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Self-Perceived vs. Clinically Assessed Malocclusion in Adolescents: A Cross-Sectional Study

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Abstract

Background: Malocclusion can influence not only oral function, but also adolescents' perception of dental appearance, psychosocial status, and oral health-related quality of life. The present cross-sectional study aimed to examine the association between the clinical severity of malocclusion and adolescents' self-perception, as well as to assess the level of agreement between clinician and patient ratings of aesthetic impairment. Methods: The study included 160 consecutive adolescents aged 12 to 17 years who were referred for orthodontic evaluation. Malocclusion severity was determined using the Index of Orthodontic Treatment Need (IOTN), considering both the Dental Health Component (DHC) and the Aesthetic Component (AC). Patients' perceptions of malocclusion severity, aesthetic concerns, and functional limitations were collected through numeric rating scales, while psychosocial impact was measured using the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ). Correlations were examined with Spearman's coefficients, agreement between clinician- and self-rated AC scores was evaluated with weighted kappa statistics, and multivariable regression analyses were used to identify independent predictors of patient-reported outcomes. Results: Moderate positive correlations emerged between IOTN-DHC and self-perceived malocclusion severity (rho = 0.42, $p < 0.001$), and between clinician-rated IOTN-AC and self-perceived severity (rho = 0.47, $p < 0.001$). Associations were stronger for aesthetic and psychosocial measures than for functional complaints, with the highest correlation observed between clinician-rated IOTN-AC and perceived aesthetic impact (rho = 0.58, $p < 0.001$). Greater clinical severity was also associated with increased psychosocial burden, as reflected by higher PIDAQ total scores. Agreement between clinician and patient evaluations of aesthetic impairment was fair to moderate (weighted kappa = 0.34) but improved when AC scores were grouped into broader categories (weighted kappa = 0.46). Overall, adolescents tended to perceive their dental aesthetic impairment as more severe than did clinicians. In the multivariable models, clinician-rated IOTN-AC remained an independent predictor of perceived severity, aesthetic impact, and psychosocial burden. Conclusions: Clinical measures of malocclusion severity and adolescents' self-perception were significantly related, although they reflected partly different aspects of orthodontic treatment need. Combining normative clinical indices with patient-reported outcomes may allow a more complete and patient-centred evaluation of malocclusion.

Keywords: malocclusion; adolescents; orthodontic treatment need; self-perception; dental aesthetics; psychosocial impact; PIDAQ; IOTN

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1. Introduction

Malocclusion is one of the most common oral health conditions affecting children, adolescents, and young adults, and it can influence not only oral function but also psychological well-being and social interactions. In recent years, increasing attention has been directed toward understanding the psychosocial consequences of dental aesthetics and their impact on patients' quality of life. Evidence suggests that malocclusion may negatively affect self-esteem, social confidence, and overall oral health-related quality of life (OHRQoL), particularly during adolescence and early adulthood when appearance plays a crucial role in social development [1,2].

Traditional orthodontic assessment has primarily relied on normative clinical indices to determine treatment need, such as the Index of Orthodontic Treatment Need (IOTN). However, several studies have demonstrated that normative assessments do not always correspond with patients' own perceptions of their dental appearance or their desire for treatment [3,4]. Psychological factors, aesthetic perception, and personal expectations may strongly influence how individuals evaluate their dental condition and the extent to which they perceive a need for orthodontic intervention.

The psychosocial impact of dental aesthetics has been widely investigated using patient-reported outcome measures such as the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ). This instrument has been shown to be a reliable and valid tool for assessing the psychological and social consequences of malocclusion and dental aesthetics in different populations [5]. Studies have demonstrated significant associations between higher malocclusion severity and increased psychosocial burden as measured by PIDAQ scores, indicating that dental appearance can substantially affect individuals' self-confidence, social interactions, and psychological well-being [6,7].

Research has also highlighted the relationship between malocclusion and Oral Health-related Quality of Life (OHRQoL). Adolescents with more severe malocclusion frequently report greater emotional distress, functional limitations, and social difficulties related to their oral condition [2,8]. These impacts are often mediated by factors such as self-perceived health, psychosocial traits, and social support, emphasizing the multifactorial nature of oral health-related quality of life [5]. Furthermore, young adults seeking orthodontic treatment often report that dissatisfaction with dental aesthetics and concerns about facial appearance significantly influence their body image and overall quality of life [3].

Importantly, discrepancies between clinician-assessed orthodontic treatment need and patients' self-perceived need have been consistently reported in the literature. Patients' perceptions are frequently driven by psychosocial concerns and aesthetic dissatisfaction rather than by the objective clinical severity of malocclusion [3,7]. For instance, patient motivation for orthodontic treatment has been shown to be more strongly associated with psychosocial distress than with clinical indicators of malocclusion severity [3]. Similarly, treatment demand may be influenced by contextual and socioeconomic factors, including access to dental care and regional disparities in healthcare resources [9].

In addition to psychosocial outcomes, malocclusion may also affect behavioural and social expressions, such as smiling patterns and social interactions. Individuals with severe malocclusion have been shown to smile less frequently and to report lower dental self- confidence compared with individuals without malocclusion [10]. These findings further emphasize the broader social implications of dental aesthetics and the importance of considering patient-centred outcomes in orthodontic care.

Given these considerations, contemporary orthodontic research increasingly supports a patient-centred approach that integrates clinical indices with patient-reported outcomes.

Understanding the relationship between malocclusion severity, self-perceived orthodontic need, and psychosocial impacts is essential for improving treatment planning

and prioritization of care. Therefore, evaluating both normative and subjective measures of orthodontic treatment need may provide a more comprehensive understanding of the true burden of malocclusion and its effects on patients' quality of life [8,11,12].

Furthermore, patients' motivations for orthodontic treatment are often strongly influenced by aesthetic concerns and psychological factors rather than purely clinical indicators. These motivations are frequently associated with self-perceived facial aesthetics, dental alignment, and psychological well- being, highlighting the importance of considering patients' subjective perceptions when evaluating orthodontic treatment needs [13].

The aim of this study was to investigate the relationship between clinically assessed malocclusion severity and adolescents' self-perception and to evaluate the agreement between clinician-rated and self-rated aesthetic impairment. We hypothesized that greater clinician-rated malocclusion severity would be associated with worse patient-reported outcomes, particularly in the aesthetic and psychosocial domains and that agreement between clinician-rated and self-rated aesthetic impairment would be limited.

2. Materials and Methods

2.1. Study Design and Setting

This study was designed as an observational cross-sectional study aimed at evaluating the relationship between self-perceived malocclusion and clinically assessed malocclusion in adolescent patients seeking orthodontic evaluation.

The study was conducted at the University of Milan, Department of Orthodontics, Fondazione IRCCS Cà Granda, Ospedale Maggiore Policlinico and Department of Interdisciplinary Medicine, University of Bari Aldo Moro.

2.2. Participants and Sample Size Calculation

A total of 160 consecutive patients were enrolled. Eligible participants were adolescents aged 12 to 17 years who attended the orthodontic clinic for an initial consultation or diagnostic assessment. Participants were recruited (25 October–26 January) using a consecutive sampling strategy, including all eligible adolescents who attended the orthodontic clinics for an initial consultation during the study period. Only patients attending their first orthodontic consultation were considered eligible. The study was conducted in university-based orthodontic clinics that serve as referral centers, receiving patients from a wide catchment area and diverse socioeconomic backgrounds.

A sample of 160 participants was considered adequate to detect a small-to-moderate association between clinical and self-perceived malocclusion with 80% power at a two-sided alpha of 0.05.

Inclusion criteria

- Age between 12 and 17 years.
- Presence of permanent or late mixed dentition sufficient for orthodontic assessment.
- Ability to understand and complete the questionnaire independently.
- Written informed consent from parents/legal guardians and assent from the participant.

Exclusion criteria

- Previous or ongoing orthodontic treatment.
- Craniofacial syndromes or congenital craniofacial anomalies (e.g., cleft lip/palate).
- Severe cognitive or developmental disorders affecting questionnaire completion.
- Acute dental pain or urgent conditions that could influence self-perception at the time of assessment.

2.3. Ethical Considerations

The study protocol was approved by the Institutional Ethics Committee of IRCCS "Giovanni Paolo II", Puglia Salute Prot. 967 of 1 October 2025. Prot. 2377/CEL.

The study was conducted in accordance with the Declaration of Helsinki.

Written informed consent was obtained from the parents or legal guardians of all participants, and assent was obtained from the adolescents.

2.4. Study Procedure

Each participant underwent:

1. Clinical orthodontic examination (objective assessment of malocclusion).
2. Self-perception assessment (subjective evaluation of malocclusion severity, aesthetic impact, and functional impact).
3. Psychosocial impact assessment using a validated patient-reported outcome measure.

All assessments were performed on the same day, before any treatment planning discussion, in order to avoid influencing the patient's self-perception. Self-assessment questionnaires were completed by participants independently before the clinical examination, without any input from the clinician. The orthodontist performing the clinical assessment was blinded to the self-reported data at the time of examination.

2.5. Clinical Assessment of Malocclusion

Malocclusion severity was assessed using the Index of Orthodontic Treatment Need (IOTN), including:

- Dental Health Component (DHC): Used to classify normative treatment need based on occlusal traits and functional and health-related aspects.
- Aesthetic Component (AC): Used to assess aesthetic impairment according to the standardized photographic scale.

In addition, the following occlusal characteristics were recorded during the clinical examination:

- Overjet.
- Overbite.
- Crowding/spacing were recorded together as arch space discrepancies.
- Posterior crossbite.
- Anterior open bite.

All clinical examinations were performed by a trained orthodontist. To improve reproducibility, the examiner underwent calibration before the start of the study. Intra-examiner reliability was assessed in a subset of participants re-evaluated after 2 weeks, using weighted kappa for categorical variables and intraclass correlation coefficient (ICC) for continuous variables.

The Index of Orthodontic Treatment Need (IOTN) is a widely used and validated index for assessing orthodontic treatment need in children and adolescents, combining functional and aesthetic components. It has demonstrated good reliability and validity across different populations.

2.6. Self-Perceived Malocclusion and Patient-Reported Outcomes

2.6.1. Self-Perceived Malocclusion

Self-perceived malocclusion severity, aesthetic impact, and functional impact were assessed using numeric rating scales (NRS). Although these scales are not specifically validated orthodontic instruments, they are widely used in clinical research to cap-

ture subjective patient perceptions in a simple and reproducible way, particularly in adolescent populations.

Participants were asked to rate the following dimensions using a numeric rating scale (NRS) from 0 to 10:

- Perceived severity of malocclusion (0 = no problem, 10 = very severe problem).
- Perceived aesthetic impact (0 = no aesthetic impact, 10 = very high aesthetic impact).
- Perceived functional impact (0 = no functional difficulty, 10 = very high functional difficulty).

Functional impact referred mainly to perceived difficulties in chewing, biting, or oral function related to tooth position/occlusion.

2.6.2. Self-Assessment of Dental Aesthetics

Participants also completed a self-assessment of dental appearance using the IOTN Aesthetic Component (self-AC) by selecting the image that best represented their own dentition from a standardized scale of 10 colour photographs, ranging from 1 (most attractive) to 10 (least attractive). The self-rated IOTN-AC has been previously used as a patient-reported measure of dental aesthetics and has shown acceptable validity in assessing perceived orthodontic treatment need.

2.6.3. Psychosocial Impact Questionnaire

The psychosocial impact of dental aesthetics was evaluated using the Italian validated version of the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ) for adolescents. The Italian version of the PIDAQ, previously translated and validated, was used in this study.

The questionnaire assesses the effect of dental appearance on psychosocial well-being and includes domains related to:

- Dental self-confidence.
- Social impact.
- Psychological impact.
- Aesthetic concern.

The total score was calculated according to the instrument scoring guidelines. Higher scores indicated a greater psychosocial impact of dental aesthetics (except for reverse-scored items, if applicable).

2.7. Data Collection and Management

Clinical and questionnaire data were collected using standardized forms and then entered into a dedicated electronic database. Data entry was checked for completeness and consistency before statistical analysis.

Participant demographic variables included:

- Age (years).
- Sex (male/female).

No treatment-related decisions were made based on questionnaire responses.

2.8. Outcome Measures

The primary outcome was the association between:

- Clinically assessed malocclusion severity (IOTN-DHC and IOTN-AC).
- Self-perceived malocclusion severity (NRS score).

Secondary outcomes included:

- Association between clinical malocclusion and self-perceived aesthetic impact.

- Association between clinical malocclusion and self-perceived functional impact.
- Association between clinical malocclusion and PIDAQ total score.
- Agreement between clinician-rated IOTN-AC and patient self-rated IOTN-AC.

2.9. Statistical Analysis

All statistical analyses were performed using R software (R Foundation for Statistical Computing, Vienna, Austria; version 4.3.2). Statistical significance was set at a two-sided alpha level of 0.05.

Continuous variables were summarized as mean ± standard deviation (SD) or median and interquartile range (IQR), as appropriate according to their distribution, whereas categorical variables were reported as counts and percentages. Distributional assumptions were assessed by visual inspection and the Shapiro–Wilk test.

Intra-examiner reproducibility was evaluated in a subsample of 20 participants re-examined after a 2-week interval. Weighted kappa was used for ordinal variables (IOTN-DHC and clinician-rated IOTN-AC), and intraclass correlation coefficients (ICC; two-way mixed-effects model, absolute agreement) were used for continuous occlusal measurements. Interpretation of kappa values followed the benchmarks proposed by Landis and Koch.

Reliability estimates were reported with 95% confidence intervals (95% CIs).

The primary analysis assessed the association between clinically evaluated malocclusion severity (IOTN-DHC and clinician-rated IOTN-AC) and self-perceived malocclusion severity using Spearman's rank correlation coefficient (rho), with 95% CIs. Secondary Spearman correlation analyses examined the associations of clinical malocclusion indices with self-perceived aesthetic impact, self-perceived functional impact, and PIDAQ total score.

Agreement between clinician-rated and self-rated IOTN-AC was assessed using weighted kappa with 95% CIs. For the agreement analysis, the original 10-point IOTN-AC scale was also categorized into three levels of aesthetic treatment need: low (scores 1–4), moderate (scores 5–7), and high (scores 8–10). This grouping was adopted to enhance clinical interpretability and to reduce sparsity across categories in agreement analyses.

Differences in self-perceived malocclusion severity, aesthetic impact, functional impact, and PIDAQ scores across normative treatment-need categories were tested using the Kruskal–Wallis test, followed by Dunn's post hoc test with Holm adjustment when appropriate.

To identify independent predictors of patient-reported outcomes, multivariable linear regression models with robust standard errors were fitted for self-perceived malocclusion severity, perceived aesthetic impact, perceived functional impact, and PIDAQ total score. Covariates were selected a priori based on clinical relevance and included age, sex, IOTN-DHC, clinician-rated IOTN-AC, and key occlusal traits. Multicollinearity was assessed before model fitting.

Because missing data were minimal, the main analyses were based on complete cases. Multiple imputation was performed as a sensitivity analysis to confirm the robustness of the findings.

3. Results

3.1. Participant Characteristics

A total of 160 adolescents were included in the final analysis. The mean age was 14.3 ± 1.7 years (range: 12–17 years). Of these, 86 (53.8%) were female and 74 (46.3%) were male.

No major missing data were observed for the primary outcome variables. Questionnaire completeness was >95% for all items. Missing values in secondary variables were minimal (<3%) and did not materially affect the analyses (Table 1).

Table 1. Participants' characteristics and clinical findings (n = 160).

Variable	Total Sample (n = 160)
Age, years (mean ± SD)	14.3 ± 1.7
Sex, n (%)	
Male	74 (46.3)
Female	86 (53.8)
IOTN-DHC category, n (%)	
Grade 1–2 (no/little need)	34 (21.3)
Grade 3 (borderline need)	49 (30.6)
Grade 4–5 (definite need)	77 (48.1)
Clinician-rated IOTN-AC (median, IQR)	5 (3–7)
Self-rated IOTN-AC (median, IQR)	6 (4–8)
Occlusal traits, n (%)	
Crowding/spacing	98 (61.3)
Increased overjet	56 (35.0)
Deep bite	44 (27.5)
Posterior crossbite	29 (18.1)
Anterior open bite	17 (10.6)

3.2. Clinical Malocclusion Severity and Normative Treatment Need

Clinical characteristics are summarized in Table 1. Nearly half of the sample showed definite normative treatment need (IOTN-DHC grades 4–5), and the median clinician-rated IOTN-AC score was 5 (IQR: 3–7). The most frequent occlusal trait was crowding/spacing discrepancy (61.3%).

3.3. Self-Perceived Malocclusion and Patient-Reported Outcomes

The median self-perceived scores (0–10 NRS) were:

- Perceived malocclusion severity: 6 (IQR: 4–8).
- Perceived aesthetic impact: 7 (IQR: 5–8).
- Perceived functional impact: 3 (IQR: 1–5).

These findings suggest a stronger perceived burden in the aesthetic domain than in the functional domain.

The median self-rated IOTN-AC score was 6 (IQR: 4–8), slightly higher than the clinician-rated AC.

The mean PIDAQ total score was 31.8 ± 11.6 (range: 8–61), with higher scores observed among participants with greater clinician-rated aesthetic impairment (Table 2).

Table 2. Self-perceived malocclusion and psychosocial impact outcomes (n = 160).

Variable	Value
Perceived malocclusion severity (NRS 0–10), median (IQR)	6 (4–8)
Perceived aesthetic impact (NRS 0–10), median (IQR)	7 (5–8)
Perceived functional impact (NRS 0–10), median (IQR)	3 (1–5)
PIDAQ total score (mean ± SD)	31.8 ± 11.6
Questionnaire completeness, %	>95%
Missing data (secondary variables), %	<3%

3.4. Reproducibility of the Clinical Assessment

Intra-examiner reproducibility was good to excellent (weighted kappa 0.79–0.84; ICC 0.88–0.94).

3.5. Primary Outcome: Association Between Clinical and Self-Perceived Malocclusion Severity

A moderate positive correlation was found between IOTN-DHC and self-perceived malocclusion severity (NRS):

- Spearman's rho = 0.42 (95% CI: 0.28–0.54), $p < 0.001$.

A similar association was observed between clinician-rated IOTN-AC and self-perceived severity:

- Spearman's rho = 0.47 (95% CI: 0.34–0.58), $p < 0.001$.

These findings indicate that greater clinical malocclusion severity was associated with higher patient-perceived severity, although the strength of the correlation was moderate rather than strong (Table 3).

Table 3. Correlations between clinical malocclusion severity and patient-reported outcomes.

Clinical Variable	Outcome Variable	Spearman's rho	*p*-Value
IOTN-DHC	Self-perceived malocclusion severity (NRS)	0.42	<0.001
Clinician-rated IOTN-AC	Self-perceived malocclusion severity (NRS)	0.47	<0.001
IOTN-DHC	Perceived aesthetic impact (NRS)	0.39	<0.001
IOTN-DHC	Perceived functional impact (NRS)	0.18	0.020
Clinician-rated IOTN-AC	Perceived aesthetic impact (NRS)	0.58	<0.001
Clinician-rated IOTN-AC	Perceived functional impact (NRS)	0.21	0.008
IOTN-DHC	PIDAQ total score	0.36	<0.001
Clinician-rated IOTN-AC	PIDAQ total score	0.52	<0.001

Agreement was interpreted according to Landis and Koch criteria (poor: <0.20; fair: 0.21–0.40; moderate: 0.41–0.60; substantial: 0.61–0.80; almost perfect: >0.80).

3.6. Secondary Outcomes: Association with Aesthetic and Functional Self-Perception

Clinical malocclusion indices were more strongly associated with perceived aesthetic impact than with perceived functional impact (Table 3), with the strongest correlation observed between clinician-rated IOTN-AC and perceived aesthetic impact (rho = 0.58). Overall, these findings indicate that the association between clinical severity and patient perception was more pronounced for aesthetic concerns than for functional complaints.

Agreement between clinician-rated and self-rated IOTN-AC was fair to moderate (weighted kappa = 0.34), according to Landis and Koch criteria. After grouping AC scores into broader categories, agreement improved to a moderate level (weighted kappa = 0.46). This indicates a limited but non-negligible concordance between clinician and patient assessments, with improved agreement when reducing scale granularity.

3.7. Association with Psychosocial Impact (PIDAQ)

Higher clinical malocclusion severity was associated with greater psychosocial impact, as reflected by significant correlations with PIDAQ total score (Table 3).

3.8. Agreement Between Clinician-Rated and Self-Rated Aesthetic Impairment

Agreement between clinician-rated and self-rated IOTN-AC was fair to moderate (weighted kappa = 0.34) and improved after grouping AC scores into broader aesthetic treatment-need categories (weighted kappa = 0.46; Table 4).

Table 4. Agreement between clinician-rated and self-rated aesthetic impairment (IOTN-AC).

Agreement Analysis	Weighted Kappa (κw)	Interpretation
IOTN-AC (original ordinal scale)	0.34	Fair-to-moderate agreement
IOTN-AC (grouped: low/moderate/high)	0.46	Moderate agreement

A systematic tendency toward higher self-ratings was observed, with participants generally rating their aesthetic impairment as more severe than clinicians.

3.9. Group Comparisons by Normative Treatment Need

Participants with definite normative treatment need (IOTN-DHC grades 4–5) reported significantly higher self-perceived malocclusion severity, perceived aesthetic impact, and PIDAQ total scores than those with no/little treatment need (all $p < 0.001$). By contrast, differences in perceived functional impact across treatment-need categories were smaller, although the overall comparison remained statistically significant ($p = 0.03$).

3.10. Multivariable Analyses

In multivariable linear regression models (with robust standard errors), clinician-rated IOTN-AC remained an independent predictor of (Table 5):

(1) Self-perceived malocclusion severity (NRS)
- β = 0.41 (95% CI: 0.25–0.57), $p < 0.001$

(2) Perceived aesthetic impact (NRS)
- β = 0.53 (95% CI: 0.37–0.69), $p < 0.001$

(3) PIDAQ total score
- β = 2.10 points per 1-unit increase in IOTN-AC (95% CI: 1.42–2.78), $p < 0.001$

Table 5. Multivariable regression models for patient-perceived outcomes. Only predictors that remained statistically significant in the fully adjusted final models are shown.

Outcome	Predictor	Effect Type	Estimate	*p*-Value
Self-perceived malocclusion severity (NRS)	Clinician-rated IOTN-AC	B	0.41	<0.001
Perceived aesthetic impact (NRS)	Clinician-rated IOTN-AC	B	0.53	<0.001
PIDAQ total score	Clinician-rated IOTN-AC	β (points)	2.10	<0.001
PIDAQ total score	Female sex (vs. male)	β (points)	3.80	0.006
Perceived functional impact (NRS)	Anterior open bite (yes vs. no)	B	1.20	0.004

Sex was also associated with PIDAQ total score, with females reporting higher psychosocial impact than males:

- β = 3.8 points (95% CI: 1.1–6.5), $p = 0.006$

Age was not independently associated with self-perceived severity or PIDAQ score after adjustment.

For perceived functional impact, clinical severity showed a weaker independent association, and only the presence of anterior open bite remained significant in the fully adjusted model:

- β = 1.2 (95% CI: 0.4–2.0), $p = 0.004$

4. Discussion

The present findings suggest that clinician-rated malocclusion severity and patient self-perception are significantly associated, although they represent partially distinct dimensions of orthodontic treatment need. The observed correlations between clinical indices and self-perceived severity were moderate, indicating that while clinical severity contributes to how adolescents perceive their malocclusion, it does not fully explain the subjective experience.

In addition to clinical severity, psychosocial factors and the aesthetic component of malocclusion play a crucial role in shaping adolescents' self-perception. Facial appearance and dental aesthetics are closely linked to social interactions, self-esteem, and peer acceptance, particularly during adolescence. Individual psychological traits, social context, and sensitivity to appearance-related concerns may influence how malocclusion is perceived, independently of its objective severity. As a result, even mild clinical conditions may be perceived as highly impactful by some individuals, while more severe malocclusions may be underestimated by others. These psychosocial and aesthetic dimensions may partly explain the discrepancies observed between subjective perception and clinician-based assessments, highlighting the multidimensional nature of orthodontic treatment need. Although self-assessment and clinical evaluation were conducted on the same day, which may introduce a potential source of bias, measures were taken to minimize this effect by ensuring independent completion of questionnaires and blinding of the examiner. However, some residual bias cannot be completely excluded.

In line with this interpretation, both the Dental Health Component (IOTN-DHC) and the Aesthetic Component (IOTN-AC) showed significant correlations with self-perceived malocclusion severity. Similar relationships between clinically assessed malocclusion and patient perception have been reported in previous studies conducted in adolescent populations [7,8,11,12,14–18]. However, the moderate magnitude of these correlations suggests that individual perception of malocclusion is influenced not only by occlusal severity but also by psychological and social factors that are not captured by clinical indices alone [3,4,17,19–27].

A key finding of the present study is that the association between clinical malocclusion severity and patient perception was considerably stronger for aesthetic and psychosocial outcomes than for functional complaints. Clinician-rated aesthetic impairment (IOTN-AC) showed a substantially stronger correlation with perceived aesthetic impact than with perceived functional impact (ρ = 0.58 vs. ρ = 0.21). This pattern indicates that adolescents tend to be more sensitive to visible aspects of dental appearance and to the social implications of malocclusion than to functional alterations. Previous studies have similarly reported that dissatisfaction with dental aesthetics is a major motivation for seeking orthodontic treatment and is closely related to psychosocial distress associated with dental appearance [1,6,14,22,26–31].

Consistent with this interpretation, greater clinician-rated aesthetic impairment was also associated with higher psychosocial impact, as measured by the PIDAQ. Among the

clinical indicators examined, the IOTN-AC showed stronger correlations with psychosocial outcomes than the Dental Health Component. In the multivariable analyses, IOTN-AC remained an independent predictor of self-perceived severity, perceived aesthetic impact, and PIDAQ total score. These findings emphasize the central role of dental aesthetics in shaping adolescents' experience of malocclusion and confirm that aesthetic severity represents the clinical factor most strongly associated with psychosocial burden.

Another important observation of the present study is the discrepancy between clinician-rated and self-perceived aesthetic impairment. Participants tended to rate their dental appearance more negatively than clinicians, and the agreement between clinician-rated and self-rated IOTN-AC was only fair to moderate. This systematic tendency toward higher self-ratings suggests that adolescents may evaluate dental appearance through a more subjective and socially influenced perspective compared with clinicians, who rely on normative occlusal criteria. Similar discrepancies between professional assessment and patient perception have been reported in previous orthodontic research [3,11,20,24,30].

Similar discrepancies between clinician-rated and self-perceived aesthetic impairment have been reported across different populations, suggesting that this phenomenon is not limited to a specific cultural context. However, the magnitude and direction of these differences may vary depending on sociocultural factors, aesthetic norms, and expectations regarding dental appearance. Compared with findings from other countries, Italian adolescents may be influenced by specific cultural attitudes toward facial aesthetics, social comparison, and access to orthodontic care. These contextual factors could contribute to similarities as well as differences in the perception of malocclusion across populations.

In contrast, the functional dimension showed weaker associations with clinical malocclusion severity. Although statistically significant relationships were observed, the magnitude of the correlations between clinical indices and perceived functional impact was relatively low. This finding is clinically plausible in adolescent populations, where functional limitations related to malocclusion are often mild or well compensated. Consequently, adolescents may be less aware of functional alterations unless they are associated with pain or significant masticatory impairment. Previous studies have also reported that the psychosocial and aesthetic consequences of malocclusion tend to outweigh functional complaints in young populations [2,8,19,27]. Some authors have suggested that functional symptoms related to occlusion may become more evident only in specific clinical situations, such as severe occlusal discrepancies or temporomandibular disorders [32].

Sex differences in psychosocial impact were also observed in this study. Female participants reported significantly higher PIDAQ scores compared with males, indicating a greater perceived psychosocial burden associated with dental aesthetics. This finding is consistent with previous research suggesting that female adolescents may be more sensitive to appearance-related concerns and social evaluation [1,6,22,26]. Sociocultural expectations and differences in body image perception may contribute to these patterns and should be considered when interpreting patient-reported outcomes.

Taken together, the overall pattern of findings provides a coherent and clinically meaningful narrative. Clinical malocclusion severity and patient perception are significantly associated but represent distinct dimensions of orthodontic need [33–37]. The perceived burden of malocclusion in adolescents appears to be driven primarily by aesthetic and psychosocial factors rather than by functional complaints. In addition, adolescents tend to evaluate their dental appearance more negatively than clinicians, highlighting a relevant gap between professional assessment and patient self-image. Finally, clinician-rated aesthetic severity (IOTN-AC) emerged as the strongest predictor of psychosocial impact, underscoring the central role of dental aesthetics in shaping adolescents' experience of malocclusion [38–42].

Importantly, these overall patterns remained consistent across sensitivity analyses using grouped IOTN categories, ordinal logistic models for NRS outcomes, and complete-case versus imputed datasets, supporting the robustness of the main findings.

These findings support the importance of adopting a patient-centred approach in orthodontic assessment and treatment planning [43,44]. In addition, recent advances in precision medicine and digital technologies have increasingly supported the development of individualized diagnostic and treatment approaches in the craniofacial and orthopaedic fields. In particular, the application of 3D design and manufacturing techniques has enabled the production of patient-specific implants and therapeutic solutions, further emphasizing the importance of personalization in clinical decision-making. Although these approaches have been mainly explored in surgical contexts, they reflect a broader trend toward individualized and patient-centred care that is also highly relevant in contemporary orthodontics.

While normative indices such as the IOTN remain essential for evaluating clinical severity and treatment need, they do not fully capture the subjective burden experienced by patients [45,46]. Instruments such as the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ) have been widely used to assess the psychosocial consequences of dental appearance and have been validated in different populations and cultural contexts [5,15,23].

Strengths and Limitations

This study has several strengths. First, it combined clinician-rated measures of malocclusion severity with patient-reported outcomes, allowing the assessment of both normative orthodontic treatment need and subjective patient experience within the same adolescent sample. This integrated approach provides a more comprehensive understanding of malocclusion burden than the use of clinical indices alone. Second, the study examined multiple dimensions of patient perception, including self-perceived malocclusion severity, aesthetic impact, functional impact, and psychosocial burden measured with the PIDAQ. This multidimensional framework allowed a more nuanced evaluation of how malocclusion is experienced during adolescence. Third, the use of validated and widely recognized instruments, such as the IOTN and the PIDAQ, strengthens the methodological rigor of the study and facilitates comparison with previous research. In addition, the assessment of agreement between clinician-rated and self-rated aesthetic impairment provided clinically relevant insight into the gap between professional evaluation and patient self-image. The inclusion of multivariable models and the consistency of the findings across sensitivity analyses further support the robustness of the results. Finally, intra-examiner reproducibility was formally assessed and showed good-to-excellent reliability, supporting the internal validity of the clinical measurements. The representativeness of the study population should also be considered. The sample consisted of adolescents attending their first orthodontic consultation in a university-based clinical setting, which likely reflects a treatment-seeking population rather than the general adolescent population. Therefore, participants may present higher levels of perceived or clinically assessed malocclusion compared with community-based samples. However, this setting enhances the clinical relevance of the findings, as it reflects real-world orthodontic practice and is likely representative of adolescents seeking initial orthodontic evaluation in similar referral centers.

This study has several limitations that should be considered when interpreting the findings. First, the cross-sectional design does not allow causal inferences regarding the relationship between malocclusion severity and patient-reported outcomes. In addition, the sample consisted of adolescents seeking orthodontic consultation in a single clinical setting and recruited through a consecutive sampling approach, which may limit the representativeness of the study population. Treatment-seeking individuals are more likely to present greater clinical severity or greater concern about dental aesthetics, potentially

introducing selection bias and reducing the generalizability of the results to community-based populations. Furthermore, although psychosocial impact was assessed using a validated instrument, unmeasured psychological and social factors may have influenced self-perception, contributing to residual confounding. The use of self-reported measures for malocclusion severity, aesthetic impact, and functional impact introduces subjectivity, as responses may be affected by individual expectations and social context. Although the IOTN is a validated index, its aesthetic component may still be interpreted differently by clinicians and patients, leading to variability in agreement. Additionally, functional impact was assessed using a simple numerical rating scale rather than a multidimensional validated instrument, which may have limited the ability to detect subtle functional difficulties, and similar considerations apply to the use of simple scales that may not fully capture the complexity of patient experience. Another limitation concerns the use of the PIDAQ in an adolescent population; although widely applied in similar age groups, it was originally developed for young adults, and some items may be interpreted differently by younger participants, potentially influencing the reported psychosocial impact. Nevertheless, all participants were able to complete the questionnaire independently, suggesting adequate comprehension. Finally, although missing data were minimal and sensitivity analyses confirmed the robustness of the findings, some secondary analyses may have been underpowered to detect weaker associations. Future studies using longitudinal designs, population-based samples, and age-specific validated instruments would be useful to confirm and extend these results.

5. Conclusions

Within the limitations of this cross-sectional study, clinically assessed malocclusion severity and adolescents' self-perception were significantly associated, although they reflect partially distinct dimensions of orthodontic treatment need.

The findings suggest that adolescents' perception of malocclusion is influenced not only by objective occlusal severity but also by subjective and psychosocial factors. In particular, stronger associations were observed for aesthetic and psychosocial outcomes than for functional complaints.

A systematic discrepancy between professional assessment and patient perception was also observed, with adolescents tending to rate their dental aesthetic impairment as more severe than clinicians.

Overall, these results highlight the importance of integrating patient-reported measures with normative clinical indices in orthodontic assessment to better capture the multidimensional nature of malocclusion.

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References

1. Yamini Priyanka, J.S.; Bhavya, P.; Srinivas, B.; Singaraju, G.S.; Vivek Reddy, G.; Mandava, P. An Assessment of the Subjective Psychological and Social Effects of Malocclusion-Related Dental Aesthetics and Its Influence on Body Self-Image and Oral Health-Related Quality of Life in Young Adults. *Cureus* **2024**, *16*, e60120. [CrossRef]
2. Leite, S.D.C.; Herkrath, F.J.; Vettore, M.V.; Rebelo, M.A.B.; de Queiroz, A.C.; Pereira, J.V.; de Herkrath, A.P.C.Q. The association between malocclusion and health-related quality of life in adolescents: A mediation analysis. *Eur. J. Oral Sci.* **2024**, *132*, e12960. [CrossRef]
3. Zhao, G.; Zhu, F. Age matters in orthodontics: Divergent motivations, perfectionism, and patient-clinician discord in treatment need assessment. *Front. Med.* **2026**, *12*, 1714237. [CrossRef]
4. Susmitha, T.S.; Sukhabhogi, J.R.; Doshi, D. Sense of coherence and its relation to self perceived dental appearance and normative orthodontic treatment need among 12-year-old children. *J. Oral Biol. Craniofac. Res.* **2025**, *15*, 1655–1659. [CrossRef]
5. Anagnostou, C.; Zogakis, I.P.; Pagkozidis, I.; Matiakis, A.; Tirodimos, I.; Dardavesis, T.; Tsimtsiou, Z. Validity and Reliability of the Greek Version of the Psychosocial Impact of Dental Aesthetics Questionnaire (Gr-PIDAQ). *Dent. J.* **2026**, *14*, 14. [CrossRef] [PubMed]
6. Doughan, M.B.; Khandakji, M.; Khoury, B.; Ghafari, J.G. Assessment of psychosocial parameters in adolescents seeking orthodontic treatment. *BMC Oral Health* **2024**, *24*, 1299. [CrossRef]
7. Ben Gassem, A.A.; Aldweesh, A.H.; Alsagob, E.I.; Alanazi, A.M.; Hafiz, A.M.; Aljohani, R.S.; Kurdi, Y.E.; Abu Hammad, O. Psychosocial Impact of Malocclusion and Self-Perceived Orthodontic Treatment Need among Young Adult Dental Patients. *Eur. J. Dent.* **2023**, *17*, 713–719. [CrossRef]
8. Çelikel, A.D.G.; Çifter, M.; Tağrikulu, B.; Peker, K. Associations between oral health impacts attributed to malocclusion and normative and self-perceived orthodontic treatment need in Turkish adolescent patients. *BMC Oral Health* **2024**, *24*, 1253. [CrossRef] [PubMed]
9. Hoang, H.T.; Huynh, N.C.; Cao, U.M.; Ngo, C.U.; Pham, Q.L.; Nguyen, K.D. Geographical Disparities in Orthodontic Treatment Demand: 15-Year-Old Vietnamese Population Analyzed by Dentist-Population Ratio. *J. Clin. Exp. Dent.* **2025**, *17*, e1163–e1171. [CrossRef]
10. Mohammed, H.; Kumar, R., Jr.; Bennani, H.; Perry, J.; Halberstadt, J.B.; Farella, M. Malocclusion severity and smile features: Is there an association? *Am. J. Orthod. Dentofac. Orthop.* **2023**, *164*, 14–23. [CrossRef] [PubMed]
11. Farronato, G.; Maspero, C.; Farronato, D.; Gioventù, S. Orthodontic treatment in a patient with cleidocranial dysostosis. *Angle Orthod.* **2009**, *79*, 178–185. [CrossRef] [PubMed]
12. Krekmanova, L.; Shakrchi, S.; Gicic, A.; Naoumova, J. Comparison of the Opinions of Adolescents with Different Orthodontic Treatment Needs. *Clin. Exp. Dent. Res.* **2024**, *10*, e944. [CrossRef]
13. Wang, T.; Li, H.; Xia, W.; He, F.; Guo, Y. Orthodontic retreatment need and related self-perceived factors among contemporary college freshmen in China. *J. Clin. Pediatr. Dent.* **2023**, *47*, 74–84. [CrossRef]
14. Akbeyaz Şivet, E.; Sezer, B.; Karanlık, U.; Kargül, B. Evaluation of the relationship between the psychosocial impact of dental appearance and self-perceived aestheticstreatment need among dental students. *BMC Med. Educ.* **2026**, *26*, 370. [CrossRef] [PubMed]
15. Alharbi, R.A.; Eshky, R.T.; Marae, S.O.; Hifnawy, T.; Alsulaimani, M. Translation and validation of the Arabic version of the Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ). *J. Orthod. Sci.* **2020**, *9*, 19. [CrossRef] [PubMed]
16. Maspero, C.; Fama, A.; Cavagnetto, D.; Abate, A.; Farronato, M. Treatment of dental dilacerations. *J. Biol. Regul. Homeost. Agents* **2019**, *33*, 1623–1627.
17. Tejaswini, D.; Kulkarni, S.; Doshi, D.; Srilatha, A. Self perceived oro-facial behaviour and malocclusion among young adults in Hyderabad city. *Int. J. Adolesc. Med. Health* **2020**, *33*, 195–200. [CrossRef]
18. do Amaral, B.A.; Gondim Filgueira, A.C.; da Silva-Neto, J.P.; de Lima, K.C. Relationship between normative and self-perceived criteria for orthodontic treatment need and satisfaction with esthetics and mastication in adolescents. *Am. J. Orthod. Dentofac. Orthop.* **2020**, *157*, 42–48.e2. [CrossRef]
19. Kunz, F.; Platte, P.; Keß, S.; Geim, L.; Zeman, F.; Proff, P.; Hirschfelder, U.; Stellzig-Eisenhauer, A. Correlation between oral health-related quality of life and orthodontic treatment need in children and adolescents-a prospective interdisciplinary multicentre cohort study. *J. Orofac. Orthop.* **2018**, *79*, 297–308. [CrossRef]
20. Cai, Y.; Du, W.; Lin, F.; Ye, S.; Ye, Y. Agreement of young adults and orthodontists on dental aesthetics & influencing factors of self-perceived aesthetics. *BMC Oral Health* **2018**, *18*, 113. [CrossRef]
21. Farronato, M.; Boccalari, E.; Del Rosso, E.; Lanteri, V.; Mulder, R.; Maspero, C. A Scoping Review of Respirator Literature and a Survey among Dental Professionals. *Int. J. Environ. Res. Public Health* **2020**, *17*, 5968. [CrossRef]
22. Chakradhar, K.; Doshi, D.; Kulkarni, S.; Reddy, B.S.; Reddy, S.; Srilatha, A. Self perceived psychosocial impact of dental aesthetics among young adults: A cross sectional questionnaire study. *Int. J. Adolesc. Med. Health* **2017**, *32*, 3. [CrossRef]

23. Garg, K.; Tripathi, T.; Rai, P.; Sharma, N.; Kanase, A. Prospective Evaluation of Psychosocial Impact after One Year of Orthodontic Treatment Using PIDAQ Adapted for Indian Population. *J. Clin. Diagn. Res.* **2017**, *11*, ZC44–ZC48. [CrossRef]
24. Monteiro, A.K.A.P.; Sarmento, D.J.S.; Pinto-Sarmento, T.C.A.; Diniz, M.B.; Granville-Garcia, A.F.; Duarte, D.A. Normative need for orthodontic treatment and perception of the need for such treatment among Brazilian adolescents. *Dent. Press J. Orthod.* **2017**, *22*, 41–46. [CrossRef]
25. Eslamipour, F.; Riahi, F.T.; Etemadi, M.; Riahi, A. Correlation coefficients of three self-perceived orthodontic treatment need indices. *Dent. Res. J.* **2017**, *14*, 37–42. [CrossRef]
26. Dos Santos, P.R.; Meneghim, M.C.; Ambrosano, G.M.; Filho, M.V.; Vedovello, S.A. Influence of quality of life, self-perception, and self-esteem on orthodontic treatment need. *Am. J. Orthod. Dentofac. Orthop.* **2017**, *151*, 143–147. [CrossRef]
27. Silva, L.F.; Thomaz, E.B.; Freitas, H.V.; Pereira, A.L.; Ribeiro, C.C.; Alves, C.M. Impact of Malocclusion on the Quality of Life of Brazilian Adolescents: A Population-Based Study. *PLoS ONE* **2016**, *11*, e0162715. [CrossRef] [PubMed]
28. Maspero, C.; Gaffuri, F.; Castro, I.O.; Lanteri, V.; Ugolini, A.; Farronato, M. Correlation between Dental Vestibular-Palatal Inclination and Alveolar Bone Remodeling after Orthodontic Treatment: A CBCT Analysis. *Materials* **2019**, *12*, 4225. [CrossRef]
29. Taghavi Bayat, J.; Huggare, J.; Mohlin, B.; Akrami, N. Predicting orthodontic treatment need: Reliability and validity of the Demand for Orthodontic Treatment Questionnaire. *Eur. J. Orthod.* **2017**, *39*, 326–333. [CrossRef] [PubMed]
30. Omer, Y.T.; Bouserhal, J.; Hawas, N.; Abdel Moneim El Sayed, A. Association between normative and self-perceived orthodontic treatment need in a Lebanese population. *Int. Orthod.* **2016**, *14*, 386–398. [CrossRef] [PubMed]
31. Yi, S.; Zhang, C.; Ni, C.; Qian, Y.; Zhang, J. Psychosocial impact of dental aesthetics and desire for orthodontic treatment among Chinese undergraduate students. *Patient Prefer. Adherence* **2016**, *10*, 1037–1042. [CrossRef]
32. Svedström-Oristo, A.L.; Ekholm, H.; Tolvanen, M.; Peltomäki, T. Self-reported temporomandibular disorder symptoms and severity of malocclusion in prospective orthognathic-surgical patients. *Acta Odontol. Scand.* **2016**, *74*, 466–470. [CrossRef]
33. Silva, L.F.; Thomaz, E.B.; Freitas, H.V.; Ribeiro, C.C.; Pereira, A.L.; Alves, C.M. Self-perceived need for dental treatment and related factors. A cross-sectional population-based study. *Braz. Oral Res.* **2016**, *30*, e55. [CrossRef]
34. Farronato, G.; Galbiati, G.; Esposito, L.; Mortellaro, C.; Zanoni, F.; Maspero, C. Three-Dimensional Virtual Treatment Planning: Presurgical Evaluation. *J. Craniofac. Surg.* **2018**, *29*, e433–e437. [CrossRef]
35. El-Angbawi, A.; McIntyre, G.; Fleming, P.S.; Bearn, D. Non-surgical adjunctive interventions for accelerating tooth movement in patients undergoing orthodontic treatment. *Cochrane Database Syst. Rev.* **2023**, *6*, CD010887. [PubMed]
36. Alikhani, M.; Alyami, B.; Lee, I.S.; Almoammar, S.; Vongthongleur, T.; Alikhani, M.; Alansari, S.; Sangsuwon, C.; Chou, M.Y.; Khoo, E.; et al. Saturation of the biological response to orthodontic forces and its effect on the rate of tooth movement. *Orthod. Craniofac. Res.* **2015**, *18*, 8–17. [CrossRef] [PubMed]
37. Kapoor, P.; Kharbanda, O.P.; Monga, N.; Miglani, R.; Kapila, S. Effect of orthodontic forces on cytokine and receptor levels in gingival crevicular fluid: A systematic review. *Prog. Orthod.* **2014**, *15*, 65. [CrossRef]
38. González Oneto, H.; Torres Pinto, M.I.; Macherone Chaparro, M.; Zedan Abuawad, Y.; Vargas Buratovic, J.P.; Ortuño Borroto, D. Cross-cultural adaptation of PIDAQ questionnaire to evaluate the psychosocial impact of dental esthetics in Chilean adolescents with malocclusion. *Community Dent. Health* **2026**, 265539X261429988. [CrossRef]
39. Wan Hassan, W.N.; Yusof, Z.Y.; Makhbul, M.Z.; Shahidan, S.S.; Mohd Ali, S.F.; Burhanudin, R.; Gere, M.J. Validation and reliability of the Malaysian English version of the psychosocial impact of dental aesthetics questionnaire for adolescents. *Health Qual. Life Outcomes* **2017**, *15*, 54. [CrossRef] [PubMed]
40. Patri, V.; Patri, G.; Sahoo, N. Psychometric Evaluation of the Odia-Adapted Psychosocial Impact of Dental Aesthetics Questionnaire (PIDAQ): A Cross-Sectional Study Assessing the Psychosocial Impact of Malocclusion in Eastern Indian Adolescents. *Cureus* **2025**, *17*, e82658. [CrossRef]
41. Fidalgo, J.; Botelho, J.; Proença, L.; Mendes, J.J.; Machado, V.; Delgado, A.S. Cross-Cultural Adaptation and Validation of the Portuguese Version of the Psychosocial Impact of Dental Aesthetics Questionnaire. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9931. [CrossRef]
42. Maspero, C.; Giannini, L.; Galbiati, G.; Kairyte, L.; Farronato, G. Upper airway obstuction in class II patients. Effects of Andresen activator on the anatomy of pharingeal airway passage. Cone beam evalution. *Stomatologija* **2015**, *17*, 124–130.
43. Wan Hassan, W.N.; Yusof, Z.Y.; Shahidan, S.S.; Mohd Ali, S.F.; Makhbul, M.Z. Validation and reliability of the translated Malay version of the psychosocial impact of dental aesthetics questionnaire for adolescents. *Health Qual. Life Outcomes* **2017**, *15*, 23. [CrossRef] [PubMed]
44. DiBiase, A.T.; Sandler, P.J. Malocclusion, orthodontics and bullying. *Dent Update* **2001**, *28*, 464–466. [CrossRef] [PubMed]

45. Zhang, G.; Li, J.; Li, J.; Zhou, X.; Xie, J. Selective Laser Melting Molding of Individualized Femur Implant: Design, Process, Optimization. *J. Biomim. Eng. Engl. Ed.* **2021**, *18*, 128–137. [CrossRef]
46. Zhang, G.; Li, J.; Zhang, C.; Xie, J.; Zhou, X.; Wang, A. Design Optimization and Manufacturing of Bio-fixed tibial implants using 3D printing technology. *J. Mech. Behav. Biomed. Mater.* **2020**, *1117*, 104415.