tsolka et al. (1995)* also found an association with class II division 1 which became especially clear when looking at the shifts between non-TMD and TMD subjects. [27] So far, the evidence is still weak and their suggestions need further investigation. Seemingly, DDWR and DDWIL may be associated with class II division 1 (not 2) malocclusion.

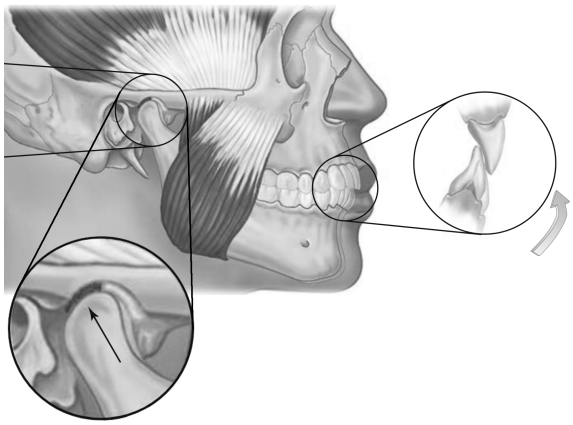


Figure 1: Orthopedic instability (here: due to heavy anterior contacts) disallows the posterior teeth to occlude normally. When loaded, the elevator muscles force the posterior teeth into occlusion, resulting in posterior deflection of the condyle. This is a risk factor to develop disc displacements since it can lead to elongation of the inferior retrodiscal lamina and discal ligament as well as thinning of the posterior border of the disc. [20]

For the treatment of DDWR and DDWIL, the first step is the elimination of the macrotraumatic or microtraumatic etiological factors and the elimination of painful reciprocal clicking by replacing the condyle relatively centrally in the fossa with an anterior positioning appliance – as illustrated in figure 2. Then, the therapeutic occlusal relation or pre-treatment occlusion may be stabilized – for which orthodontic treatment may be advantageous over prosthodontic options or the option of selective occlusal reduction in its minimal invasiveness. [17,20] Merging the longitudinal studies by *Moloney & Howard (1986)* and by *Okeson (1988)*, the orthodontic treatment appears advantageous over the option of not changing the occlusion. *Okeson (1988)* reported 66% of joint clicking reoccurrence and 25% of pain reoccurrence after 2.5 years if no occlusal alterations were received. [29] *Moloney & Howard (1986)* reported only 50% of joint clicking reoccurrence after 3 years and 1 month on average when orthodontic stabilization of the therapeutic occlusal relation was performed, but they also reported 35% of local TMJ pain reoccurrence during the initial orthodontic treatment. [30] Proper studies are needed to be actually able to compare the investigated options. Based on the discussed evidence, it is not reasonable to assume that the association between class II division 1 malocclusion and DDWR and DDWIL means that malocclusion is an etiological factor – it may as well be a common symptom. [29,30] Still, as long as the question of etiology remains unclear and therefore several treatment approaches may be chosen by trial and error – it may be acknowledged that the orthodontic treatment may be advantageous over prosthodontic options in the aspect of reversibility. [17]

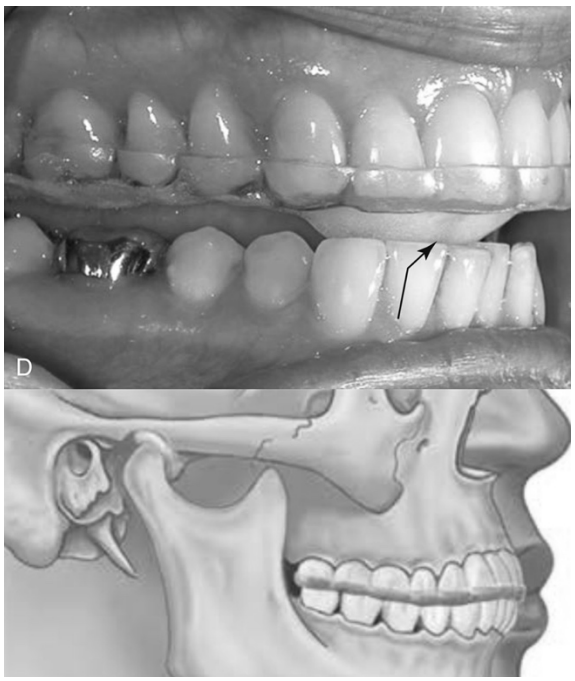


Figure 2: Occluding on the (arrow-indicated) ramp of the anterior positioning appliance, the mandible is guided forward and the condyle is repositioned on the disc in a more normal relationship. [20] The disc position may be compared to figure 1.

Disc displacement without reduction

Aboalnaga et al. (2019) observed that subjects with disc displacement without reduction (DDWOR) had a significantly increased incidence of right mediotrusive interferences – although those were not related to joint pain or sounds and therefore not considered as a specific TMD-contributing factor. The DDWOR subjects also had steeper mandibular planes compared to normal anteroposterior and vertical craniofacial patterns. They (and also the subjects with subluxation) also had a significantly decreased Jarabak ratio – outside the four normal ranges observed in the cross-sectional studies by *Alshahrani (2018)* and *Kuramae (2007)*. [22,31,32] Figure 3 is an illustration of the Jarabak ratio. The DDWOR subjects also had a significantly increased MP/FH angle which describes the clockwise rotation of the mandible. [22] In another cross-sectional study, also *Sakar et al. (2011)* observed that the presence and progression of (any type of) disc displacement were associated with significant changes in cephalometric parameters, particularly related to the mandible. The severity of disc displacement was related to the clockwise rotation of the mandible and decreased ramus height and Jarabak ratio. [33] There had been studies that suggested that the decrease in posterior facial height and backward rotation of the mandible are merely symptoms of disc displacements – to which *Aboalnaga et al. (2019)* annotated that, nevertheless, these changes were more severe as internal derangement progressed to a disc displacement without reduction. Therefore, the multifactorial etiology may include certain dentocraniofacial

morphological changes that progress along the progression of the partially initiated disc displacement. [22] *Okeson (2020)* described the etiology of DDWOR to most commonly be macrotrauma and microtrauma. [20] If there was no macrotraumatic event and no other more relevant microtraumatic etiological factor can be detected, orthodontic treatment to correct the mediotrusive interferences, the increased MP/SN angle, and the significantly greater vertical facial form may be advantageous to not only reduce the symptoms but possibly also decelerate the progression of the condition.

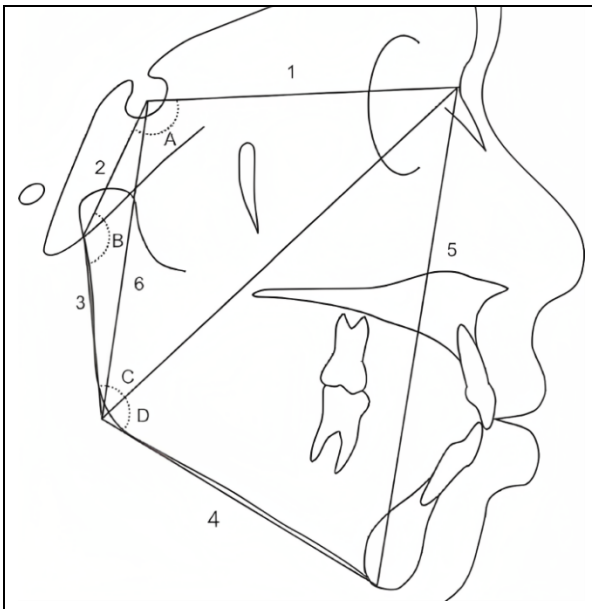


Figure 3: N-Me (anterior facial height) and 6. S-Goc (posterior facial height). (S-InGo)/(N-Mn) is the Jarabak ratio which described the vertical facial form. [22,32]

Synovitis and capsulitis

Synovitis and capsulitis were described by *Okeson (2020)* as follows: They usually arise from infection spread from adjacent tissues and therefore require antibiotic treatment. But they may also arise in a sterile way – secondarily from macrotrauma or, less commonly, also from microtrauma.

One possible symptom is malocclusion, but it should be merely observed and stabilized only by occlusal appliances after all other measures were attempted or at least considered – due to its possibly dual nature. *Or and Yücetas (1986)* described that premature occlusal contacts (and the masticatory muscle spasms associated with it) may be common microtraumatic etiologies of disc derangements causing capsulitis. They suggested treatment by grinding those premature contacts which they found effective for over 80% of their subjects. [34] The etiological chain *premature contacts – disc derangements – capsulitis* is not conflicting with

the multifactorial concepts as by *Okeson (2020)*, but it is not the only possible etiological chain. The microtrauma may also be associated with DDWR and DDWIL which (as previously described in a separate paragraph) may be partially caused by a malocclusion. [20]

For the reason of uncertainty which exact and possibly multifactorial etiological chain is underlying, it may be considered advantageous if the treatment strategy is as non-invasive as possible and reversible. Therefore, when no other possible underlying condition can be detected or when malocclusion is suspected to be etiologically involved, orthodontic treatment may be as effective as the prosthodontic adjustments tested by *Or and Yücetas (1986)* – with the additional advantage of lesser invasiveness and reversibility. [17,34]

Retrodiscitis

As described by *Okeson (2020)*, retrodiscitis is an inflammation that is usually caused by trauma. Extrinsic trauma will most likely not recur – so then, only supportive treatment with analgesics, movement restriction according to the pain, and a soft diet are indicated. Acute malocclusion may be a symptom caused by condyle displacement to the posterior direction from the traumatic force, anterior displacement from the following swelling of the inflamed retrodiscal tissues, and displacement from condyle fracture due to the force resistance of the outer oblique and the inner horizontal portions of the temporomandibular ligament. The affected side usually presents with an inability to bite on the posterior teeth and joint pain when force is applied. In these cases, the occlusion should be stabilized using a regularly adjusted stabilization-type appliance to prevent tooth clenching from the further provocation of the inflammation. Orthodontic treatment of acute malocclusion should not be part of the supportive treatment. [20]

According to *Okeson (2020)*, intrinsic trauma is associated with DDWR which (as previously described in a separate paragraph) may be partially caused by malocclusion orthodontic treatment may be considered in some cases. [20]

Degenerative joint diseases

Okeson (2020) described that also for the degenerative joint diseases (DJD) osteoarthritis and osteoarthrosis, the often unclear etiology may be DDWR and DDWIL. [20] Those possibly underlying conditions may be treated with possibly advantageous orthodontic involvement – as described in a previous chapter. *Aboalnaga et al. (2019)* theorized that the

retropositioned mandible may encourage the thinning of the posterior band of the disc and consequently its anterior displacement, or that anterior displacement of the disc leads to the gradual collapse of the joint space, with subsequent superior and posterior positioning of the condyle and clockwise rotation of the mandible clinically leading to increased vertical dimension and retropositioning of the mandible. They observed in a cross-sectional study that the few DJD subjects with these diseases had significantly more retropositioned mandibles and steeper mandibular planes compared to normal anteroposterior and vertical craniofacial patterns. The DJD subjects also had a significantly decreased Jarabak ratio – outside the four normal ranges observed in the cross-sectional studies by *Alshahrani (2018)* and *Kuramae (2007)*. [22,31,32] An illustration of the Jarabak ratio is to be found in figure 3. In the cases in which malocclusion may have been part of the multifactorial etiology of the DJD, the high progression of the cascade into osteoarthritis or osteoarthrosis logically possibly makes it very unlikely that orthodontic treatment of the etiologically underlying malocclusion is still advantageous to a relevant degree. But still, the main treatment of osteoarthritis is supportive and for that matter, the orthodontic treatment may still be advantageous. [20]

Influence of orthodontic treatment

Luther et al. (2010) attempted to investigate the effectiveness of orthodontic treatment to treat TMDs, but their main result was that none of the 284 found studies met the inclusion and quality criteria – stating an example of the low evidence in this field. In their non-systematic review, then, they recaptured that there was no sufficient evidence to show that active orthodontic treatment could prevent or relieve temporomandibular disorders. [35] Coming to signs and symptoms of TMDs, however, *Fernández-González et al. (2015)* recaptured in a systematic review that, in some of the included studies, orthodontic treatment could be advantageous – though they did not draw overall conclusions from that. [24] *Abrahamsson et al. (2013)* observed in a longitudinal study that subjects with dentofacial deformities had a higher frequency of myofascial pain and arthralgia than the control group of matching age and gender. 18 months after the combined orthodontic and orthognathic treatment, the frequency of TMD was lower in the treatment group – as illustrated and described in figure 4. [36]

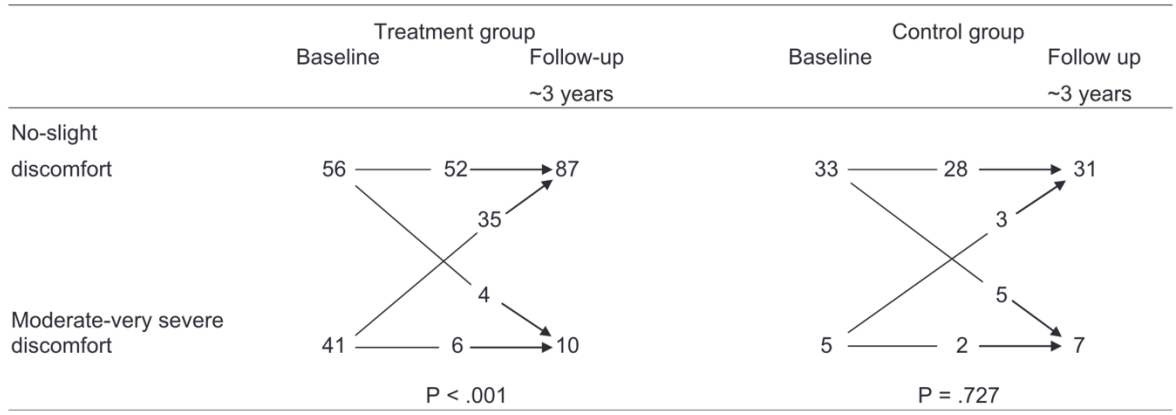


Figure 4: Before the treatment, 42.27% (41/97) of the treatment subjects were with moderate to very severe pain – while this was only the case for 13.36% (5/38) in the control group. In the treatment group, 85.37% (35/41) of subjects with previously moderate to very severe discomfort, the discomfort improved after the treatment – while in the control group, this development was observed only for 60% (3/5). The worsening of previously slight or no discomfort occurred for 15.15% (5/33) in the control group – and only for 7.14% (4/56) in the control group. After the treatment duration, only 10.31% (10/97) of the treatment subjects were with moderate to very severe pain – while in the control group, the incidence had risen to 18.42% (7/38). [36]

Conclusion

Some specific types of malocclusion seem to be associated with TMDs. This has occasionally been observed to exceed the status of a mere symptom, but to participate in the multifactorial etiology of the TMD. Orthodontic treatment may often be advantageous when the diagnostics suggest that malocclusion may have contributed to the development of disc displacements that may ultimately lead to secondary conditions. Especially mediotrusive interferences have been observed to be relevant for that matter – for which reason their orthodontic correction may be advantageous for the treatment and prevention of TMDs. One important guideline, however, is that for inflammatory diseases in the TMJ, the malocclusion should not be treated before all other attempts to treat the overall condition which commonly includes malocclusion as a mere symptom.

Improvement of periodontal condition

Influence of malocclusion on oral hygiene

The associations between malocclusion and periodontitis are mostly secondary ones to poor oral hygiene – as it had been emphasized by *Melsen (2022)* and others. [37–39] *Arora & Bhateja (2015)* observed in a cross-sectional study that there was a significant association between decreased oral hygiene status and malocclusion – compared to normal occlusion. [40] *Salim et al. (2021)* observed in a cross-sectional study that specifically crowding in both arches and poorer oral hygiene are to be associated – agreeing with several previous publications. Even moderate crowding was observed to have higher values of OHI-S compared to cases of mild or no crowding. [37,38,41,42] *Kolawole & Folayan (2019)* recaptured the association between crowding and poor oral hygiene to be caused by increased chances for food accumulation and plaque retention in those critical areas. [42] The only contrary study worth to be mentioned by *Salim et al. (2021)* was the cross-sectional study by *Abu Alhaija & Al-Wahadni (2006)*. They interpreted their observation to be without any correlation between occlusal irregularity and the number of sites with plaque. [43]

Influence of orthodontic treatment on oral hygiene

With respect to the principle of prevention over intervention, *Salim et al. (2021)* and *Melsen (2022)* suggested that orthodontic treatment may enable improvement in individual oral hygiene through accessibility and manual dexterity of brushing. [41] And due to the significantly more frequent dental appointments (compared to normal non-orthodontic patients) – motivational methods may also be very effective during and after the orthodontic treatment – as supported by data from a systematic review and meta-analysis by *Huang et al. (2018)* and a randomized controlled study by *Barbe et al. (2021)*. [44] Still, a combination of both technical and motivational factors may be the true nature of improvement of oral hygiene – as observed once more by *Glans et al. (2003)* in a longitudinal study. All subjects had significant improvements in oral hygiene when comparing the status before and after the orthodontic treatment, but the improvement was greatest in subjects that initially presented with crowding. [45,46] Older studies emphasized that behavioral change is not to be overestimated are the ones by *Ainamo (1972)* and *Behlfelt et al. (1981)*. In intra-subject

comparisons, they observed that the gingival condition was better around aligned than around malaligned teeth. [47,48] Also *Liu et al. (2022)* observed in a cross-sectional study that localized gingivitis was five times more common in schoolchildren than generalized gingivitis. This, after the chi-square test and binary logistic regression analysis, was also related to deep overjet and crowded teeth, deep overjet – as illustrated in figure 5. [49] From this, it may be assumed that not poor oral hygiene habits, but the difficulty of access to certain sites lead to gingivitis. Still, also studies similar to the ones by *Glans et al. (2003)*, *Ainamo (1972)*, and *Behlfelt et al. (1981)* should be re-conducted by modern standards for higher evidence. Regarding oral hygiene, it is to be concluded that orthodontic treatment may enable technical improvements when access is limited to crowded sites. Due to its nature of very frequent check-ups, it is also effective for motivational improvements. However, if motivation seems to be the main issue, the same check-up frequency may be implemented without orthodontic treatment to follow the principle of minimal invasiveness during the motivational treatment.

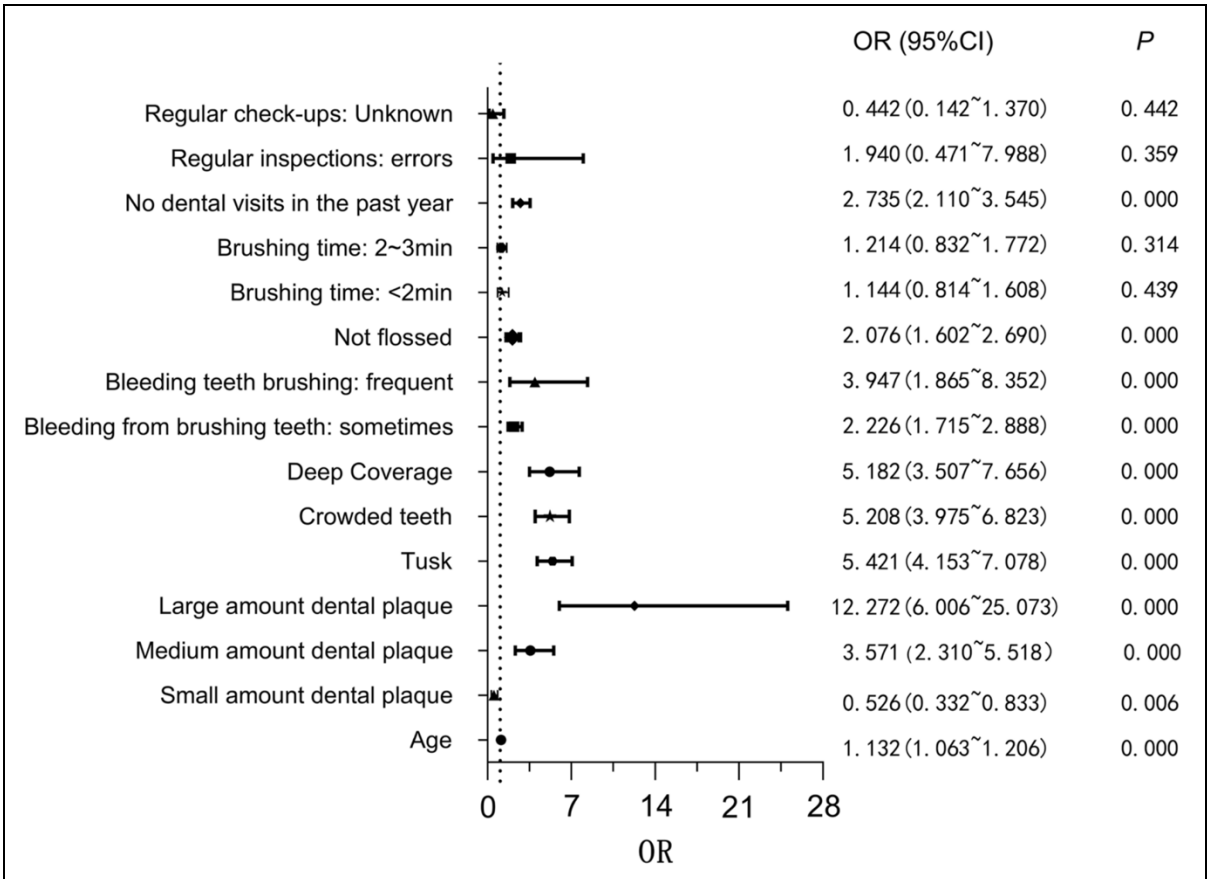


Figure 5: Binary logistic visual regression analysis of risk factors for gingivitis. OR = odds ratio, CI = confidence interval, P = P-value. [49]

Gingival recession

As *Mythri et al. (2015)* observed in their own cross-sectional study and recaptured from many previous ones, an abnormal tooth position may be part of the likely multifactorial etiology of gingival recession without any inflammation. [50] In a longitudinal study, *Antanavičienė et al. (2021)* observed that the simple orthodontic alignment was effective for 58.8% of the sites to induce the resolution of the recession and is advantageous over gingival plastic surgery in its lower invasiveness and resolution of the etiology. [51] The following discussion, however, will focus on inflammatory conditions and traumatic lesions of the periodontium.

Periodontitis

From a systematic review, *Bollen (2008)* reported that 19 out of the 25 included publications observed significantly more and greater periodontal disease in subjects with greater malocclusion. [52] In a cross-sectional study, *Harrel and Nunn (2009)* observed that the prognosis of teeth may already be impacted in independent association with minor occlusal discrepancies – as illustrated in figure 6. [53] As *Melsen (2022)* recaptured from several studies over the last half-century, malocclusion usually has no direct influence on the periodontal breakdown, but is associated with a more rapid progression of periodontal disease. Associations have been found between periodontal pocketing and crowding, between bone level and crowding, and between bone loss and tooth rotation. In general, an unstable occlusion (exposed to “jiggling forces”) and discrepancies between initial contact and centric occlusion, centric relation, and working and balancing contacts have been observed to be accelerating the regression of clinical attachment level (CAL). [37–39] Similar associations were investigated previously with a wide variety of positive and negative results which were well-summarized and methodologically criticized by *Bernhardt et al. (2006)*. [39] But also recent studies still require methodological criticism – as to be seen in the example of the literature review of *Fan & Caton (2018)* with blunt initial statements based on questionable search keywords and small concessions for opposing and inevitably reasonable suggestions. [54] *Sim et al. (2017)* and *Melsen (2022)* emphasized (as others previously) that all the previously listed associations between malocclusion and periodontitis are secondary ones to periodontal pathogens from poor oral hygiene. [37–39] In a longitudinal study, eight periodontal pathogens have been observed by *Thornberg et al. (2009)* to be more prevalent in subjects with periodontitis and malocclusion

– and to reduce during the retention phase of orthodontic treatment. [37,55] One observation of *Nunn & Harrel (2001)* that Melsen decided not to mention from the otherwise recaptured retrospective and longitudinal studies was the following. When excluding all subjects with suboptimal individual oral hygiene from treatment and control groups in a multiple regression model, they observed the same negative effect of malocclusion on the periodontal status and prognosis – indicating that malocclusion may be not only an accelerating factor but even an independent risk factor (synergistically) contributing to periodontal disease. Although only *Nunn & Harrel (2001)* provided relevant evidence for the independent periodontal risk of malocclusion, their methodological critique of other studies with deviating and opposing suggestions is logical and applicable even to recent studies. Therefore, a similar study should be repeated concerning the minor critique of *Nunn & Harrel (2001)* on their own method. [56,57] *Proffit (2007)* and *Li et al. (2022)* pointed out the biomechanic impact of occlusal trauma on the periodontium. Subjects with periodontitis have decreased areas of (possibly pre-existing) periodontal ligament (PDL) and more apically located centers of resistance (COR) which leads to increased pressure and moment from the same amount of occlusal forces, especially when they are in suboptimally directed due to malocclusion – as illustrated in figure 7. [58–60]

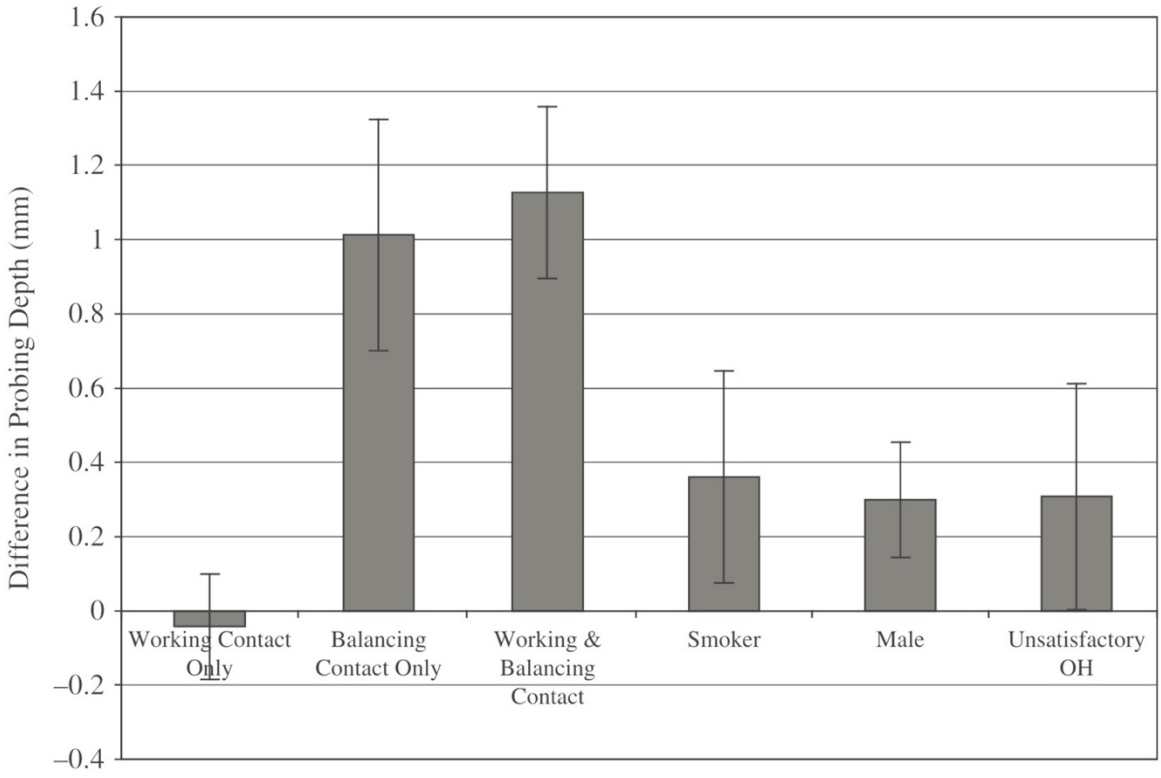


Figure 6: Difference in probing depth of teeth with contact type (working only, balancing only, working and balancing) compared with traditional risk factors associated with increased probing depth – after multiple GEE regression. [53]

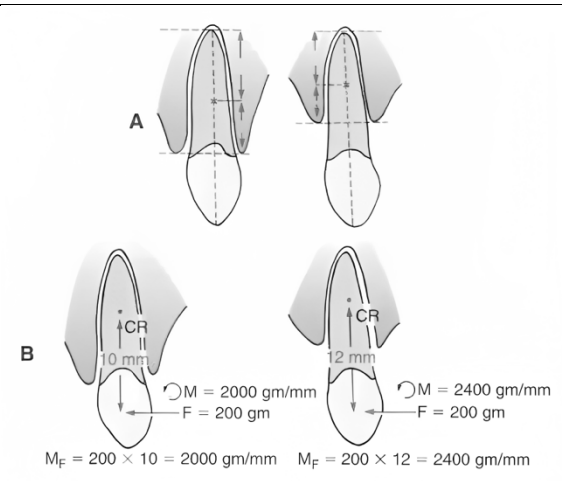


Figure 7: A) Loss of alveolar bone height (right) moves the center of resistance (COR) closer to the root apex. B) M_F = tipping moment from the force. F = force. If the COR moves apically, the M_F increases. [58]

Influence of orthodontic treatment

Similar precautions should be paid when considering orthodontic treatment. However, *Li et al. (2022)* and others claimed that orthodontic treatment (after initial periodontitis control) may also enable, accelerate, or otherwise beneficially participate in the treatment of localized

periodontitis by re-arranging the dentition, eliminating occlusal trauma, restoring stability, and dispersing the occlusal force. [58–60] In a systematic review *Zasčiurinskienė et al. (2016)* did (as others previously) not find rigorous scientific evidence that supports orthodontic treatment on periodontally compromised patients. However, they specify that the suggestions of improved PPD and clinical crown height are reasonable and that the improvement of CAL may still be discussed after studies with improved methodology. [52,61,62] Also very recent studies still had major methodological issues. For example, the 10 years longitudinal study by *Rocuzzo et al. (2018)* was planned prospectively but still lacked a control group to confirm the suggested benefit of orthodontic inclusion into the periodontal treatment. [63] In a cross-sectional study with 23,625 participants that were representative of the South Korean general population, *Sim et al. (2017)* observed that a history of orthodontic treatment was associated with a decreased rate of periodontitis – based on which they suggested that orthodontic treatment may have a preventive effect on periodontitis. The questionnaire results left the suggestion that individual oral hygiene may be the mediator for this association. [37] But once again, it is to be mentioned that this last suggestion is not uncritically supported by the longitudinal study by *Harrel & Nunn (2001)* in which the exclusion of subjects with suboptimal oral hygiene did not distort the general results of a positive effect of orthodontic treatment – as illustrated in figure 8. [56] As pointed out by *Bernhardt et al. (2006)*, differentiating between types of malocclusion and periodontitis is necessary to find stronger associations inside those otherwise vague supercategories. [39] Therefore, in the following, different types of periodontitis will be analyzed separately – although etiology and treatment aims are more or less the same because the strategies inside and outside the orthodontic field that may accompany periodontal treatment have a wide range – depending on the type of malocclusion.

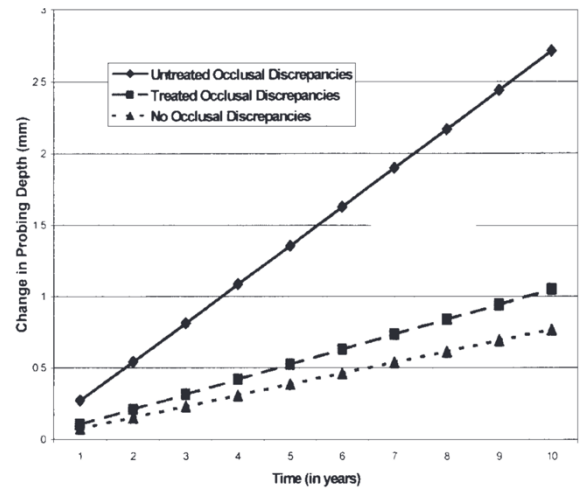


Figure 8: Periodontal probing depth comparison with the exclusion of surgically treated subjects. Similar results were obtained when only including subjects with good oral hygiene. [56]

Extrusion and intrusion

In a cross-sectional study, *Bernhardt et al. (2006)* observed that the alteration of occlusion contacts by elongation of teeth was significantly associated with the loss of CAL. [39] When, due to periodontitis, the tooth is extruded or the bone level is lowered – the COR will be found in a relatively higher position which will transmit occlusal forces worse distributed, leading to acceleration of bone loss or tooth extrusion – as illustrated in figure 9. In a 20-years-longitudinal study, *Melsen (2022)* observed that orthodontic treatment indeed had the potential to lower the COR into a normal position and (relative) rise of marginal bone level, thereby stabilizing the tooth physically while the other side of the self-reinforcing process was controlled with periodontal preparation and maintenance. The discussion about whether intrusion leads to true CAL gain or an establishment of a long epithelial attachment is not over, but anyways, the method has been observed to be clinically beneficial as it was at least mid-term successful for 19 out of 30 subjects. [38,64] In experimental animal studies with macaca rhesus monkeys and (foxhound) dogs, *Melsen et al. (1988)* and *Diedrich et al. (1996 & 2003)* also observed the histological benefit (besides the clinical benefit) of the orthodontic participation in this method with full recovery and new formation of the periodontium in the half year after the treatment. [38,60,65,66] For studies that do not agree with the benefits or even suggest the opposite of intrusion for periodontal benefits, *Melsen (2022)* and others claim iatrogenic problems, namely precise directions of forces did not respect the topography of the pre-existing defects and continuous hygiene and inflammation control. [38,65,67] However, this treatment option should mainly be applied if the clinical crown is rather long before the treatment (for abnormal or normal reasons) as the teeth may be intruded for up to 4 mm.

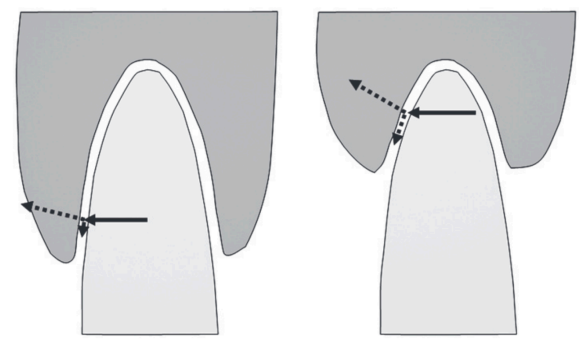


Figure 9: When forced horizontally, this force is converted into shearing forces. The more oblique (as closer to the apex) the surface, the more the shearing force leads to extrusion. [38]

Straight intrusion

If the tooth is intruded into the destructed periodontal tissues, orthodontic extrusion is the most obvious solution. The periodontal benefits of this orthodontic involvement in interdisciplinary treatment are by far less controversial than in cases of orthodontic intrusion. [38] According to *Zachrisson (2003)*, the alveolar crest and the gingival margin follow the orthodontic extrusive tooth movement on a scale of up to 80%. [68] In several case studies, *Mantzikos & Shamus (1997 & 1999)* and *Roth et al. (2004)* observed that orthodontic extrusion of unrestorable teeth with localized periodontitis before extraction for implantation (dynamic extraction) has the potential to reduce the periodontal pocket depth (PPD) by simple eversion, but also to let the eversed sulcus epithelium (red patch) mature to (normal) keratinized gingival epithelium after 4-6 weeks, and to increase the amount of alveolar bone – even into the interdental space and covered with the critical papilla. This method of (orthodontic) dynamic extraction is only to be compared with the pre-implantation protocol of extraction and bone grafting – above which the orthodontic method has the advantage of minimal invasiveness and better gingival contour including papillae. [68–70] In several case studies, also *Ingber (1974 & 1976)* observed that orthodontic extrusion may be useful in treating isolated one- or two-wall infrabony pockets – with the advantages of minimal invasiveness, higher aesthetic expectations, and better crown-root-ratio over surgical extrusion – as illustrated in figure 10. [71,72] In an experimental animal study, *van Venrooy & Yukna (1985)* consistently observed favorable clinical, radiographic, and histologic changes in the supporting tissues resulting from orthodontic extrusion – namely increased crestal bone levels, reduced bleeding upon probing, and reduced sulcus depth. Based on studies that observed periodontitis acceleration from intrusion without debridement, they suggested one key element of the consistent success of extrusion to be the shallowing of the pockets and conversion of subgingival microbial plaque to supragingival plaque – momentarily enabling professional debridement. [73]

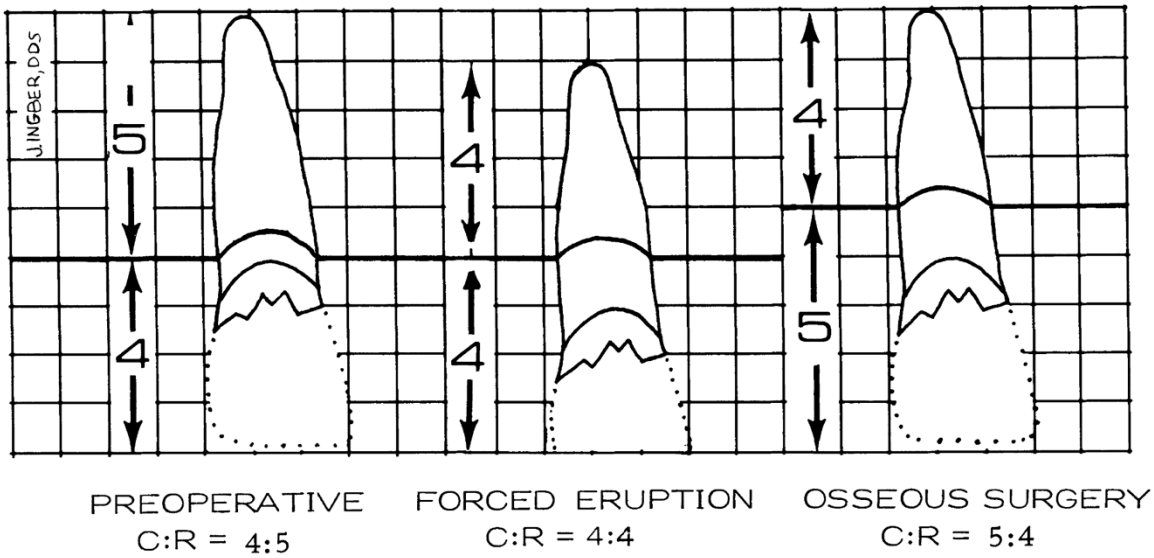


Figure 10: Comparison of the relative crown-to-root ratio (C:R) in pre-operative state vs. option of orthodontic forced eruption vs. option of osseous surgery. [72]

Intrusive tilting

Melsen (2022) and others described the relation between abnormal tilting and vertical periodontal defects – which is why uprighting has been observed to be beneficial. In a retrospective study, *Tu et al. (2022)* observed that orthodontic uprighting of molars may improve the overall efficiency of the localized periodontal treatment and accelerates it. The influenced improvements namely were the reduction of PPD, gain in CAL, new bone formation and the turnover rate for bone grafts, and desirable changes in the periodontal architecture. [74] The observations were similar to several previous clinical and histological studies – which are illustrated in figures 11 and 12 below – and for which *Brown (1973)* suggested that this is not only due to better access to periodontal treatment (which also is increasingly enabled by orthodontic uprighting) but also by the new axial inclination for more favorable distribution of periodontal force. [71,75,76] *Tu et al. (2022)* indirectly demonstrated the causality of orthodontic treatment for accelerated periodontal improvement when they point out the significance of the timing and direction of orthodontic forces. [74] The benefits of orthodontic uprighting for periodontal purposes were absolutely predictable for *Cohen (1984)* and fully successful (over 90%, the rest still partially successful) for *Tu et al. (2022)* – for which reason they all suggested the routined inclusion of orthodontic uprighting into localized periodontal treatment. [74,76] One more suggested reason for the high success rate of orthodontic uprighting by Proffit. Moving the tooth into the periodontal bone defect decreases the defect

area relative to the root surface which may be favorable for periodontal regeneration. [58] This suggestion lacks evidence, but *Tu et al. (2022)* observed that also the contrary is not evident. Moving teeth into the bone defect and the transplanted regeneration material did not lower change the success rate. [74] There have been studies that did not support the benefits of orthodontic inclusion in the treatment, but *Melsen (2022)* mentions their tendency to neglect the importance of a continuous periodontal regime (as also mentioned for other orthodontic treatments) – the crucial basis for any treatment strategy towards periodontitis. [38]

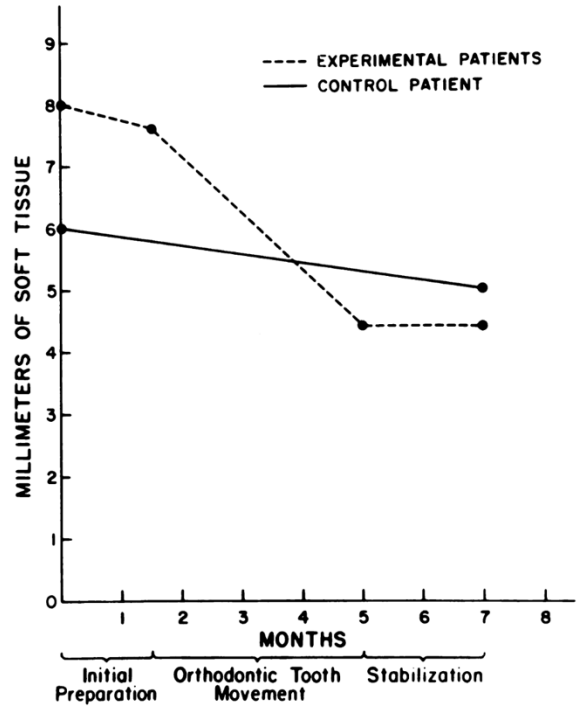
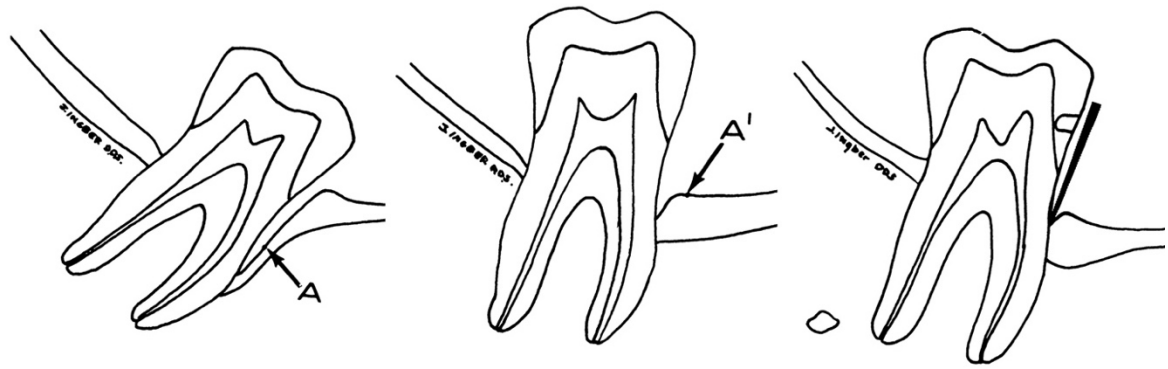


Figure 11: Comparison of soft tissue depth in subjects who underwent both initial preparation and orthodontic treatment to that in subjects who had no orthodontic therapy. [76]



Figures 12: Decrease in periodontal pocket depth resulting in part from the eversion of the pocket wall as the mesially inclined molar is uprighted. [75]

Deep traumatic overbite

Deep traumatic overbite describes the malocclusion with an overbite so deep that the incisal edges traumatically occlude onto the damage to the opposing periodontium during habitual or centric relation, often with retroclined upper incisors – as illustrated in figure 13. [77–82] Logically, lateral periodontal lesions have been associated with the severity of the overbite, but also the oral hygiene condition – as by *Nasry & Barclay (2006)* in retrospective case studies. [78] However, it is important to note that the deep traumatic overbite is by definition the origin of the traumatic lesions and that the severity of the lesion may be influenced by poor oral hygiene. Based on their observation of the uncommon pathogenesis of the periodontal pockets that start to progress from a more apical level within the pocket, not from the gingival margin – *Nasry & Barclay (2006)* suggested the synergistic mechanism of the deep overbite with the oral hygiene. Incisal edges may push plaque and calculus subgingivally which chronically complicates individual oral hygiene. [78] For the reason of complicated periodontal involvement, periodontal treatment should always be included in the therapy – although the correction of the traumatic malocclusion may enable self-healing of the periodontium if the inflammation is not too progressed.

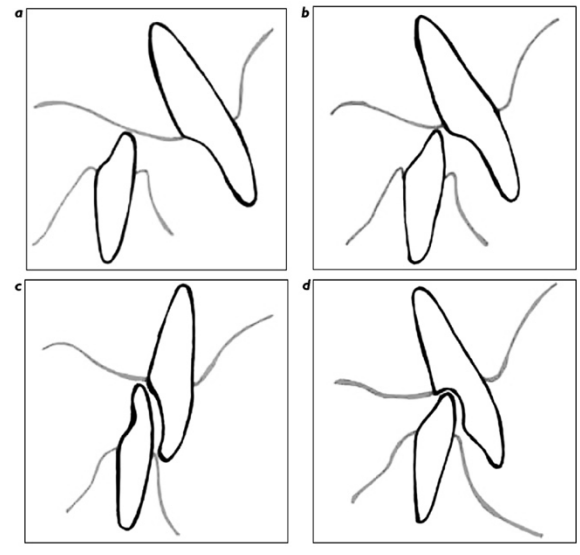


Figure 13: Traumatic overbite classification according to Akerly: (a) type I, (b) type II, (c) type III, (d) type IV. [82]

In most cases, the basis of the deep traumatic overbite is class II malocclusion with supra-eruption of the anterior teeth, infraocclusion of the posterior teeth, excessive overbite, or a combination of those. For the treatment of such deep bites, there is a wide variety of commonly accepted treatment strategies that are mostly inside the orthodontic field – as described by *Jain (2021)*. [83,84] *Takeda et al. (2022)* recaptured the ongoing discussions:

extraction vs. non-extraction, removable vs. fixed appliances, and sectional vs. continuous wires. Finally, they concluded from the frame of these debates that there is a consensus for orthodontic treatment options to be the only relevant ones for this type of malocclusion. [81,85] It is to be mentioned that the current evidence about treatment success is weak and highly biased – as *Millett et al. (2012)* concluded in a systematic review. [86] Still, also *Millett et al. (2018)* acknowledged in a later review that only in severe cases as described by *Jain (2021)*, the field of orthodontic treatments may be extended to the addition of orthognathic surgery. In marginal severity, choosing one of the many orthodontic options over the surgical one has the advantage of minimal invasiveness. Also, the establishment of a traumatic deep overbite is most common in children – another relative contraindication for surgery. [81,83,87]

Aside from the most severe cases mentioned before, there are a few more exceptional etiologies of a deep traumatic overbite that, in such cases, may offer relevant treatment alternatives outside the orthodontic field. Those less common etiologies are the altered dental morphology, failure of the age-related opening of the bite, and the early loss of teeth may result in lingual tipping of the anterior teeth – as listed by *Jain (2021)*. [83]

The altered dental morphology may be the etiology of deep traumatic overbite if the crowns of the anterior teeth are too long. The orthodontic options and their effectiveness (if chosen accordingly) remain the same, but in addition to the alternative method and the same critique of surgical alternatives, also the option of enamel reduction was described by *Beddis et al. (2014)*. This may be a faster solution when the etiology is restricted to this single factor and the degree is minimal. However, in most cases, orthodontics will still offer better options due to its minimal invasiveness and reversibility and a lower tendency for relapse. [88] Other options from the therapeutic and prosthodontic fields should not be compared to the orthodontic options in these cases – as the orthodontic options will be considered first. Only if orthodontic treatment is not possible or insufficient, those other options may be considered – as schematically illustrated in figure 14. [88]

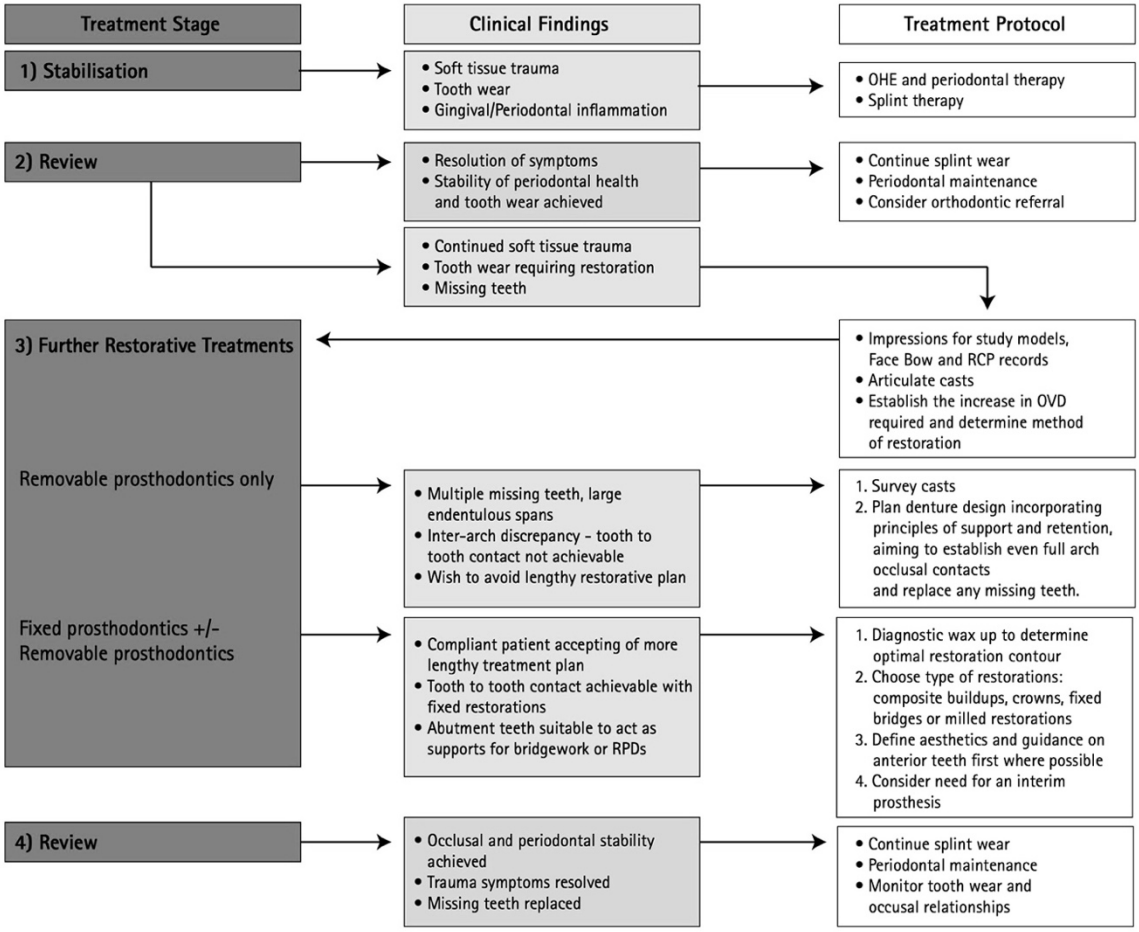


Figure 14: Treatment protocol for cases of deep or traumatic overbite. [88]

The condylar growth pattern may be the etiology of deep traumatic overbite if it deviates from the normal growth pattern which normally lets the head of the condyle grow upward and backward and push the mandible as a whole forward and downward. [84] In these cases, due to vertical condylar growth – the mandible rotates around a fulcrum in the incisor or premolar region which means that a deviation from condylar growth will also deviate the rotation of the whole mandible and thereby may push the occlusion into a deep overbite. [89] By the philosophy of primarily treating the cause, not the symptom, and by the higher level of effectiveness, surgical correction of the condylar anatomy is indicated. Still, as described by *Wang et al. (2016)* and others, many patients decline this commonly accepted first choice of treatment because of anxiety, the risk of unwanted side effects, or high costs. For those patients and such with objective contraindications for surgery, orthodontic camouflage treatment is the second most effective option and may be advantageous to offer the patients treatment of just acceptable results, but also without any major surgery (minimal invasiveness). [89–92]

Especially the uprise of temporary anchorage devices in the last 20 years increased the orthodontic potential to correct such vertical discrepancies. [90,91,93]

According to *Varshini et al. (2020)* and others, the loss of posterior support may be the etiology of deep traumatic overbite in such a way that posterior teeth are lost or drifted out of the normal occlusion which, in some cases, may already have been orthodontically prevented by space maintenance after the premature loss of primary molars. In cases with migrated posterior teeth after permanent tooth loss, orthodontic space re-gaining and alignment is the treatment of choice to prepare the clinical situation for a prosthodontic restoration to create a stable occlusion with a normal vertical dimension of occlusion. [84,94,95]

Conclusion

From the included studies about localized impaction-related periodontitis of which most should ideally be repeated with improved methodology, the following may be suggested. Orthodontic treatment is advantageous as a part of the treatment of localized periodontitis if the treatment is well-coordinated and the periodontal care is continuous and thorough. It increases the potential and speed of improvement of hard and soft tissues on clinical and histological levels. In cases with occlusal-traumatic impaction of the periodontium, it is to be concluded that it is current consensus that, in most cases, orthodontic options are the most effective to correct the malocclusion as it is the main etiological factor of this type of periodontal lesion.

Improvement of dental decay vulnerability

Influence of malocclusion

In a systematic review, *Sá-Pinto et al. (2018)* recaptured that three of the four included studies observed a positive association between moderate and severe malocclusion and dental caries. Due to the previously observed linkage between caries and socioeconomic status, these three studies controlled if malocclusion and socioeconomic status are codependent – and found that they are not. Moderate and severe malocclusion remained independently associated with

dental caries. [96] The fundamental difference between those three and the one remaining included study may have been that the merely dichotomized DMFT (decayed, missing, and filled teeth) scores ≤8 vs. >8 – an unnecessary categorization that may have influenced the outcome to alter from the other included studies. The meta-analysis of the systematic review by *Sá-Pinto et al. (2018)* revealed that, although subjects with mild malocclusion (Dental Aesthetic Index DAI <26) had a lower DMFT index than subjects with moderate and severe malocclusion (DAI ≥26), there was no proportionality. Subjects in both categories of moderate malocclusion (DAI 26-30 vs. 31-35) were scoring similarly on the DMFT index. *Sá-Pinto et al. (2018)* additionally reported high heterogeneity in the category of severe malocclusion (DAI ≥36), but heterogeneity may be ignored until further investigation as it is the mere symptom of categorization whilst malocclusion does not occur in natural categories. [96] Non-systematically, *Sá-Pinto et al. (2018)* and others recaptured that it is commonly suggested that the association of malocclusion with the increased vulnerability of dental decay may be related to increased plaque build-up with and restricted accessibility for oral hygiene in those same areas. [42,96,97]

Crowding

Logically, these areas have been and still are commonly suggested to be crowded – although a systematic review by *Hafez et al. (2012)* lead to the conclusion that until then, there were no high-quality studies to confirm (or refute) the possible association between dental crowding and caries. [98] There have been several more recent cross-sectional studies since the systematic review was conducted, but their quality of evidence is no higher than the older included studies when assessing by the method used by *Hafez et al. (2012)*. [42,98–100] The same critique applies for a contrary cross-sectional study by *Salim et al. (2021)* in which the relationship was statistically insignificant between the DMFT index and crowding in differentiated degrees of severity. [41,101] It may be remarked that they still logically acknowledged the decay-accelerating potential of dental crowding due to their observation of increased plaque accumulation. In their study, the DMFT values were higher as the severity of contact point deflection increased. [41] To dissolve the unclarity between the moderate-quality cross-sectional studies, *Hafez et al. (2012)* called for further high-quality longitudinal studies – such as the one by *Chen & Zhou (2015)*. They compared the DMFS (decayed, missing, and filled tooth surfaces) values of comparable subjects in treatment vs. non-treatment groups which were without significant difference before the treatment group received orthodontic

treatment in one dental arch. The data of their study supported the suggestion of crowding as a relevant mode of malocclusion – as surface-differentiated DMFT value differences between the treatment and non-treatment groups at long-term follow-up were the greatest for mesial and distal surfaces, although only insignificantly greater than buccal and lingual – as to be read from their results displayed in table 1. [102]

Table 1: Decayed, missing, and filled surfaces (DMFS) in treatment vs. non-treatment groups at long-term follow-up time – differentiated by tooth surface. [102]

	Treatment group DMFS	Non-treatment group DFMS	Difference
Mesial	43/720 (5.97%)	84/720 (11.67%)	41 (5.7%)
Distal	41/720 (5.69%)	90/720 (12.5%)	49 (6.81%)
Occlusal	115/360 (31.94%)	122/360 (33.89%)	7 (1.95%)
Buccal	26/720 (3.61%)	59/720 (8.19%)	33 (4.58%)
Lingual	22/720 (3.06%)	50/720 (6.94%)	28 (3.88%)

Influence of orthodontic treatment

According to *Sá-Pinto et al. (2018)*, the cross-sectional study by *Feldens et al. (2015)* scored 9/10 points on the Newcastle-Ottawa scale – indicating that the quality of evidence is high. [96,103] Based on their observation of malocclusion in association with dental caries, they suggested that early prevention and treatment of malocclusion may reduce the prevalence and severity of caries. [103] *Sá-Pinto et al. (2018)* still called for longitudinal studies to raise the level of evidence, but it should be considered that these will only have higher validity than the cross-sectional studies included in the previously discussed systematic review if the non-treatment group subjects would receive the same amount of attention as the treatment group subjects – as patient motivation is commonly known to be crucial for the individual oral hygiene. [96]

In a prospective cohort study, *Doğramacı & Brennan (2019)* observed that malocclusion had no statistically significant associations with any domain of the DMFT index after adjustment for participant self-reported sociodemographic factors, dental health behaviors, and malocclusion. [97] From this observation, they and *Cave & Hutchison (2020)* concluded that orthodontic treatment does not provide superior long-term dental health outcomes concerning caries – which is logically flawed. Their observation should rather be understood in the following way: When there was no difference in decay prevalence between

subjects with normal occlusion who have no history of orthodontic treatment and those subjects with normal occlusion achieved by orthodontic treatment – while malocclusion is in significant association with caries prevalence and therefore adjusted in their analytic model – then orthodontic treatment fully normalized the malocclusion-related decay prevalence of those treated subjects. [97,104] Their results of insignificantly but consistently lower DMFT values of treatment groups compared to non-treatment groups at age 30 within each category of baseline malocclusion severity at age 13 can be seen in table 2. These results could be obtained – although the study did not investigate how much of the DMFT score was accumulated before vs. after the orthodontic treatment in the treatment groups. [104] Based on the knowledge obtained from the previously discussed systematic review by *Sá-Pinto et al. (2018)*, the subjects may have had higher decay incidences while still with malocclusion – which was disregarded in the study by *Doğramacı & Brennan (2019)*. [96,104] This differentiation may therefore have illuminated the possibly also statistically significant benefit of orthodontic treatment for the decay prevalence – which is why further research is necessary.

Table 2: Decayed, Missing, Filled Teeth (DMFT) at age 30 in treatment vs. non-treatment groups – differentiated by Dental Aesthetic Index (DAI) at baseline age 13. [104]

Group	Predictive variable – orthodontic treatment	Distribution (n)	DMFT		
			Unadjusted mean (SE)	*P*	Effect size *r*
≤DAI_{13} 25	No treatment	143	5.0 (0.4)	0.67	0.04
	Treatment	53	4.6 (0.5)		
DAI_{13} 26-30	No treatment	82	4.1 (0.4)	0.74	0.04
	Treatment	32	3.8 (0.6)		
DAI_{13} 31-35	No treatment	35	6.1 (0.7)	0.20	0.20
	Treatment	27	4.3 (0.9)		
≥DAI_{13} 36	No treatment	26	5.4 (1.2)	0.41	0.11
	Treatment	43	4.3 (0.5)		
Entire cohort	No treatment	291	4.9 (0.3)	0.24	0.07
	Treatment	157	4.3 (0.3)		

In their longitudinal prospective study, *Chen & Zhou (2015)* observed at the long-term follow-up that the DMFS values were lower in the treatment groups than in the non-treatment

groups – as to be seen in table 3. The chi-square test confirmed that this was statistically significant for all included posterior teeth. Within the treatment group, the DMFS value was significantly lower in the treated arch. They concluded that orthodontic treatment significantly decreased caries risk. [102]

Table 3: Decayed, missing, and filled surfaces (DMFS) in treatment vs. non-treatment groups at long-term follow-up time – differentiated by tooth number. [102]

	Treatment group DMFS	Non-treatment group DFMS	Difference
17 & 27	48/600 (8%)	107/600 (17.83%)	59 (9.83%)
16 & 26	66/600 (11%)	97/600 (16.17%)	31 (5.17%)
15 & 25	35/600 (5.83%)	78/600 (13%)	43 (7.17%)
13 & 23	6/480 (1.25%)	8/480 (1.67%)	2 (0.42%)
12 & 22	33/480 (6.88%)	34/480 (7.08%)	1 (0.2%)
11 & 21	38/480 (7.92%)	42/480 (8.75%)	4 (0.83)

Conclusion

From the discussed systematic reviews and studies, it may be concluded that malocclusion and caries are positively associated – although without proportionality. Instead of the severity of the general malocclusion – rather, specific types of malocclusion or modifying factors may impact hygiene which is crucial in caries prevention. This has most commonly been suggested for dental crowding, although high-quality evidence is still rare. It is also still rare to prove that orthodontic treatment is advantageous in this matter, but there have been several supporting suggestions and one longitudinal prospective study which concluded that orthodontic treatment significantly decreased the caries risk.

Improvement of the masticatory system

Malocclusion is thought to have a negative influence on masticatory performance. A simple explanation may be that teeth with suboptimal occlusal fit have imprecise intercuspation for shearing and less platform area for crushing food. Also, improper mandible position

(possibly originating from malocclusion) may have the masticatory muscles contract in directions that do not allow the best energy utilization. In the following discussion, from electromyographical (EMG) theory over movement patterns until the practical performance, malocclusion, and orthodontic treatment will be investigated towards their relation with mastication.

Electromyography

The EMG is recorded as illustrated in figure 15. EMG patterns of masticatory muscles have been observed to be relevant for the analysis of masticatory movements in a cross-sectional study by *Ingervall & Egermark-Eriksson (1979)* in which especially complex dual bite dynamic phases were in perfect alignment with their EMG activities. [105] Still, it is important to acknowledge that the etiological chain from EMG activity until practical masticatory performance is long – which is why in an experimental study, *Shim et al. (2020)* found that minor deviations from the ideal occlusion are noticeable in EMG patterns, but not in practical masticatory performance. [106] Therefore, this discussion is for the sake of completeness of all possible advantages of orthodontic treatment – while the EMG analysis itself should never be a treatment indication.

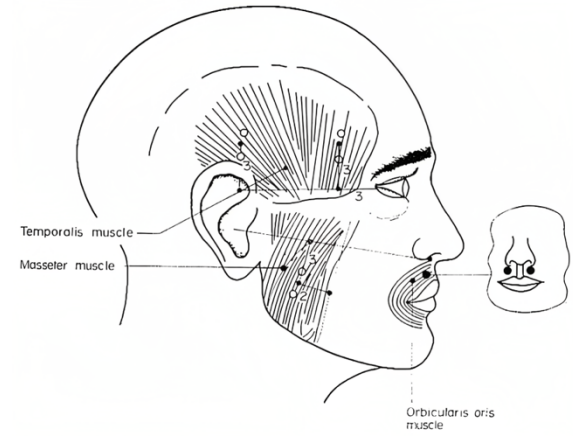


Figure 15: Standardized positions of electrodes. [107]
●–● indicates electrode distance in cm.
○ ○ indicates electrode distance of 1 cm.
● ● indicates electrode distance of 2 cm.

In the past 60 years, there have been many suggestions that EMG activity is strictly increased or strictly decreased in patients with malocclusion. But the overall conclusion to be drawn from all findings combined is that the EMG activity deviation of each masticatory muscle depends on the exact mode of malocclusion with its mandible position and movement patterns – which was often not recognized due to lack of categorization or even inclusion of

different types of malocclusion in those studies. *Shim et al. (2020)* included subjects with previous orthodontic treatment and confirmed many of the previous findings. Major, but also even slight deviations of the optimal occlusion (still within the limits of commonly accepted normal occlusion) have an impact on the balanced and symmetrical EMG activity of masticatory muscles and the absolute activity potentials of it – with the degree of EMG activity deviations being positively correlated with the size of interferences in the intercuspal position. This is illustrated in figure 16. [105–115] Authors that found such EMG activity deviations were investigating the intercuspal position and vice versa – which was argued to be based on the findings that peak muscle activity is close (in space and timing) to this position which also is the most used one during mastication and swallowing. [110,111,116] The found EMG patterns by *Shim et al. (2020)* also indicated that subjects with better occlusal relationships may have recruited more muscle fibers and/or their muscle fibers contracted more and that the muscles were slightly less prone to muscle fatigue. [106] In cross-sectional, experimental, and longitudinal studies from 1977 until 1992, it was observed that, in subjects with naturally stable, splint-stabilized, or treatment-stabilized occlusion, masticatory muscles can produce higher levels and longer durations of maximum obtainable EMG activity, so voluntarily contract for a longer duration and more forcefully and have normalized postural activity. [111,112,116–118] It may be concluded that orthodontic correction of malocclusion has an advantageous effect on EMG characteristics of the masticatory muscles.

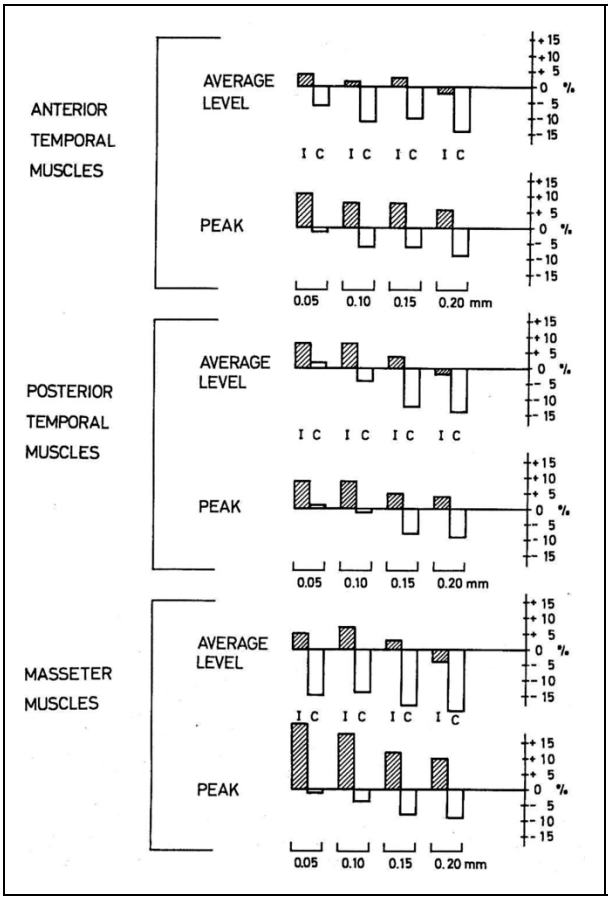


Figure 16: Mean action voltage in mandible elevator muscles on the ipsilateral (I) and contralateral (C) sides to the unilateral premature contact which height is indicated on the X-axis. [110]

Biting force

More practically, this influences the masticatory movements in such a way that subjects with malocclusion (or even just slight deviations from the ideal occlusions) have been observed in a cross-sectional study by *Møller et al. (1984)* to use greater relative bite force. It is key to understand that this means not the maximum obtainable force was greater, but the relative percentage of the maximum obtainable force used during normal mastication – indicating that the muscles had to work with more effort (in both dynamic and static phases) when used in malocclusion. [112] It may still be mentioned that also maximum bite force had been cross-sectionally observed by *Bakke (2006)* to be higher in normal occlusion compared to malocclusion and prosthetically supported occlusion – as illustrated in figure 17. [119] *Hwang et al. (2022)* suggested after an experimental study that minor (normodivergent) sagittal skeletal malocclusion could be compensated by naturally common inclinations of posterior teeth in the parameter of maximal obtainable force. [120] However, *Møller et al. (1984)* observed in a study that this parameter was unaltered – even without such dental compensation. [112] With a similar effort of CBCT imaging and Dental Prescale System, in the future, it

should be investigated which degree of malocclusion is unable to compensate itself in the matter of relative bite force.

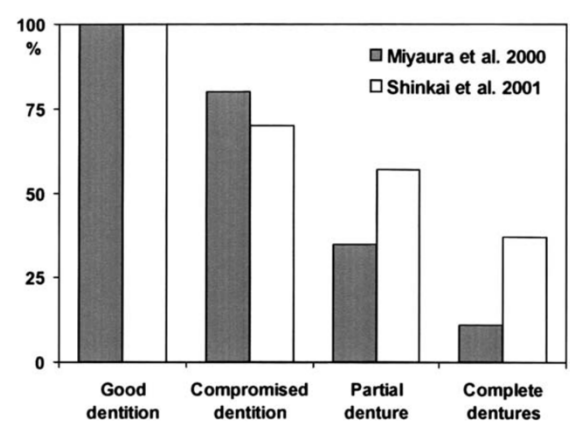


Figure 17: Good dentition: normal posterior occlusal support. Compromised dentition: no posterior support without any removable prosthesis. Complete dentures: both upper and lower complete dentures. The fewer natural teeth were present, the lower the maximum bite force. [119]

Masticatory movements

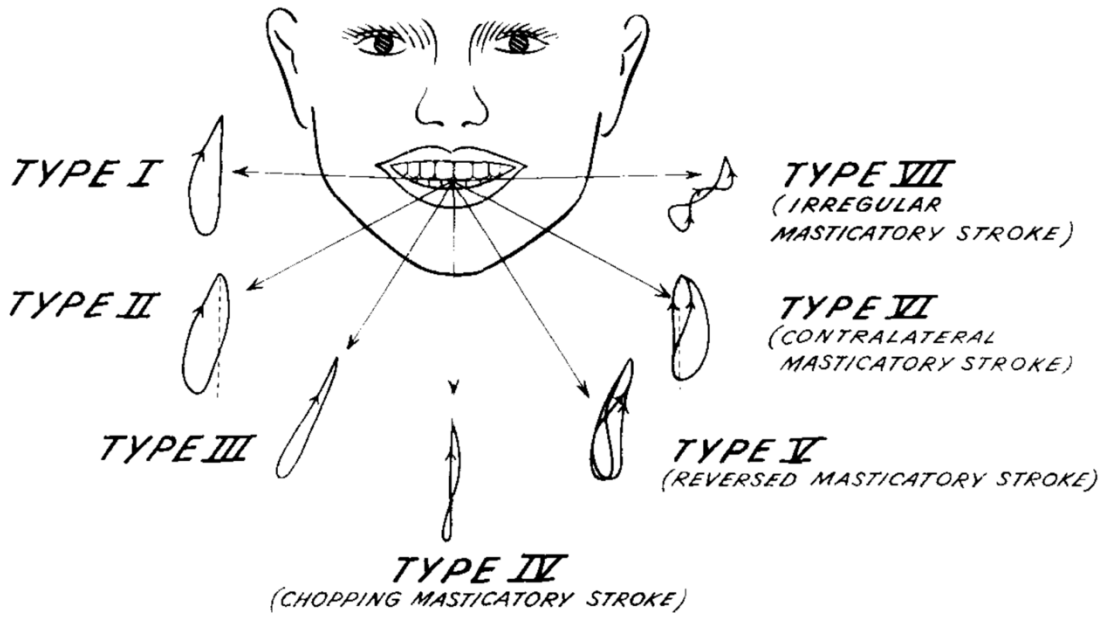
In that same and an experimental study by *Hannam et al. (1977)*, it was also observed that subjects with malocclusion close their jaw slower in the measures of absolute speed and relative to the overall chewing cycle – which as well is indicating that their muscular effort to compress and crush bolus is less efficient. [112,116] In the experimental part of the second study, it was also observed that occlusal adjustments improve the absolute speed. [116] Seemingly contrary to the findings of absolute and relative speed, *Shim et al. (2020)* observed in a study that subjects with worse details within the normal occlusion (compared to subjects fulfilling the details for ABO standards) had to chew faster to soften the gum given in the experiment. However, they analyzed the faster chewing rate of subjects with suboptimal occlusion which may still include a slower absolute and relative contraction time within each cycle – bringing all mentioned findings into a possible accordance. [106] In a longitudinal study, *Jang et al. (2019)* observed that after orthodontic treatment, there were no changes in absolute speed and timing but the study will have to be repeated with a control group and the inclusion of relative speed to achieve a proper level of evidence. [121]

Certain types of malocclusion cannot allow normal movements paths because of physical blockage by the interference of malpositioned teeth which may be problematic – as *Uesugi & Shiga (2017)* have observed a close correlation between the masticatory performance and masticatory movement in an experimental study. [122] Dual bite is defined by its specific two-phase movement (and contact) pattern including mandible retrusion and then sliding

forward into the intercuspal position – as it has been described by *Ingervall & Egermark-Eriksson (1979)* after a cross-sectional study. [105] But tendencies for altered masticatory movement patterns are also common in types of malocclusion that are not per se defined by these patterns – as had been observed in several studies by *Neill & Howell (1986)*, *Hannam et al. (1977)*, and *Ahlgren (1966 & 1967)*. An illustration of the masticatory movement patterns and their distribution according to the Angle classification can be found in figure 18 and table 4. Subjects with normal occlusions had wider and rather consistent masticatory movement patterns – while subjects with malocclusion deviated into (inter-subject) inconsistent, but overall narrower patterns with higher tendencies for chopping, reversed, contralateral, and irregular masticatory strokes. [108,116,123,124] In an experimental study, *Tome et al. (2009)* observed that the masticatory movement patterns followed the principle of the minimum variance theory of neural control and adjustment of body movements – according to the general description by *Harris & Wolpert (1998)*. [125,126] *Tome et al. (2009)* namely observed that, firstly, to reduce energy consumption – the movement was deviating from the straight path to avoid the later need for jerking reflexes to correct itself from the premature contacts. Secondly, damage reduction was performed by avoiding the collision of maloccluding contacts or decelerating before the collision of it is inevitable. [126] This physiologic response may be coordinated via feedback mechanisms from periodontal pressoreceptors – as it was suggested after an experimental study with electrical stimulations by *Hannam & Lund (1981)* and others. [110,116,117,127] Several studies by *Ingervall et al. (1975 & 1979 & 1982)* had results indicating that also in the swallowing process, there is a tendency to avoid any tooth contact for subjects with any premature contacts, crossbite, or dual bite. [105,109,128] In an experimental study, *Riise & Sheikholeslam (1984)* observed that natural and artificial premature contacts lead to a tendency of subjects away from the normal random shift of chewing side to preferring unilateral mastication on the more stable side – interfering harmonious sensory input essential for regular and co-ordinated masticatory movements. After the end of the dissolution of the artificial malocclusion, the changed masticatory patterns normalized again. [108,111]

After the end of the dissolution of the artificial malocclusion in the experimental study by *Riise & Sheikholeslam (1984)*, the changed masticatory patterns normalized again – indicating that this may also be possible for natural malocclusion. [111] In a longitudinal study, *Hannam et al. (1977)* observed a tendency for occlusal adjustment by selective grinding to be associated with an increase in the previously narrow lateral excursions of the mandible during jaw closure. It is important, however, to mention that the opposite tendency (reduction of lateral

excursions) occurred for a few subjects – so that conventional orthodontic treatment would have had the advantage of minimal invasiveness and reversibility. [116] *Tome et al. (2009)* confirmed that orthodontic correction of the underlying malocclusion is effective to achieve normal physiology and enable the movement of the jaw in the most efficient paths – even when the subject was not conscious of the altered movement paths. [126]



Occlusion of the teeth	Number of cases	Form of masticatory movements*) Percentage distribution							
		Type I	Type II	Type III	Type IV	Type V	Type VI	Type VII	Total
"Normal"	30	48	18	32	2	0	0	0	100
Class I	111	13	15	11	28	12	13	8	100
Class II, div. 1	108	23	26	17	16	8	7	3	100
Class II, div. 2	37	24	26	18	18	6	5	3	100
Class III	34	4	7	6	40	18	16	9	100
All cases	320	19	19	15	23	10	9	5	100

Figure 18 and table 4: Normal occlusion subjects were restricted to half-ellipsoid chewing patterns (type I-III) with less individual variation in form – while malocclusion subjects varied greatly across all categories. [123]

Masticatory efficiency

Effectively, the previously described deviated jaw movements may be the origin of patients with malocclusion having a weaker masticatory efficiency and masticatory ability compared to patients with normal occlusion – as concluded in the systematic review by *Magalhães et al. (2010)* and the prospective longitudinal study by *Gameiro (2017)*. [129,130] Opposing major malocclusion, minor deviations within the category of normal occlusion had been observed to be patient-subjectively and clinically irrelevant for the masticatory performance – as described by *Shim et al. (2020)* after an experimental study. [106,131,132] *Bakke (2006)* confirmed previous findings of masticatory performance being most directly correlated to the area of posterior teeth in contact or near contact (ACNC). [119,129,133–135] Accordingly, *English et al. (2002)* observed in an experimental study that masticatory performance and ability were not significantly related to platform area size (area of the occlusal surfaces of posterior teeth) – whereas the ACNC was significantly related to the particle size and broadness of particle distribution of the homogenous material that each subject chewed on for a set amount of cycles, so their masticatory performance was higher. Simply said, the basis of decreased masticatory performance is indeed the relation between occlusal surfaces and not the anatomy of the occlusal surfaces. It was observed that subjects with normal occlusion by far had the largest ACNC, followed by malocclusion type I, then II, then III. [133,134] Seemingly, ACNC is the mediator between masticatory performance and artificial categorizations like the Angle classification and index of the complexity, outcome, and need (ICON) – which can be assumed from the observations of *Bakke (2006)* and *Khosravanifard et al. (2012)* that these categorizations (that are linked to ACNC) have weak (and sometimes even no) correlations to masticatory performance while the strongest correlation of that performance is with ACNC itself. [119,136] It may be assumed that the correction of any malocclusion may lead to improved ACNC and thereby improved masticatory performance. *Hwang et al. (2020)*, however, observed in a cross-sectional study that minor (normodivergent) class II and III malocclusion may be compensated by posterior dental tipping to prevent the alteration of ACNC compared to subjects with normal occlusion – possibly resulting in unaltered masticatory performance despite the minor malocclusion. [120] Further investigation will be needed to explore which degree of malocclusion will influence the masticatory performance.

In the second part of the studies by *Owens et al. (2002)* and *English et al. (2002)*, they investigated how many chewing cycles the groups of participants performed until they

swallowed the pieces of actual food that they were given – as illustrated in figure 19. With these real foods of non-homogeneous consistency – covering the chewy and the other hard and brittle spectrum of the actual food consistencies – there was no occlusion which required significantly fewer chewing cycles until the subject swallowed. In the discussion of both studies, these results were interpreted to be indifferent in masticatory efficiency between the types of occlusion. [133,134] However, with an even more realistic experiment design, *Uesugi & Shiga (2017)* evaluated the bolus, not for their particle size or chewing count or time, but for the glucose extraction which is also directly linked to the surface increase – the main masticatory functions. They found that subjects with worse masticatory kinematics (which had been previously shown to be closely correlated to malocclusion) had less glucose extraction from the experimental gummy jelly. [122] *Ingervall & Carlsson (1982)* argued that it depends on the adaptation of the patient if occlusal interferences may or may not have practical negative effects. [128] It is important to note, however, that the technical efficiency is negatively affected, so that the common superficial adaption to that problem simply means the swallowing of bigger particles of actual food, so the compromisation of the first step of digestion which depends on mastication providing increased bolus surface area for higher enzyme action in later steps – as suggested by *Kamaratih et al. (2022)* after a cross-sectional study. [130,134,137,138] Another adaptation may be the neglect of eating – as indicated by the observations in a cross-sectional study by *Koskela et al. (2021)* where subjects with severe malocclusion were likely to be leaner than controls, and underweight subjects had more often retrognathic maxilla. [139]

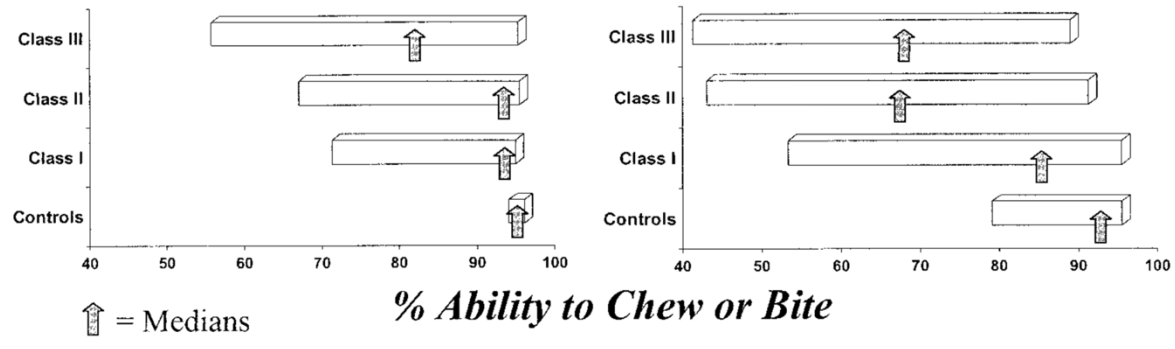


Figure 19: The effect of malocclusion on masticatory ability. Left: chewing or biting fresh carrots or celery sticks. Right: steak or other firm meats. [134]

Influence of orthodontic treatment

Orthodontic treatment has been observed to be effective for this matter. In longitudinal studies, *Gameiro et al. (2017)* and *Lee et al. (2022)* observed (as others previously) that orthodontic treatment (with or without extraction of premolars) was effective to improve the masticatory performance of malocclusion subjects to a level similar to the ones of subjects with normal occlusion. [130,140,141] In another longitudinal study, *Sohn et al. (1997)* accordingly described (as others previously) the increased grinding patterns, faster jaw movement velocity in the lateral direction, and fewer incidences of silent periods (protective mechanism in minimum variance theory) of the superficial masseter muscle. [125,126,141] Similar descriptions of the faster jaw closing after an increase of occlusal stability by occlusal adjustment were also given by *Bakke et al. (1992)* in a cross-sectional study. [117] For adult subjects with malocclusion related to cleft lip and palate, *Miura et al. (2022)* observed in a cross-sectional study that orthodontic treatment could significantly improve the masticatory efficiency generated by the temporomandibular joint, muscles, and orthodontically achieved normal occlusion, although a significant difference was still found compared to the control group with normal occlusion. [142]

Contrary to the suggestions in the previous paragraph, *Henrikson et al. (2009)* discussed that the improvement of masticatory performance that was observed in their own (longitudinal) and other studies may have occurred only simultaneously with orthodontic treatment, but not in causality. They based this suggestion on the improvement of masticatory performance occurring in all three subject groups: subjects with class II malocclusion receiving orthodontic treatment, control subjects with class II malocclusion not receiving treatment, and control subjects with normal occlusion with no history of orthodontic treatment. However, their data presented in table 5 also show that the control subjects with class II malocclusion (not receiving treatment) had the weakest improvement of masticatory performance during puberty. [143] Therefore, the results of *Henrikson et al. (2009)* are merely an addition to the ones of *Lee et al. (2022)*, *Gameiro et al. (2017)*, and *Sohn et al. (1997)* – different in nothing but the unconventional interpretation. [130,140,141] Still, the criticism of *Henrikson et al. (2009)* is relevant since puberty indeed includes significant changes in maximum bite force – as observed in a longitudinal study by *Roldán et al. (2016)* and by others. [144–146] *Bakke et al. (1990)* observed in a cross-sectional study that, for the subjects above the age of 25 years, the number of posterior teeth in contact was most relevant, followed by the number of occlusal contact points (not exactly ACNC) – excluding sex and body height. However, the measurement of

occlusal contact points was significantly less advanced than the measurement of ACNC in newer studies – so the study should be repeated with more advanced measures to properly estimate the degree to which orthodontic treatment is advantageous for the improvement of masticatory performance. [145]

Table 5: Masticatory efficiency at the start of the study and after two years. [143]

	Masticatory efficiency index (MEI)					
	Start			Two years		
	Mean	Median	S.D	Mean	Median	S.D
Class II Orthodontic group	10.3	9.1	8.1	15.2	14.0	8.3
Class II group (untreated)	12.4	11.5	9.0	16.4	14.8	10.7
Normal group	17.1	14.6	10.7	21.5	20.9	10.7

Another relevant critique of *Henrikson et al. (2009)* on their own study also applies to similar and future studies. Treatment and control groups of subjects with malocclusion are usually not comparable because it would be unethical to let chance (for the sake of a neutral study) decide to which group a patient will belong – instead of the clinical indications. Therefore, the treatment groups will usually include more severe cases than the control groups – increasing the chance for result distortion. Based on these critiques and a vague reference to orthognathic patients, *Henrikson et al. (2009)* suggest that (absolute) bite force in patients with normal occlusion (compared to those with malocclusion) may play the biggest role in the higher masticatory efficiency than the malocclusion itself. [143] This assumption was not based on their study results, but that indeed absolute bite force is lower in subjects with malocclusion had been observed in a longitudinal study by *Roldán et al. (2016)* and by many others. [144,147–150] Still, one should understand the lower absolute bite force in patients with malocclusion as part of the neural muscle control to avoid collision of maloccluding contacts – as earlier described as minimum variance theory [125,126] and, specifically for the aspect of absolute bite force, also supported by the observation of *Ahlberg et al. (2003)* that maximum bite force was significantly associated with the numbers of occluding contacts. [147] The unconscious memory of where the masticatory contraction is supposed to end is a learned skill – which is why, in a longitudinal study, *Makino et al. (2014)* could observe bite force (and

subsequently pressure) to increase gradually in one year of retention phase since the physiologic response of the neural system has to adapt to the newly arranged peripheral structures. [111,141,151] *Makino et al. (2014)* suggested that such long follow-ups for the evaluation of masticatory abilities and performance are necessary as the re-organization of the elastic alveolar crest fibers (and other periodontal tissues) requires more than six months [67,151] – which influences the periodontal pressoreception and thereby the masticatory abilities and performance. The points of criticism by *Henrikson et al. (2019)* (puberty influences, random study design) should still be investigated more specifically for more clarity.

Comparing the previously mentioned studies by *Lee et al. (2022)*, *Gameiro et al. (2017)*, and *Sohn et al. (1997)* with the systematic review by *Magalhães et al. (2010)* about the influence of orthognathic surgery on masticatory performance, it seems that orthodontic treatment is not only advantageous over orthognathic surgery in being less invasive but also in the mere ability to improve the masticatory performance. [129,130,140,141] However, more investigation is needed to compare these results in one unifying study since the subjects with orthognathic surgery may have presented more difficult clinical situations in the first place.

Conclusion

From the included studies, the following may be suggested about the influences of malocclusion and orthodontic treatment on masticatory performance. EMG activity is negatively affected (imbalanced and lower potentials) by malocclusion and can be improved by orthodontic treatment, but should not be used for treatment need indication. Masticatory movements are negatively affected by malocclusion (unsymmetrical and restricted) and can be improved by orthodontic treatment – which may be a sole indication in cases of severe asymmetry and restriction. Practical masticatory performance is negatively affected by malocclusion (bigger food particles or higher chewing effort) and can be improved by orthodontic treatment – which may be a sole indication if the patient complains about objectively detectable deficiencies.

Improvement of speech distortion

Influence of malocclusion

According to *Ocampo-Parra et al. (2015)*, respiratory disorders may cause some types of stuttering, laryngeal abnormalities may cause hoarse or false voices, and alterations of articulation organs may produce dyslalias. [152] There is a general scientific consensus that functional dyslalias and certain malocclusion are to be associated – which was once more confirmed in a cross-sectional study by *Amr-Rey et al. (2022)*. [139,153–158] They and *Mogren et al. (2022)* suggested that this may be attributed to the commonality in neuromuscular supply and that the orofacial musculature involved in speech may be affected by the presence of malocclusion – seemingly implying that the correction of malocclusion may not necessarily affect the other one. But *Mogren et al. (2022)* clarify that, after the establishment of both malocclusion and dyslalia, still an occlusally stable jaw is a prerequisite for controlled movements of the lips and tongue. [153,158] *Ocampo-Parra et al. (2015)* claimed from their own and other studies that there is no correlation between the severity of the malocclusion and the severity of functional dyslalia. [152,159] But seemingly, it simply depends on the selection of the index or method to define the severities – whether or not such correlations may be found. For example, it remains unclear if by severity, they referred to the degree of severity within one type of malocclusion (which may be multifactorial, to name another problem) or if they ranked different types of malocclusion merely by their subjectively perceived severity or if the latter was conducted with objective measures or indexes which were not mentioned. Opposingly, *Mogren et al. (2022)* observed in a cross-sectional study that the mean value of the Dental Health Component of the Index of Orthodontic Treatment Need (IOTN-DHC) was significantly increased for the subjects with speech sound disorders compared to those with typical speech development. [158] And *Leavy et al. (2016)* observed in a cross-sectional study that the value of the Orthodontic Treatment Priority Index (OTPI) rose proportionally with the tendency for tongue placement errors and functional dyslalias. They also observed that the phonemes /s/ and /t/ were especially sensitive to deviations in the dentition – and suggested that this is due to the contact of the lingual apex with the alveolar ridge for sound production. [154] Accordingly, in a cross-sectional study, *van Lierde et al. (2015)* observed significantly more functional dyslalias of the alveolar phonemes /s/, /n/, /l/, and /t/ in children with normal speech intelligibility seeking orthodontic treatment. The most common functional dyslalia was

addental articulation, meaning the articulation with the tongue tip against the central incisors instead of the upper alveolus. They also confirmed the previous observation that the functional dyslalia of these phonemes was significantly associated with an anterior tongue position at rest or the presence of tongue thrust. [157] Although general tendencies are already observable in studies that did not differentiate between the types of malocclusion, the distinction reveals that not the undifferentiated severity, but the type of malocclusion determines the tendency and mode of functional dyslalia and the effectiveness of orthodontic measures within the treatment. [158] For that purpose, in the following, each type of malocclusion that had been claimed to be associated with dyslalias will be discussed separately.

Posterior crossbite

Amr-Rey et al. (2022) confirmed previous observations of the strong association of posterior crossbite with altered tongue position and functional dyslalias and specified this association to the fricative phonemes (forcing air through a narrow channel) /z/, /s/, and /f/ – which are illustrated in figure 20. [153–155] *Mogren et al. (2022)* observed that all posterior crossbites in subjects with speech sound were functional and suggested that this was due to the more muscle-related difficulties in those subjects. However, this only explains the significantly increased incidence of functional posterior crossbite – while it remains unclear why the incidence of non-functional posterior crossbite is decreased to zero. A similar study should be conducted with a greater sample and respecting their own critique of sample selection. [158] Although the posterior crossbite requires treatment in any case, it is highly questionable if the orthodontic measures within the multidisciplinary treatment have any effect on the effectiveness of the speech therapy. As *Leavy et al. (2016)* described, most consonants are produced in the anterior oral region and the ones that *Amr-Rey et al. (2022)* observed to be impacted are no exception – which is why the malocclusion may have no direct negative effect and its correction will not change the underlying muscular problem, as *Mogren et al. (2022)* suggested. [153,154,158] Evidence for these suggestions is still lacking.

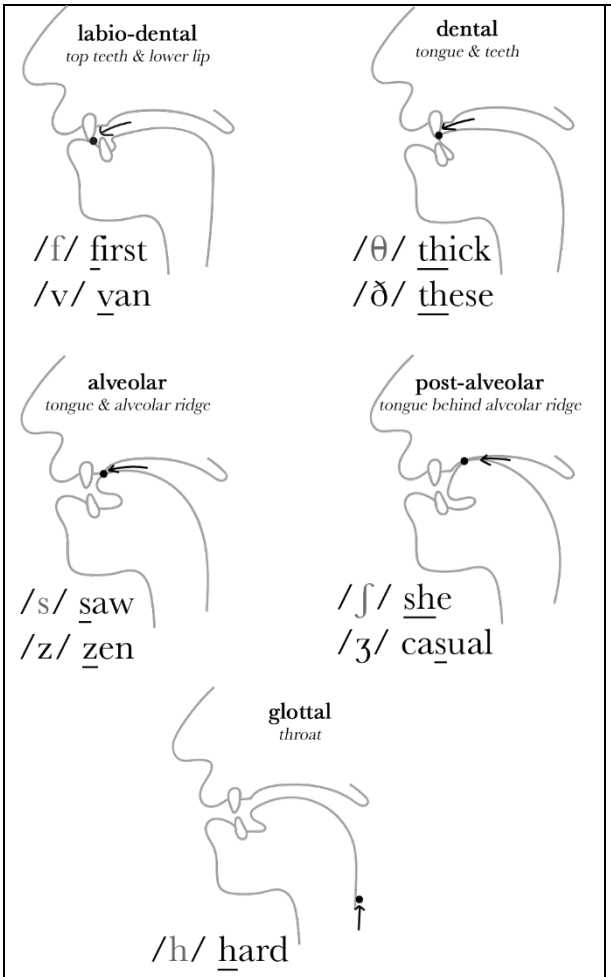


Figure 20: Fricative consonants are made by squeezing air between a small gap as it leaves the body. The fricative sounds /v/, /ð/, /z/, /ʒ/ are voiced, they are pronounced with vibration in the vocal cords, whilst the sounds /f/, /θ/, /s/, /ʃ/, /h/ are voiceless; produced only with air. [160]

Anterior open bite

Amr-Rey et al. (2022) and others observed that anterior open bite (AOB) was significantly associated with the functional dyslalia of specific sets of phonemes for all degrees of severity and with no sign of proportionality – but the sets of phonemes were different between the studies. [152,153] *Amr-Rey et al. (2022)* explained the association with the defective air outlet when there is no occlusion between the anterior teeth and the lip praxis is difficult. [153] *Ocampo-Parra et al. (2015)* questioned if AOB leads to phonetic changes or phonetic alterations cause AOB – vaguely based on their observation that the critical phonemes have dental, alveolar, and palatal articulations – never requiring the observed protrusion of the tongue between the anterior teeth. [152] Anyway, more fundamentally, *Artese et al. (2011)* theorized that the characteristic altered lingual position creates the characteristics of AOB and also susceptibility for lingual protrusion during sound production – being the root of both sides of the previously mentioned association. [161] *Amr-Rey et al. (2022)* and others recaptured from studies in different languages and stressed that the exact mode of functional dyslalia

depends on the language spoken. [153,154,157,162] Extraordinarily, *Assaf et al. (2021)* only observed an association of AOB with altered tongue position, but not with any functional dyslalia. However, they themselves justify their unusual finding with the language of examination and the lack of differentiation by the severity of the malocclusion. They suggested that the Portuguese language (used in their study) may be of rather high tolerance of such functional dyslalias to be considered normal. [155] However, in another cross-sectional study in the Brazilian-Portugese language with better differentiation between the phonemes, *Sahad et al. (2008)* observed a significant relationship between AOB and anterior lisping and/or anterior tongue thrust in the articulation of the lingua-alveolar phonemes /t/, /d/, /n/, and /l/. [163] By justifying why the differentiation by severity was impossible, *Assaf et al. (2021)* acknowledged that this may have been important to explain their unusual observations. [155] The study by *Leavy et al. (2016)* was conducted with such differentiation and observed that as little as 2 mm of AOB may cause functional dyslalias. It is important to note that in this study, the observed speech distortion was merely visible in 80% of the subjects – while auditory distortions (true sound errors) were heard in only 20% of the subjects. [154] This may be perceived as unnecessary confusion for the debate, but the differentiation between merely visual and actual auditory speech distortion may be another key problem why the discussed studies are not compatible – for which reason, in the future, studies should differentiate not only by severity but also by mode of perception of the speech distortion – to be able to properly compare and discuss observed incidences and associations. In a literature review, *Maspero et al. (2021)* reviewed studies to compare the three relevant treatment options: orthodontic treatment only, myofunctional or speech therapy only, and both combined. They recaptured that orthodontic treatment was effective to correct the AOB as the anatomical component of the dyslalia, but not the habitual component – leading to visual, but not necessarily audible improvement of the dyslalia, and to high risk of recurrence. Myofunctional or speech therapy without orthodontic involvement may, to a minor degree, positively influence the tongue behavior at rest and action, but appears to not be sufficiently effective when not adjunctive to orthodontic treatment. The combined treatment has the best outcomes since the advantages of each component (as described before) are the weak spots of the other one and vice versa. [164] Accordingly, *Leavy et al. (2016)* and *van Lierde et al. (2015)* suggested that orthodontic measures may be advantageous to be integrated into the treatment of AOB, but stress that the orthodontic correction of the dental and skeletal framework usually only re-establishes the visually normal structure and function with true auditory distortions remaining. They suggest the additional referral to a speech pathologist by default for assessment and management

before, during, and after orthodontic treatment. [154,157] Since, according to the literature review by *Rosa et al. (2019)*, the vast majority of AOB is self-correcting during the mixed dentition phase [165] – orthodontic treatment should only be conducted after that phase or after ensuring that the occlusion will most likely not self-correct. In other cases, less effective measures may be used until the proper treatment timing.

Edge-to-edge bite

Amr-Rey et al. (2022) observed that edge-to-edge bite was related to the phoneme disorders /r/, /s/, /z/ /t, d/, /l, ll/. [153] In a cross-sectional study, *Everett & Chen (2021)* observed that populations with significantly increased incidence of edge-to-edge bites also developed languages with significantly fewer labiodental phonemes, indicating that edge-to-edge bites restrict the ease of such articulations. [166] *Leavy et al. (2016)* observed subjects who misarticulated /t/ to have an increased tendency for dental edge contact but declares that this tooth relation by itself in the context of sound production is merely a visual inaccuracy and it is rather the increased association of anterior visual inaccuracies with the placement error of lingual protrusion. [154] Possibly, orthodontic treatment may accelerate the effects of speech therapy and reduce the dependency on patient compliance by the integration of habit-breaking appliances into measures for the seemingly only indirectly related correction of the edge-to-edge bite. For this suggestion, evidence is still lacking, but future studies – observing the differences between orthodontic treatment only, myofunctional or speech therapy only, and combined treatment – may be informative about the etiology of the dyslalia and the influence of orthodontic treatment on the effectiveness of the speech therapy.

Anterior crossbite

Leavy et al. (2016) did not observe any significant association between sound production errors and anterior crossbite. [154] The data by *Assaf et al. (2021)* also reveal a slight tendency for functional dyslalias with normal tongue position, but there has not been a statistical test as *Leavy et al. (2016)* conducted. *Assaf et al. (2021)* also seem to have interpreted the findings as not significant enough to be mentioned in the discussion. [155] *Amr-Rey et al. (2022)* did perform a statistical test that confirmed their observation that anterior crossbite impacted the phonemes /ch/, /s/, and /t, d/ due to the position of the tongue in relation to the upper incisors. [153] However, a closer look at the chosen statistical tools used by *Leavy et al.*

(2016) and *Amr-Rey et al. (2022)* reveals the root of the major difference between their findings. The latter used the ANOVA test which is to be used when both categorical and continuous variables are included – which was not the case. All variables were categorical, so the choice of the chi-square test by *Leavy et al. (2016)* was correct. [167] Since anterior crossbite cannot be directly and independently associated with dyslalia, orthodontic correction cannot be expected to be advantageous for this matter. However, evidence is still lacking and future studies may provide clarity – by observing the differences in outcome from orthodontic treatment only, myofunctional or speech therapy only, and combined treatment.

Angle class II

Amr-Rey et al. (2022) and others observed that Angle class II malocclusion was associated with altered tongue positions and dyslalias of specific phonemes – suggestively, due to the difficulty in performing a correct lip seal, of bringing the lower lip against the palatal side of the upper incisors, or the difficulty of producing airflow at the anterior level due to an increase in the overbite or overjet. [153,168,169] *Mogren et al. (2022)* only found an insignificant tendency toward that association. [158] *Assaf et al. (2021)* and *Leavy et al. (2016)* did not observe this association, but *Assaf et al. (2021)* suggested the high adaptability of subjects with class II malocclusion who, in their study, were able to adjust their joints to produce all vowels. [154,155] This suggestion may be weakly supported by considering the age ranges of other studies. *Amr-Rey et al. (2022)* investigated children of 4-7 years, *Farronato et al. (2012)* investigated children of 6-10 years in a cross-sectional study, *Assaf et al. (2021)* of 7-13 years, *Leavy et al. (2016)* of 8-36 (mean ca. 12) years. *Amr-Rey et al. (2022)* found a significant association of class II with certain functional dyslalias, *Farronato et al. (2012)* found a low tendency for this association, and *Assaf et al. (2021)* and *Leavy et al. (2016)* did not find it. Altogether, the age ranges and observed associations support Leavy et al. in their suggestion of (longitudinal) adaptability of speech when impacted by class II malocclusion. Longitudinal or cephalometric studies may be helpful to investigate this suggestion. [153,155,156,169] Since, seemingly, it is dependent on the possibly age-related adaptation if there is a relation between class II malocclusion and dyslalia – also the advantages of orthodontic measures for that matter are dependent on these factors. More research is needed to not draw weak conclusions.

Angle class III

Amr-Rey et al. (2022) and others observed that Angle class III malocclusion was associated with the impaction of specific sets of phonemes – which, however, were different in each study. [153,154,158,159,168] *Amr-Rey et al. (2022)* suggested the low position of the tongue at rest and during swallowing to be a mediator between class III malocclusion and dyslalias. [153] *Assaf et al. (2021)* did not observe the increased tendency for functional dyslalias in those subjects; their data reveal a slight tendency for altered tongue position. [155] *Leavy et al. (2016)* did not observe an impact of class III malocclusion on speech and suggested validating their unusual findings with the methodological critique of previous studies. [154] Indeed, some recent studies still did not use proper statistical tests when investigating more than one occlusal trait and allowed combined multiple factors – as previously explained for edge-to-edge malocclusion. [167] *Buyuknacar & Gulec (2020)* used a proper statistical test in their cross-sectional study and found an association between class III malocclusion and alterations of the phoneme /s/. [168] To ultimately determine if orthodontic correction of class III malocclusion will be advantageous for the treatment of dyslalia in these patients, future research should focus on cross-sectional studies respecting the critique of *Leavy et al. (2016)* and integrating more objective auditive measures.

Malocclusion-modifying factors

In a contemporary review, *Doshi & Bhad-Patil (2011)* recaptured conflicting suggestions from previous studies regarding possible associations between dyslalias and increased overbite, spacing, and crowding – categories that were not often discussed in recent studies. [159] *Mogren et al. (2022)* observed that deep overbite was significantly more common for dyslalia subjects, but suggests that this is the result of constant clenching which is the reason for clenched articulation and also an adaptive mechanism to the unstable occlusion. [158] *Leavy et al. (2016)* found none of these associations. [154] *Amr-Rey et al. (2022)* found no association between crowding and dyslalias. [153] *Van Lierde et al. (2015)* observed overbite in the context of dyslalia and did not mention an association. [157] Extraordinarily, *Assaf et al. (2021)* found that deep overbite appeared as a protective factor for altered tongue position and speech distortion. [155] It is possible that these categories are not discussed due to the belief of irrelevance. However, future research should still include those as categories since associations with dyslalia have previously been suggested which seems logical due to the anterior location.

After determining the relevance of these modifying factors, the influence of their orthodontic correction on dyslalias may be determined or further investigated.

Conclusion

Recapturing all those ongoing debates about each type of malocclusion in relation to dyslalias, *van Lierde et al. (2015)* and others summarized the significant differences in findings to be mainly related to the different language issues, the lacking consensus of methodology, the non-consideration of age ranges, and the ever-problematic absence of a control group. [157] Regarding the language, especially studies with children investigated the subjects rather casually-ordinarily or playfully to keep the participants compliant. But even study designs with adults and high levels of differentiation between phonemes could not reach true comparability due to the natural differences of languages that use partially different sets of phonemes. [153–155,157] But anyway, the key question is not only which phonemes are impacted by which malocclusion, but also the relevance of the impaction – to ultimately determine how to handle the impaction appropriately. If certain impactions are subjectively not recorded in studies of a certain language, this may indicate that this phoneme is somewhat irrelevant for that language – though there may be a theoretical objective impaction. Due to this reason, for the types of malocclusion that have been suggested to be associated with certain dyslalias, practitioners should mainly consider dyslalia studies in the languages actually spoken by the patient – while still controlling their international critique. In any case, a consultation with a speech pathologist may be useful. It remains unclear if the inclusion of orthodontics in the multidisciplinary treatment is advantageous in all types of coincidence of malocclusion and speech distortion – as there only one study could be found which compared the treatment alternatives of mere orthodontic treatment, mere myofunctional or speech therapy only, and both combined. In that study on anterior open bite subjects, however, it was observed that the addition of orthodontic treatment to myofunctional or speech therapy is advantageous in terms of improvement of visual and audible speech distortions.

Improvement of sociocultural reception and psychosocial well-being

Sociocultural attention

In an eye-tracking study, *Wang et al. (2016)* observed significantly deviating scan paths for target faces with malocclusion compared to those with normal occlusion. The smiling with malocclusion attracted abnormally much attention from the participants – so the times allocated to the eyes and nose were significantly decreased. Based on these results which are illustrated in figure 21, the authors suggested a negative impact of malocclusion on face-to-face communication. [170] Similar studies were conducted by *Richards et al. (2015)* and *Tanaka et al. (2020)*. *Richards et al. (2015)* additionally observed the proportionality between the severity of malocclusion and the focus of attention on the mouth region. *Tanaka et al. (2020)* observed in that the beginning of scan path alteration started only when the diastema (the focus of that study) exceeded 1.5mm which may mark the limit for sociocultural normality. Another observation by Richards et al. was that normatively worse dental aesthetics received more attention in attractive faces than it did in less attractive faces – stressing the significant effect of dental aesthetics on the overall facial appearance as an important platform for social interactions. [170–172]

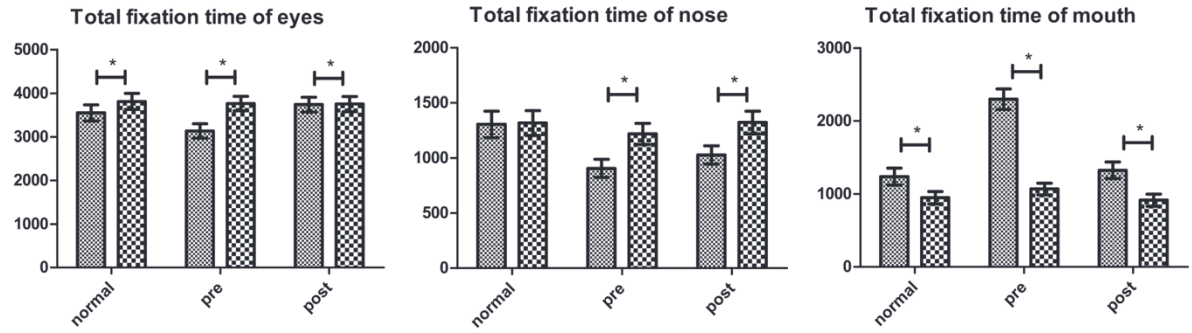


Figure 21: Mean fixation times on eyes, nose, and mouth for smiling vs. repose images of normal, pretreatment, and posttreatment faces. [170]

Sociocultural reception

It is not surprising that visual sociocultural abnormalities alter the received attention, but study participants even tend to unconsciously associate malocclusion with negative non-visual characteristics. *Gasparello et al. (2022)* and others observed in a cross-sectional study

that also the employability ratings for target people with malocclusion were lowered. [173–176] In the comparison of target people with low vs. moderate vs. severe treatment needs, target people with moderate or severe orthodontic treatment needs were also rated lower for honesty, intelligence, ability to complete obligations on time, and being older – as illustrated in figure 22. [173] *Khela et al. (2020)* observed in a cross-sectional study (as others previously) that target people with photo-manipulated malocclusion (to the same level as subjects with visibly missing teeth) received significantly worse ratings by the young adult observers for attractiveness, perceived intelligence, the likelihood of dating, and perceived nervousness – compared to the same target people with photo-manipulated normal occlusion. They clarified that these impacted categories were more directly linked to overall body and facial attractiveness, but dental aesthetics still acted as a relevant mediator. [173,177] *Pithon et al. (2014)* observed in a cross-sectional study that target people with malocclusion were rated lower for athletic performance, popularity, and leadership capability. [174] *Olsen & Inglehart (2011)* conducted a cross-sectional study similar to the ones by *Khela et al. (2020)* and *Gasparello et al. (2022)*, but with methodologically and technically higher quality photo manipulations – as to be seen in figure 23. In the differentiated investigation of normal occlusion, open bite, deep bite >7 mm, underbite, overjet >9 mm, crowding, and spacing – they observed that target persons with normal occlusion were evaluated as most attractive, most intelligent, most agreeable, most extraverted, and (together with subjects with open bite or overjet) most conscientious. The different types of malocclusion deviated to different degrees from these highest standards, as to be seen in Table 6. [176] In all the previously discussed studies, the observing subjects were investigated in vitro, but in vivo descriptions of social interactions have also been collected. In a cross-sectional study by *Hassan et al. (2014)*, over 40.4% of the child subjects with borderline or definite treatment needs reported teasing regarding their teeth by peers – more than twice as common as in the child subjects with no or little treatment need. [178] In a cross-sectional study with adult subjects, *Pabari (2011)* observed that over 45.9% of them reported current or previous experiences of teasing regarding their teeth – of which 56.9% were even consciously motivated for the treatment by those experiences. [179]

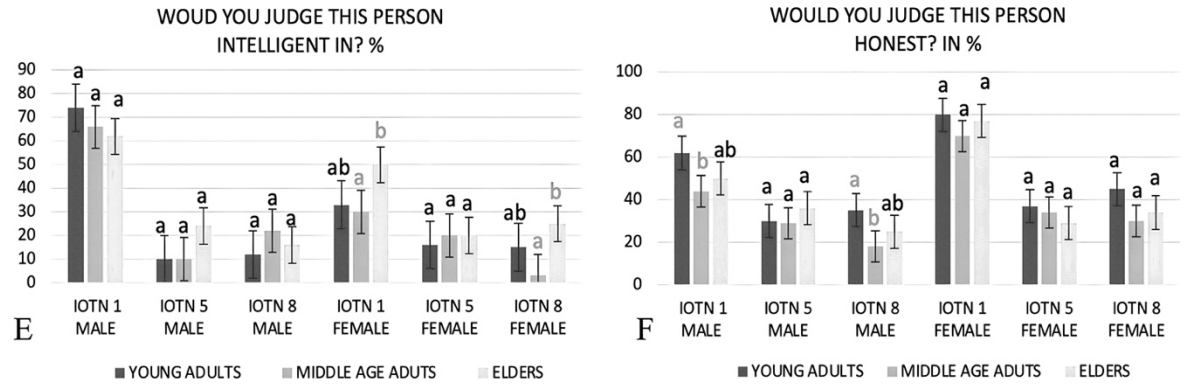


Figure 22: Perception of intelligence and honesty. [173]

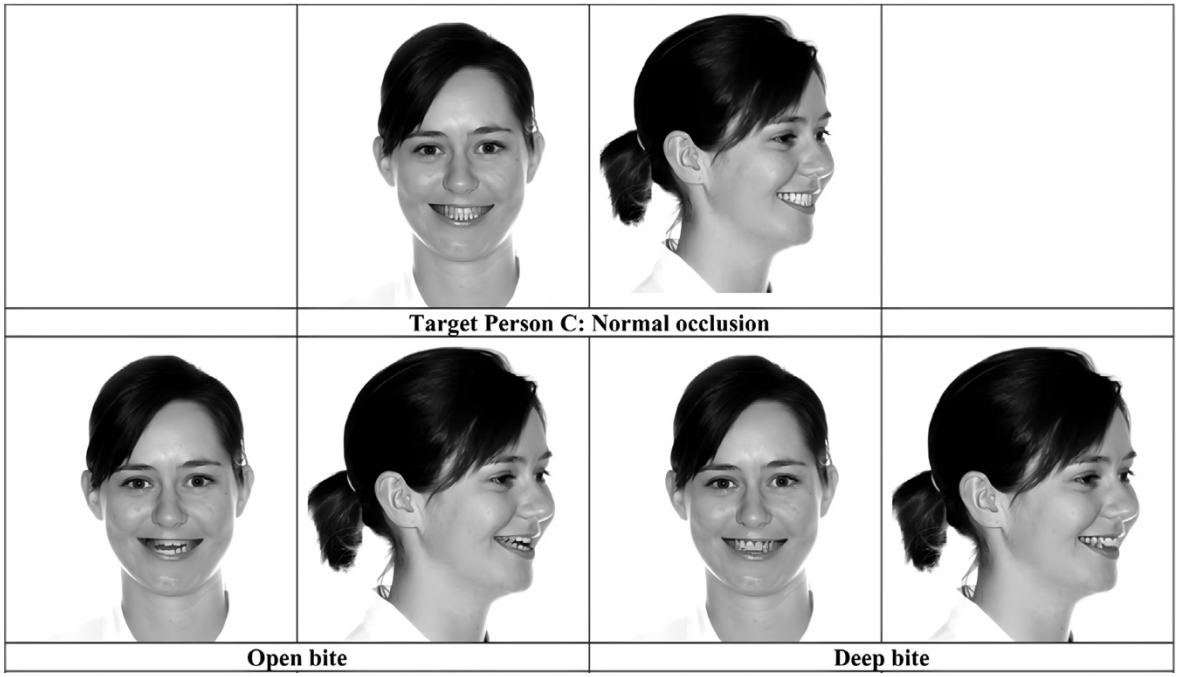


Figure 23: An excerpt from the photo manipulations of one of the female targets. [176]

Table 6: Average ratings of faces with normal occlusion vs those with malocclusions. Characteristic expression scores weakest to strongest from 1 to 7. Significant differences between normal occlusion and a certain malocclusion were marked with letters: a) for open bite, b) for deep bite, c) for underbite, d) for overjet, e) for crowding, and f) for spacing. [176]

*Characteristics**	*Normal occlusion n = 126*	*Open bite n = 121*	*Deepbite n = 132*	*Underbite n = 121*	*Overjet n = 133*	*Crowding n = 125*	*Spacing n = 123*	P†
Attractiveness	5.43	4.79	5.22	4.60	4.71	4.94	4.72	<0.001 a, c, d, e, f
Intelligence	5.43	5.04	5.26	4.91	5.17	5.12	4.97	0.01 a, c, e, f
Personality traits								
Conscientiousness	5.18	5.21	5.02	4.92	5.20	5.08	4.86	0.047 c, f
Agreeableness	4.36	4.04	4.15	4.00	3.93	4.15	3.92	0.039 a, c, d, f
Neuroticism	2.50	2.56	2.55	2.84	2.77	2.67	2.73	0.179
Lack of openness	3.42	3.47	3.53	3.63	3.46	3.40	3.66	0.512
Extraversion	5.21	4.91	4.87	4.61	4.79	4.92	4.77	0.019 b, c, d, f
Behavioral intention								
Index: desire to interact	4.75	4.65	4.51	4.25	4.54	4.42	4.37	0.089

Sociocultural etiology

Discovering possible reasons for these altered social interactions is necessary to find a solution to this sociocultural problem. In a cross-sectional study, *Shafiee et al. (2012)* observed that for adolescents with malocclusion, the IQ score was within normal limits for all subjects, but still with significant differences between the socioeconomic classes. The upper-class subjects achieved the highest IQ scores, then the middle class, then the lower class – possibly due to financial restriction of (partly extracurricular) education and activities. They also reported that patients from the lower classes mostly cannot afford the costs of (the even more necessary) orthodontic treatments – which altogether lead to the subjects with the untreated malocclusion to indeed be the ones with the lowest IQ scores. Still, such reasoning should be neglected. The differences in intelligence are insignificant and the logical pathway for this stereotype is contorted. A similar critique goes for other suggestions by *Gasparello et al. (2022)* and others for mediators between those stereotypes and malocclusion, such as being perceived as older or of the female gender. [173,180] It is more likely that laypeople simply have incorporated sociocultural norms into the rather uncoordinated intuitive network. [181–183] Accordingly, the opposite is also true for people (orthodontists) whose intuitive network is not only fed by mass media but also by (abnormal) high amounts of malocclusion. *Ng et al. (2013)* and others observed in a longitudinal study that, compared to laypeople, orthodontists were

less critical upon target people with certain malocclusion regarding domains of attractiveness. [184] Based on this observation, it may be assumed that the increased confrontation with certain appearances normalizes them – even when the observer (orthodontist) is capable of understanding their objective abnormality. Respecting this insight – back to laypeople. *Pithon et al. (2014)* argued that the tendency of young observers to rate target people more harshly than older observers do (which was observed in several studies) is their age-related susceptibility to being more easily influenced by mass media which contemporarily do not represent malocclusion accurately. [173,174,176] Thereby, malocclusion is socioculturally abnormalized – planting the seed for skepticism against people with malocclusion. The underlying problem is sociocultural, but *Ao et al. (2020)* observed in a cross-sectional study that social reinforcement from parents had a more prominent direct impact on adolescent subjects compared to peers and mass media – for which reason parents should be engaged to show acceptance for minor occlusal deviations without clinical treatment need. It must also be discussed if orthodontic treatment may still be effective to soothe the symptoms of the affected individual.

Orthodontic treatment

Bradley et al. (2014) observed in a longitudinal study that 91% and 83% of the subjects reported that family and friends respectively had given unrequested positive feedback on the normatively improved aesthetic. [185] This was also observed in a randomized controlled retrospective longitudinal study by *Albino et al. (1994)*. [186] The achieved positive feedback by parents and peers may be interpreted as crucial as those individuals (which are also not free from mass media influences) have a more direct influence on the aesthetic self-perception of the adolescent subject – as *Ao et al. (2020)* observed (as others previously) in a cross-sectional study that led to the schematic illustration in figure 24. [187,188] Similar improvements were also observed for evaluations of emotionally-uninvolved participants. In the previously mentioned eye-tracking study, *Wang et al. (2016)* observed that orthodontic treatment of the malocclusion of the target people was effective to normalize the scan path of the study participants – so that the attention brought to the post-treatment normal occlusion was perceived indifferently to the untreated normal occlusion. [170] Possibly related studies about orthognathic treatment support these tendencies. *Jesani et al. (2014)* observed in a longitudinal study that, after orthognathic treatment of class III malocclusion, all four subjects were rated significantly higher for attractiveness and non-visual traits – namely psychological

adjustability, sociability, and success. [189] *Ng et al. (2013)* observed that all ratings of attractiveness (overall face, chin, and lips) were significantly improved after orthognathic correction of class II malocclusion. [184] The previously discussed studies by *Gasparello et al. (2022)* and *Khela et al. (2020)* may be accepted as an indication that orthodontic treatment may improve personal and professional social well-being. They merely simulated longitudinal studies, but in return, the utilized photo manipulations provided optimal comparability of the occlusal status without comparability distortions between the stages due to pubertal remodeling, hairstyle, etc. – as practically unavoidable in true longitudinal studies. [173,173,177] To further raise the level of evidence, experimental studies have been suggested, but the conduction of such studies would be very difficult – for which reason the previously discussed studies should simply be repeated with respect to their own methodological critique of comparability and sample size. [176]

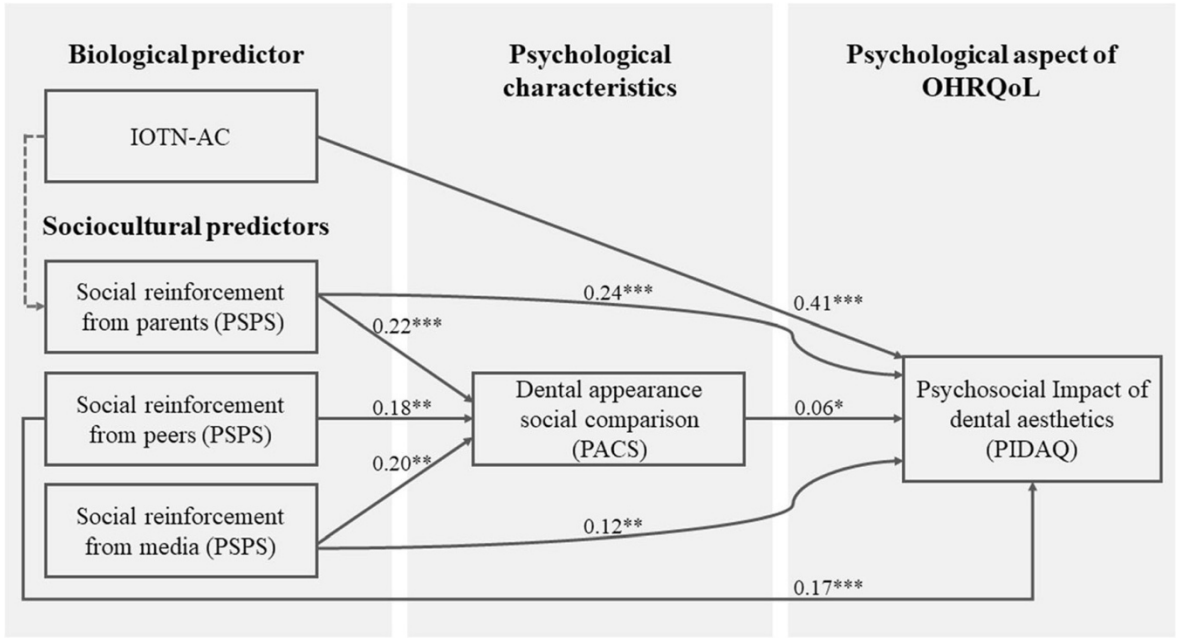


Figure 24: This final model with standardized path coefficients excludes the hypothesized pathway from IOTN-AC to social reinforcement of parents due to its statistical irrelevance. [187]

The utopian goal should be to avoid orthodontic treatments for the mere purpose of improved sociocultural reception – as in that context, it should be criticized as a body modification including unnecessary medical risks. As always in medicine, treating the underlying cause (here: sociocultural intolerance) may be more effective in the long-term than

treating the symptom (individually decreased sociocultural reception). However, as long as such long-term goals are distant, the orthodontic correction of malocclusion may be acknowledged as advantageous to immediately and significantly improve the sociocultural reception of the patient.

Sociocultural vs. psychosocial analysis

So far, this discussion was centered around studies on sociocultural reception – external observers judging target people with malocclusion – simulating social interactions. Both this sociocultural reception from the outside and the inner perception of the patients themselves are often summarized as social or psychosocial well-being – though those are merely the internal response to the external sociocultural reception or to the expectation of the latter based on sociocultural norms. The common internality may be observed in the high intercorrelation between social and psychological well-being – as done so by *Spalj et al. (2014)* in a cross-sectional study and by others. [180,190,191] In the following, the discussion will be centered around internal psychosocial well-being based on patient questionnaires.

Psychosocial well-being

Pabari et al. (2011) and others observed that subjects with malocclusion were significantly less satisfied with their dental and facial appearance and their smile – compared to subjects without malocclusion. [179,186,192–194] *Claudino & Traebert (2013)* observed in a cross-sectional study (as others before) that the degree of aesthetic dissatisfaction depended on the type of malocclusion. [186,194] *Johal et al. (2015)* observed in a longitudinal study that malocclusion significantly impacts psychosocial well-being. [195] *Dahong et al. (2014)* observed in a cross-sectional study that the degree of impact on psychosocial well-being varies when categorizing the subjects by the Angle classification without respect to its severity: highest impact in class III malocclusion, lowest for normal occlusion. [193] In concordance, but with respect to the malocclusion severity and more distinctive categories of malocclusion, *Bellot-Arcís et al. (2013)* observed in a cross-sectional study that increased overjet, tooth displacement, and increased overbite were the most psychosocially impacting occlusal conditions. [191] *Lukez et al. (2015)* and others observed that the concerns about minor aesthetic abnormalities were clearly distinguishable from the psychosocial impact of malocclusion. They clarified that these non-malocclusion aesthetic abnormalities (namely

buccal corridors, smile width, gingival display, incisor exposure, and occlusal cant) may be psychosocially relevant if they exceed certain thresholds – which ultimately leads to the Index of Complexity, Outcome, and Need (ICON) being the only significant psychosocial predictor. [9,196] Also *Isiekwe et al. (2016)* observed in a cross-sectional study (as others before) that the psychosocial impact of dental aesthetics increased with the severity of malocclusion – though this linkage was indirect. Stronger linkages were observed to their common mediator which was self-perceived dental aesthetics. [9,180,190–192,194,196–198] It may be suggested that this cascade not only goes from malocclusion via the self-perception to the psychosocial impact. The psychological profile may also be the initiator of altered self-perception – as to be suggested based on one specific association that *Isiekwe et al. (2016)* had observed. One domain of the psychosocial investigation about psychological disability (ability to relax and embarrassment) was only significantly associated with self-perceived dental aesthetics, but not with the normatively assessed dental aesthetics. [192] *Deng et al. (2018)* also observed that in cases of lowered social well-being, this was not only related to normatively worse dental aesthetics, but more significantly to negative psychological patterns, namely general body image dissatisfaction, negative affect, and low self-esteem. [180]

Self-concept and self-esteem

Due to incautious language and the close linkage between the terms self-esteem and self-concept which had been observed by *Spalj et al. (2016)*, these terms are commonly confused, but should still be differentiated. Self-esteem (here: within PIDAQ) is the conscious positive evaluation – and self-concept (here: self-perception of malocclusion) is the unconsciously emotionally charged description of oneself which, crucially, may be independent of the objective status or changes. [199,200] By these differentiated definitions, the subjects of *Deng et al. (2018)* had an impacted self-concept before the orthodontic treatment and it may be interpreted as an improvement that this psychological alienation from the clinical situation was decreased after the treatment. [180] *Albino et al. (1994)* did not observe such differences in the development of the self-concept comparing the treatment and control group subjects – but they themselves suggested that this may have simply been due to the merely mild malocclusion in their subjects which did not present abnormalities of self-concept before the treatment. [186] Thereby, they agreed with the existence of a threshold for the severity of malocclusion from which upwards, the self-concept may become distorted and from which on, orthodontic treatment may be effective to improve it.

Moving on to self-esteem. *Deng et al. (2018)* observed that some personality traits were relatively unaffected by orthodontic treatment, but may predict the potential for psychosocial improvement by the treatment. Those relatively stable traits were the crucial self-esteem, the overall body image (except for the dental region), and the positive and negative affects. [180] That self-esteem indeed is crucial for greater life satisfaction as a focal aspect of psychological health had been recaptured by *De Baets et al. (2012)* from previous studies. [9] *Deng et al. (2018)* observed that, for subjects with especially low self-esteem, the treatment benefit were minimal. Not only were those subjects more aware of their minor malocclusion, but also may this simply be the expression of the aesthetic self-evaluation being more closely linked to (negative) psychological attributes than to the clinical situation. [180] *Spalj et al. (2016)* observed in a cross-sectional study (as others before) traits closely linked to self-esteem. Subjects with lower agreeableness and conscientiousness were less affected by the increased severity of self-perceived malocclusion – as illustrated in figure 25. [200,201] Understanding agreeableness as a dependency on social affirmation and understanding conscientiousness as an obligation to social norms, these observations are in logical concordance with the previously discussed psychosocial predictability of self-esteem.

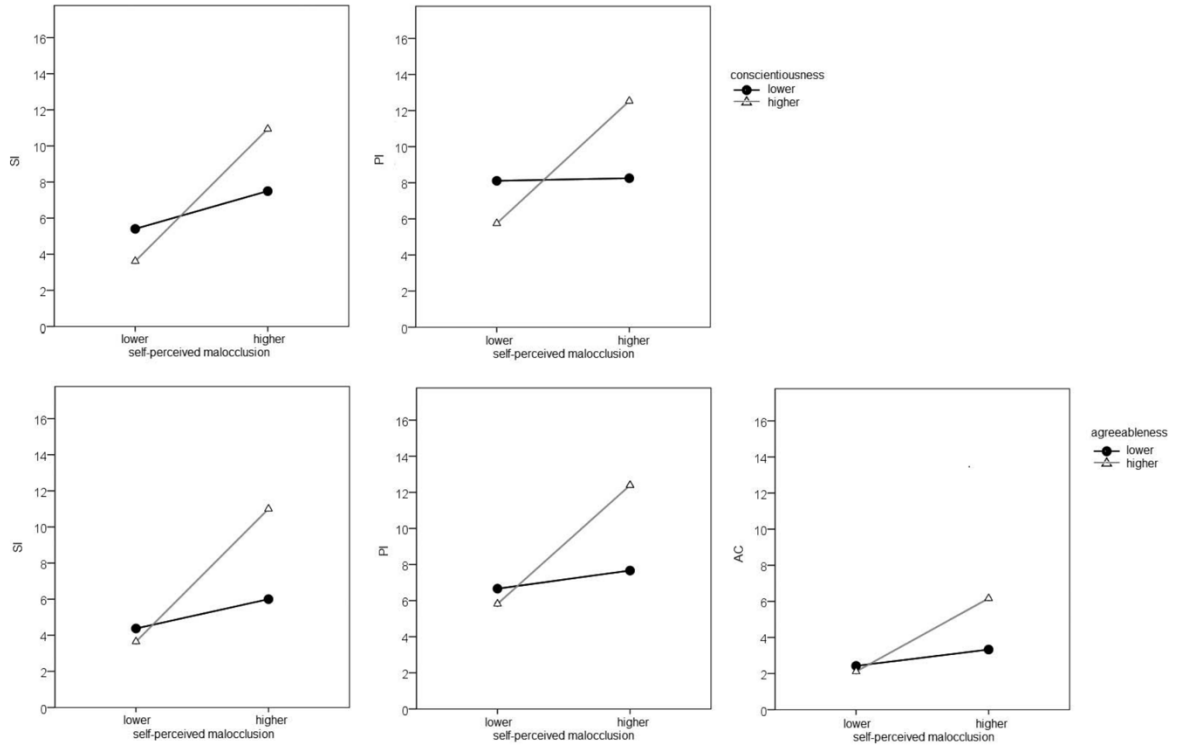


Figure 25: The moderating effect of agreeableness and conscientiousness between malocclusion and social impact (SI), psychological impact (PI), and aesthetic concern (AC). [200]

Not all studies agree that self-esteem is a psychosocial predictor and unaffectable by orthodontic treatment. *Johal et al. (2015)* observed improvement in self-esteem after the completion of the treatment, but the omission of a control group diminishes the level of evidence in direct comparison to the randomized controlled retrospective longitudinal study by *Albino et al. (1994)* which otherwise was very similar, but with the observation of self-esteem stability. [186,195] *González Murillo (2018)* also claimed (as others before) to have observed in a cross-sectional study that the pre-treatment impacted self-esteem was improved post-treatment, but they seemed to have confused self-esteem and (dental) self-confidence similarly to the previously discussed confusion of self-esteem and self-concept. It may be suggested that the discrepancy between the studies is merely due to the incautious psychological terminology of the non-psychologist researchers and the generally incompatible questionnaires. [179,202–204] In the future, researchers should try to implement the usage of compatible terminology and questionnaires and true control groups to challenge the low-evidence consensus which seemingly is that orthodontic treatment does not significantly affect self-esteem.

Influence of orthodontic treatment

No longer focusing merely on self-esteem, *Deng et al. (2018)* and others longitudinally observed substantial pre- to post-treatment improvements in self-evaluations of dental (and overall body) aesthetics and psychosocial well-being – as illustrated in figure 26. [179,180,202,204–207] Contrarily, *Albino et al. (1994)* observed in a randomized controlled retrospective longitudinal study that the improvements in self-evaluations of dental aesthetics (and overall body image) were not different between the treatment and control groups – for which reason, they suggested the psychosocial improvements to be part of the normal maturation of the adolescent subjects. [186] Contrary that, however, *González Murillo et al. (2018)* observed in a cross-sectional study that for both men and women, the separation between adolescents (15-25 years) and adults (25 to 40 years) was not linked to a statistically significant difference in the pre- to post-treatment psychosocial improvement. The only observed difference linked to age was that the adults felt like they received poorer attention from the treating orthodontists. [204] Also contrary to the suggestion of *Albino et al. (1994)*, *Pabari et al. (2011)* conducted a study with exclusively adult subjects with an average age of 34 years (so also excluding puberty influences) and their regression analysis revealed that whether the subject had finished treatment was the only one of their variables to be significantly related to facial body image, with scores improving significantly at post-treatment. [179]

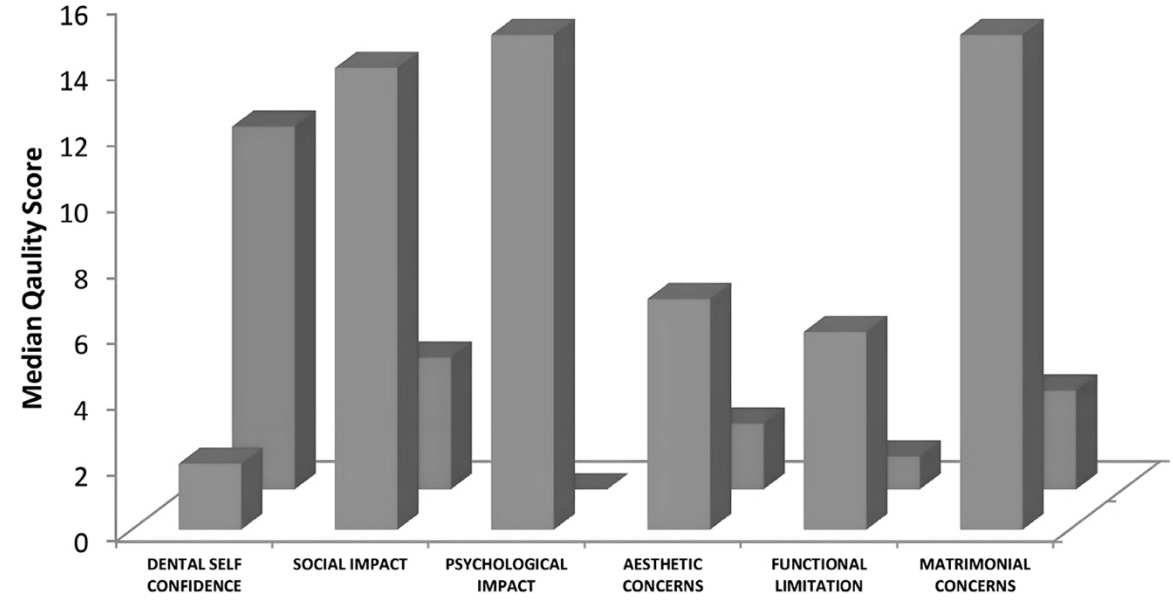


Figure 26: Longitudinal development of pre- (front) and post-treatment (back) scores of domains of psychosocial well-being. [205]

While so far in this discussion, the malocclusion subjects were those with psychosocial impaction, there have also been investigations of malocclusion subjects without (pre-treatment) psychosocial impaction – such as the longitudinal study by *Helm et al. (1985)*. Adolescent subjects (13 to 19 years old) with treatment need only became more aware of untreated malocclusion during their adulthood (28 to 34 years old). [208] Based on this observation, it may be suggested that orthodontic treatment is also advantageous for children with normal body image (and possibly self-esteem) as the treatment at the best developmental time may prevent delayed negative psychological development. *Bradley et al. (2020)* observed in a cross-sectional study that older adolescent (compared to younger adolescent) subjects were generally more positive about pre- to post-treatment psychosocial improvements – which is in agreement with the observation by *Helm et al. (1985)* as it indicates that the older adolescents were more aware of the normative improvements than the younger adolescents. Also, some subjects recalled not having been concerned before the treatment about certain psychosocial impacts which still significantly improved during the treatment, namely dental appearance, embarrassment when smiling, confidence, and happiness with teeth. [185] Seemingly opposing these two studies by *Helm et al. (1985)* and *Bradley et al. (2020)*, *Spalj et al. (2016)* observed that subjects of older age (the total range being 12–39 years) had a lesser aesthetic concern and higher social well-being – and *Lukez et al. (2015)* observed that older age (the total range being 12–39 years) was associated with higher self-esteem. [196,200] Only *seemingly* is this opposing, as all these findings about the influence of the subject age may possibly indicate that some time in late adolescence or young adulthood bears the peak of malocclusion awareness. To confirm this, similar studies should be conducted with improvements in prospective design, control groups, and more sensitive age categories.

Conclusion

From the included studies about the sociocultural and psychosocial spheres, it may be suggested the sociocultural reception of patients with malocclusion may be impacted – the severities of impact and malocclusion being proportional from a certain threshold. From this threshold, orthodontic treatment is indeed advantageous to normalize the sociocultural reception. The psychosocial well-being may also be impacted for patients with malocclusion – with the severity of impact being predicted by the severity of malocclusion, but possibly also by self-esteem. In these cases, orthodontic treatment indeed is advantageous to improve sufficient traits that combine into psychosocial well-being, so that it may be improved overall.

All these social and psychosocial tendencies have commonly been observed to be more extreme for women whenever the gender was differentiated. This is just one of the several aspects (together with socioeconomic status and age) that urgently call to approach the underlying patterns of sociocultural inequality.

LIMITATIONS AND RECOMMENDATIONS

This literature review was not prepared in a systematic search and therefore the integrity and judgement rely upon the effort and impartiality of the author.

The preliminary and also rather confident conclusions are only as good as the studies included in the review. Unfortunately, in dentistry, there is a lack of randomized clinical trials due to the length of time needed and ethical and other obstacles. In the absence of randomized clinical studies, we may have to rely on studies utilizing less reliable study designs such as cross-sectional studies and cohort studies – as also *Bollen et al. (2008)* faced. [52] The academic use of this literature review is the establishment of mistrust in common sense as it is often not founded on solid evidence. But also the criticism is opposingly biased – often leading to unreasonably polarized discussions. As long as the interpretations of studies commonly serve to underline the preoccupation of the researchers, only systematic reviews with meta-analyses should be fully trusted.

For the practice of non-orthodontic dentists, it may be concluded that the referral to orthodontists may be advantageous for the interdisciplinary treatment of types of periodontitis that clinically or radiographically seem related to malocclusion. If dentists suspect masticatory underperformance or impacted sociocultural reception and psychosocial well-being, it is reasonable to suggest orthodontic treatment. The concept of oral health-related quality of life should not be implemented in such discussion as it is still too vague for practical use. If the dentists detects caries in interdental spaces or other regions that are practically inaccessible due to crowding or other types of malocclusion, it is not unreasonable to suggest orthodontic treatment – although the evidence is weak. If dentists detect temporomandibular disorders or speech distortions that indeed may be etiologically confounded on malocclusion, the referral should not be to orthodontists, but to specialists of temporomandibular disorders or speech

distortions. They will design treatment strategies that may include the possibly advantageous orthodontic treatment – although the evidence is still weak.

For the practice of orthodontists, it may be concluded that not every referral from non-orthodontists should be taken as a legit treatment indication. Orthodontists are the practitioners actually conducting the orthodontic treatment and therefore responsible for constantly updating their knowledge in this field which had been illuminated to be filled with unfounded common sense and weak evidence for most suggestions.

CONCLUSION

Referring to the introduction, it may be concluded that indeed the evidence for many alleged advantages of orthodontic treatment is weak or lacking at all – which may be caused by the lack of motivation or necessity to follow evidence-based guidelines in the commonly private justification path between the patient and the orthodontist without tax-mediated healthcare.

This literature review comes to several conclusions of different degrees of confidence. About the oral health-related quality of life, it may be preliminarily concluded that it may indeed be improved by orthodontic treatment, but the concept itself still is so vague that this conclusion should be taken as nothing more than a call for further research. About the temporomandibular disorders, it may preliminarily be suggested that the inclusion of orthodontics in the interdisciplinary treatment may often be advantageous when the diagnostics suggest that certain types of malocclusion, especially mediotrusive interferences, may have contributed to the etiological chain, but other etiological factors should be respected to not precipitate the orthodontic treatment. About the different modes of periodontitis, it may rather confidently be concluded that the inclusion of orthodontics in interdisciplinary treatment may often be advantageous. When it comes to localized impaction-related periodontitis, this presents as the increased potential and speed of improvement of hard and soft tissues. When it comes to occlusal-traumatic periodontitis, orthodontic treatment is advantageous over the irrelevant alternatives in terms of effectiveness to correct the malocclusion which is the main etiological factor. About dental decay, it may preliminarily be suggested that orthodontic treatment of certain types of malocclusion may be advantageous due to the evident positive

relation between malocclusion and dental decay. About the masticatory system, it may rather confidently be concluded that orthodontic treatment may normalize the symmetry and range of masticatory movements and improve the practical masticatory performance in terms of bolus particle size and chewing effort. About the speech distortions, it may be only concluded that it remains unclear if the inclusion of orthodontics in multidisciplinary treatment is always advantageous. Only one study could be found that compared mere orthodontic treatment, mere myofunctional or speech therapy, and both combined. In that study on anterior open bite subjects, however, it was observed that the addition of orthodontic treatment to myofunctional or speech therapy is advantageous in terms of improvement of visual and audible speech distortions. About the sociocultural reception, it may rather confidently be concluded that orthodontic treatment may be advantageous to normalize the sociocultural reception. Also for psychosocial well-being, orthodontic treatment may be advantageous to improve overall psychosocial well-being.

Despite the limitations of evidence in most fields, this literature review supports non-orthodontic dentists to refer certain cases of periodontitis and caries to orthodontists for an interdisciplinary treatment. It also supports dentists to suggest the referral in certain cases of masticatory underperformance or impacted sociocultural reception and psychosocial well-being. For temporomandibular disorders or speech distortions, the first referral should not be to orthodontists, but to specialists of temporomandibular disorders or speech distortions. This literature review encourages orthodontists to question referrals from non-orthodontists and the common sense of orthodontists. Due to the heated debates, only systematic reviews with meta-analyses should be fully trusted for that purpose.

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