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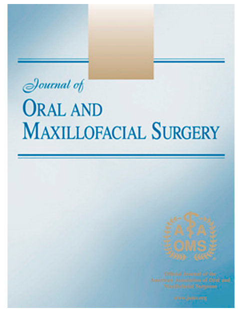

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Temporomandibular joint disorders in patients with different facial morphology. A systematic review of the literature

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Running Title

TMD and facial morphology

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ABSTRACT

Aim: The present paper aims to review systematically the literature on the relationship between facial skeletal structures and temporomandibular joint (TMJ) disorders.

Materials and Methods: A systematic search in the dental and medical literature was performed to identify all studies on humans assessing the relationship between TMJ disorders and facial morphology. Articles were included based on study design, irrespective of the TMJ disorders (e.g., disc displacement, osteoarthrosis, or unspecified), skeletal features, diagnostic strategies (e.g., imaging techniques and/or clinical assessment), and population (e.g., demographic features of the participants) under investigation. The selected articles were discussed according to a PICO-like structured format and quality was evaluated based on the Newcastle-Ottawa Scale.

Results: Thirty-four (n=34) articles were included in the review, 27 of which on adult and 7 on adolescent samples. Quality was generally moderate. The articles dealt with the relationship between facial morphology and the following TMJ disorders, assessed clinically or by magnetic resonance (MR): disc displacement (n = 20), osteoarthritis/osteoarthrosis (n = 8), temporomandibular disorders (TMD) signs and symptoms (n = 6). The different approaches featuring the various investigations and the presence of some potential methodological bias made difficult to summarize findings. Most studies reported that some features related with the vertical dimension of the face might help discriminating between patients with potential TMJ disc displacement or MR-detected signs of osteoarthrosis and those without TMJ disorders.

Conclusions: The quality of the available literature is not enough to provide evidence-based on the topic. Despite the heterogeneity of design and findings of the reviewed papers, it seems reasonable to suggest that skeletal class II profiles and hyperdivergent growth pattern are likely associated with an increased frequency of TMJ disc displacement and degenerative disorders.

KEYWORDS

Temporomandibular joint; Temporomandibular disorders; Facial morphology

INTRODUCTION

Temporomandibular disorders (TMD) embrace heterogeneous conditions involving the masticatory muscles and/or the temporomandibular joint (TMJ) as well as their associated structures.[1] Such disorders have a multifactorial etiology, with several risk factors interacting differently at the single individual level.[2] In particular, after years of debate about the potential role of occlusal features as causal or risk factors for TMD, there is now agreement on the low etiological relevance of dental occlusion and inter-arch relationship.[3] Notwithstanding that, it was suggested that some gross malocclusions, such as a large overjet and an anterior open bite, may increase the risk for TMD, and TMJ disorders in particular.[4,5] Those occlusal features may be the expression of some peculiar skeletal type or facial growth pattern.

Whilst the TMD-occlusion literature was reviewed in several papers,[6,7] the studies on the association with the different facial morphologies have never been summarized systematically. The potential existence of a skeletal predisposition to TMJ disorders was suggested in a recent hypothesis postulating that, for the occurrence of disease, there is a need for an unbalance between the load exerted on the joints and their loadability. The hypothesis also identified clenching-type bruxism as the main risk factor for joint overload and proposed that certain facial morphologies may be less suitable to bear loads due to the unfavorable muscle force vectors acting on the TMJs.[8] Recent papers on the different patterns of TMD diagnoses in clenching-type bruxers with different occlusal features provided preliminary support to this concept.[9,10]

Considering these premises, the present systematic literature review attempts to answer the clinical question: is there a facial morphology that is associated with TMJ disorders?

MATERIALS AND METHODS

Search strategy and literature selection

On June 30, 2014, a systematic search of the dental and medical literature was performed to identify all peer-reviewed articles in the English language dealing with the topic of facial morphology-TMD relationship published over the past thirty years (i.e., from 1985 onwards). The systematic review was performed according to PRISMA guidelines .

As a first step, the National Library of Medicine's Medline Database was browsed independently by two of the study authors (A.R., N.A.) to identify a working list of citations, based on the 2xN different combinations of the keywords "temporomandibular disorders" (or the acronym "TMD") or "temporomandibular joint" (or the acronym "TMJ") with the keywords "facial/dentofacial morphology", or "skeletal form", or "cephalometry", or "short/long face", or "facial asymmetry", or "sagittal/vertical relationship". The criteria for inclusion in the review were based on the type of study, viz., clinical studies on humans assessing the relationship between TMJ disorders and the facial morphology. In cases of duplicate studies (i.e., studies presenting the same findings and/or conducted on the same populations), only one article was included. As a further screening, the abstracts of the selected citations were read, and the potentially relevant papers were retrieved in full-text and assessed for possible admittance in the review. Then, as a second-step search expansion, the full-text retrieval was extended to potentially relevant papers identified within other two databases (i.e., Scopus and Google Scholar) as well as the reference list of included papers. The decision to include or exclude papers was taken by consensus in a collegium discussion with the two leading authors (D.M., M.S.).

Quality assessment

To increase the strength of this review, and in line with current needs to weigh the quality of the reviewed literature in systematic reviews, studies that were pertinent for inclusion underwent a quality assessment by adopting the Newcastle-Ottawa Scale (NOS) for case-control studies or, when applicable, for cohort studies.[11] Quality assessment was performed by the same two authors who performed the initial search and a third investigator (L.L). The NOS assigns a score to each study based on the evaluation of three categories (i.e., 1. Selection; 2. Comparability; 3. Exposure). The items for the evaluation of case-control studies are formulated as follows:

- 1. *Selection*: four items (i.e., 1a. case definition; 1b. representativeness of cases; 1c. selection of controls; 1d. definition of controls).

The item 1a assesses the adequacy of case definition:

a) yes, with independent validation ✪ (e.g., assessment were made from more than one examiner or referred to TMJ imaging records)

b) yes, e.g. record linkage or based on self-reports

c) no description

The definition was judged adequate for studies adopting validated clinical TMD diagnoses or imaging-based assessment of TMJ status

The item 1b assesses the representativeness of the cases with respect to the target disease population:

a) consecutive or obviously representative series of cases ✪ (e.g., all cases recruited consecutively in a certain period of time, or an appropriate sample of those cases)

b) potential for selection biases or not stated

The item 1c assesses the population from which controls were selected:

a) community controls ✪ (e.g., controls recruited in the same community than cases)

b) hospital controls

c) no description

The item 1d assesses the definition of controls:

a) no history of disease (i.e., TMD) ✪

b) no description of source

- 2. *Comparability*: one item (i.e., 2a. comparability of cases and controls based on the design or analysis).

The item 2a assesses the actual comparability/matching of groups based on the control for potential confounding factors that are judged important by the reviewers:

a) study controls for bruxism ✪

b) study controls for psychosocial factors ✪

- 3. *Exposure*: three items (i.e., 3a. ascertainment of exposure; 3b. same method of ascertainment for cases and controls; 3c. non-response rate).

The item 3a assesses the ascertainment of exposure:

a) secure record (i.e., cephalometric assessment) ✪

b) structured interview where blind to case/control status ✪

c) interview not blinded to case/control status

d) written self-report or medical record only

e) no description

The item 3b verifies the choice of the same method of ascertainment for cases and controls

a) yes ✪

b) no

The item 3c assesses the report of non-response Rate:

a) same rate for both groups ✪
b) non respondents described
c) rate different and no designation

The formulation of items for the evaluation of cohort studies are different, providing four items for the Selection (i.e., 1a. representativeness of the exposed cohort; 1b. selection of the non-exposed cohort; ascertainment of exposure; 1c. demonstration that outcome of interest was not present at start of the study), one item for the Comparability category (i.e., 2a. comparability of cohorts on the basis of the design or analysis), and three items grouped under the "Outcome" category (i.e., 3a. assessment of outcome; 3b. length of follow up; 3c. adequacy of follow up of cohorts).

Based on NOS guidelines, a study can be awarded a maximum of one star for each numbered item within the Selection and Exposure/Outcome categories. A maximum of two stars can be given for Comparability. Thus, the highest quality studies are awarded up to a score of nine.

Data extraction

Data from the selected papers were extracted by same three authors who performed the quality assessment (A.R., N.A., L.L.) based on a format that enabled a structured reading of the articles in relation to 4 main issues, viz., Patients/problem/population, Intervention, Comparison, and Outcome (PICO).[12] For each article, the study population ("P") was described in terms of the sample size, mean age and/or age range, and prevalent complaint. Methodological features of the studies were analyzed in the section reserved to the study intervention ("I"), viz., longitudinal or cross-sectional design, type of experiment/intervention protocol, assessment instruments, and statistical analysis. The comparison criterion ("C") assessed the presence of a control group or a specific comparison between subgroups of the patient population. The study outcome ("O") was evaluated based on the research findings and main conclusions with regard to the association between TMJ disorders and facial morphology.

RESULTS

Literature selection

The combination of different search keywords in the Medline database identified 92 potentially relevant citations, 45 of which were retrieved in full text after abstract reading. The search expansion strategy allowed adding 9 further full texts for consideration. Based on the full texts reading, 12 articles were excluded for not fulfilling the inclusion criteria and 8 articles due to redundancy problems, thus accounting for a total of 34 articles included in the review. For discussion purposes, the reviewed articles were grouped based on the targeted age class of the study population (i.e., adolescents or adults based on if patients were teenagers at the end of the study) and of the TMJ disorder under investigation, viz., disc displacement (adolescents, n = 4; adults, n = 16), osteoarthritis/osteoarthrosis (adolescents, n = 0; adults, n = 8), or unspecified TMD signs and symptoms (adolescents, n = 3; adults n = 3) (Figure 1).

Quality assessment

Quality assessment showed that methodology was not optimal, since none of the reviewed papers satisfied all the criteria for the highest possible quality score based on the Newcastle-Ottawa scale. Range of scores is between 2 and 6, with a median of 4. In particular, the main shortcomings were the failure to consider other potential risk factors for temporomandibular disorders (e.g., bruxism, psychosocial factors) in the explanation of the potential TMD-facial morphology association, the poor representativeness of cases, and the absence of a true community-based control group. Also, the fact that only two studies had a longitudinal design with an adequate follow-up or multiple observation points further limits the possibility to speculate about the cause-and-effect relationship between facial morphology and TMJ disorders.

Thus, on average, the quality of the literature on the facial morphology-TMJ disorders relationship should be improved and is currently not enough to provide high-quality evidence on the argument. Tables 1-2provide a summary of quality assessment of the individual papers.

Summary of findings of adolescent studies

- Relationship between facial morphology and disc displacement (Table 3)

Four studies[13-16] assessed the relationship of facial morphology with TMJ disc displacement (or "internal derangement") in adolescents. All four studies came from the same research group. Only one study[13] had a longitudinal design, providing 2 observation points over a 3-year follow-up time; all the others[14-16] were cross-sectional studies with a single observation point. In all studies, cephalograms were used to evaluate the skeletal features, whilst bilateral MR was performed to assess TMJ status, without any clinical assessment. A control/comparison group was included only in two studies,[13,16] and the statistical design was based on multiple variable regression analysis in all papers.

In general, the findings supported an association between TMJ disc displacement and a facial morphology characterized by a vertical and sagittal mandibular discrepancy. In particular, a reduced forward growth of the maxillary and mandibular bodies and a reduced downward growth of the mandibular ramus seem to be associated with TMj disc displacement. The external validity of findings is limited by the single-research group production on this topic.

- Relationship between facial morphology and TMD signs and symptoms (Table 4)

Three studies[17-19] on adolescents were based on a clinical TMD assessment, as performed with very different diagnostic strategies, among which the Craniomandibular Index[20] and Helkimo's index[21]. Lateral cephalometry was used for facial measurements in all studies. Only one study was longitudinal,[17] and covered a 14-year follow-up period. Single- or multiple-variable regression analyses were adopted for statistical purposes.

The longitudinal study shows that at the follow-up assessment, TMD signs were associated with a sagittal shorter midface in adults who already had such facial feature at childhood.[17] The other two studies provide inconsistent findings, since one investigation did not find any significant association between facial variables and the severity of Craniomandibular Index,[18] whilst the other study shows an association, even if weak, with an increased craniocervical angulation.[19] Interestingly, the same study reports that muscle tenderness is associated with a long-face facial morphology and a lower bite force.

In general, the findings are hard to interpret. A suggestion that long-face features seem to be associated with an increased frequency of positive TMJ findings could be drawn, even if the inconsistent criteria adopted for TMD diagnosis in the three investigations made difficult the identification of specific associations with any skeletal traits.

Summary of findings of adult studies

- Relationship between facial morphology and disc displacement (Table 5)

Sixteen studies[22-37] assessed the association between facial morphology and TMJ disc displacement (or "internal derangement") in adult samples. Almost half of the investigations (7 studies) have been conducted by the same research group. Samples' recruitment strategies were variable, including subjects with either malocclusion or dentofacial deformities (skeletal class II or III, anterior open bite), and/or different degrees of TMJ disc displacement. Cephalometry was used to assess facial features in all studies but one,[37] which adopted the overjet/overbite discrepancy as a dental proxy for morphological assessment. Different imaging techniques were adopted for TMJ assessment, and were integrated with a clinical evaluation in five studies.[26,31,33-35] A true control group was included in eleven studies,[23,24,26,27-31,33,35,37] even if standardized diagnostic criteria (i.e., Research Diagnostic Criteria for TMD)[38] were used only in one study.[34] The study population was further split into two or more comparison subgroups in eight studies.[22,23,25,32-34,36,37]

As for the findings, all studies except one[24] found a relationship between skeletal features and TMJ disc displacement.

In general, skeletal class II, retrognathic mandible and hyperdivergent growth pattern were suggested to be associated with TMJ disc displacement. Also, the severity of such skeletal abnormalities seems to be related with the severity of the articular pathology.

- Relationship between facial morphology and TMD signs and symptoms (Table 6)

Three articles[39-41] assessed the association of facial morphology with the presence of either imaging- or clinically-detected TMD signs and symptoms in adults. None of the studies combined both imaging and examination findings for TMJ assessment. Lateral cephalography was adopted in all studies to evaluate facial morphology. All studies included a control group.

As for the findings, a correlation between the structure of the lower face (e.g., tendency to hyperdivergent profile) and TMD signs and symptoms was found in two studies,[39,41] while the third study[40] is hardly comparable due to the selection of patients with TMD symptoms in absence of TMJ imaging-detected abnormalities.

- Relationship between facial morphology and TMJ osteoarthritis/osteoarthrosis (Table 7)

Eight studies[42-49] assessed the relationship between facial morphology and TMJ degenerative disorders (e.g., flattening, erosion, or osteophyte in the joint surfaces). Recruitment strategies and inclusion criteria varied between studies. Different imaging techniques were employed to assess TMJ status. Several methodological differences were detected, with frequent flaws such as the lack of control groups and an unclear strategy for group comparisons in the cross-sectional studies.[42,47,49] Multiple variable regression analysis was used to estimate the association between TMJ MR findings and cephalometric parameters in only one study.[42]

Results from all studies suggested that a relationship may be hypothesized between TMJ degenerative disorders and some facial patterns.

In general, degenerative joint disorders were reportedly associated with a mandibular ramus deficiency, a larger gonial angle, a clockwise rotation of the mandible, a retrognathic appearance and a vertically elongated facial pattern, leading to a skeletal class II relationship.

DISCUSSION

In this manuscript, the available literature on the relationship between facial morphology and TMJ disorders was reviewed. As a general remark, the quality of the available literature is questionable. Indeed, even in the absence of threshold scores for the NOS instrument, quality assessment shows some recurrent methodological flaws. Importantly, the populations chosen for each study were quite heterogeneous (e.g., orthodontic patients; TMDpatients; subjects with malocclusions), and not all studies included a true control group. As a consequence of the variable selection process for the study populations, the percentage of TMD patients differs between the various investigations. Moreover, the number of studies that felt into a comparable "category" is low, especially in terms of the very few research groups that were involved. Based on the above, this review's suggestions are more based on the reviewers' attempt to find a common theme in such miscellaneous findings than on evidence-based data.

Findings suggest that disc displacement or degenerative joint disease have been often reported in association with a decreased growth of the mandible, both in the adolescent and adult samples. Skeletal features associated with TMJ disorders include short ramus height and mandibular length, a steep mandibular plane angle, and an increased profile convexity and retrognathism.[48] Facial asymmetry has also been found associated with unilateral or bilateral pathology of greater severity on the ipsilateral side.[16,50]

The association between TMJ disorders and facial morphology in adults was mainly assessed by comparing the prevalence of imaging-detected abnormalities and/or clinical signs and symptoms in subjects with different skeletal features. Such study design did not allow determining which condition occurred first (i.e., the skeletal morphology or the TMJ disorder) and whether the two conditions are causally related. In theory, both hypotheses are potentially plausible. For instance, several authors suggested an etiological role of TMJ internal derangement in the abnormal facial skeleton development, based on the concept that the condyle represents an important growth site within the craniofacial skeleton.[22,25,32,34,51] According to such view, disc displacement may be seen as a localized disturbance in the functional environment of the TMJ, thus accounting for compressive stress and reduced lubrication of the joint surfaces with inflammation and tissue damage, ultimately resulting in a condylar and ramus height reduction.[52] Animal experiments also found that disc displacement occurring during the developmental period induced impairment of mandibular growth.[53] On the opposite, it is also possible that the genetically determined or acquired skeletal deformity may contribute to the onset of disorders within the TMJ because of the increased susceptibility to micro- or macro-trauma to the joint system.[33,46-48,54,55]

Studies on growing subjects should have been more suitable to investigate the above hypotheses, but, unfortunately, most studies are cross-sectional and did not provide any cause-and-effect information. The reviewed literature on adolescent samples supports in part the association of TMJ disc displacement with reduced posterior facial height, reduced mandibular length, clockwise rotation and retruded mandible position, viz., a skeletal class II profile with shorter mandibular corpus and ramus. Interestingly, findings from adolescent studies dealing with the presence of clinical TMD signs and symptoms did not support their association with any specific growth patterns, possibly suggesting that such younger asymptomatic individuals may develop clinical TMD symptoms later in life as a result of the progressive loss of their TMJs' adaptive capacity.

In summary, both studies on adults and adolescents suggest that short ramus and posterior facial height as well as the backward position and rotation of the mandible are the main features associated with TMJ disc displacement. Those features are common to skeletal class II and/or hyperdivergent growth patterns. The same skeletal features also related positively with the progression of degenerative joint disease or TMD signs and symptoms in adults.

Based on these observations, it can be suggested that individuals with skeletal class II and hyperdivergent facial patterns are more prone to TMJ disorders. A possible explanation for such findings may be found in the literature describing that such joints are characterized by poor reciprocal fitting of the articular surfaces (i.e., small condyle and wide glenoid fossa), and they are potentially at risk of developing disc position abnormalities because of joint instability.[8] On the contrary, patients with skeletal class III and hypodivergent pattern may be less predisposed to TMJ disc displacement, because of their biomechanical advantage.[56]

Unfortunately, all the available studies lack any information on other potential risk factors for TMD and are based on a single-factor design (i.e., facial morphology vs TMJ disorders), not taking into account for the complexity of biological models. In particular, the absence of data on bruxism activities and psychological features, together with the aforementioned methodological heterogeneity, is a strong limitation to the possibility of drawing clinical implications from this review. As a recommendation for the future, studies on the topic are also encouraged to combine clinical and imaging TMJ assessment as well as to adopt standardized diagnostic guidelines to ease data comparison and increase the external validity of findings. In addition, there is a need for investigations including the most representative populations as possible, comprising different age and sex groups, and for multiple-factor longitudinal investigations with multiple observation points, so as to get deeper into the interpretation of the possible causal relationship between the two conditions (i.e., abnormalities of the facial morphology and disorders of the temporomandibular joint).

CONCLUSIONS

Based on the systematic literature review on the possible associations between TMJ disorders and facial morphology, the following suggestions can be drawn:

- The quality of the available literature is not enough to provide evidence-based on the topic.
- Despite the heterogeneity of design and findings of the reviewed papers, it seems reasonable to suggest that skeletal class II profiles and hyperdivergent growth pattern are likely associated with an increased frequency of TMJ disc displacement and degenerative disorders.
- Prospective cohort studies are needed to assess the actual existence of a causal link.

DECLARATIONS

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The authors declare no conflicts of interest.

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TABLES

Table 1. NOS quality assessment of the reviewed case-control papers. Columns showed the quality items. Stars indicate positive endorsement.

Study first author, year	1a. Is the case definition adequate?	1b. Representa tiveness of the cases	1c. Selection of controls	1d. Definition of controls	2a. Comparability of cases and controls on the basis of the design or analysis	3a. Ascertainment of exposure	3b. Same method of ascertainment for cases and controls	3c. Non response rate	Total quality score (0-9)
Nebbe, 1999[14]	✪					✪	✪	✪	4
Nebbe, 1999[15]	✪					✪	✪	✪	4
Trpkova, 200016	✪			✪		✪	✪	✪	5
Pereira, 2007[18]						✪	✪	✪	3
Sonnesen, 2001[19]						✪	✪	✪	3
Ahn, 2006[22]	✪			✪		✪	✪	✪	5
Bósio, 1998[23]	✪			✪		✪	✪	✪	5
Brand, 1995[24]	✪			✪		✪	✪	✪	5
Byun, 2005[25]	✪			✪		✪	✪	✪	5
Fernández Sanromán, 1998[26]	✪			✪				✪	3
Gidarakou, 2002[27]	✪			✪		✪	✪	✪	5
Gidarakou, 2004[28]	✪			✪		✪	✪	✪	5
Gidarakou, 2004[29]	✪			✪		✪	✪	✪	5
Gidarakou, 2003[30]	✪			✪		✪	✪	✪	5
Inui, 1999[31]	✪			✪		✪	✪	✪	5
Jung, 2013[32]	✪			✪		✪	✪	✪	5
Muto, 1998[33]						✪	✪	✪	3
Sakar, 2011[34]	✪			✪		✪	✪	✪	5
Stringert, 1986[35]	✪	✪		✪		✪	✪	✪	6
Yang, 2012[36]	✪			✪		✪	✪	✪	5
Yura, 2009[37]	✪			✪		✪	✪	✪	5
Almăşan, 2013[39]						✪	✪	✪	3
Gidarakou, 2003[40]	✪			✪		✪	✪	✪	5
Hwang, 2006[41]						✪	✪	✪	3
Bertram, 2011[42]	✪	✪				✪	✪	✪	5
Cho, 2009[43]	✪			✪					2

Estomaguio, 2005[44]						✪	✪	✪	3
Gidarakou, 2003[45]	✪			✪		✪	✪	✪	5
Ioi, 2008[46]						✪	✪	✪	3
Krisjane, 2012[47]	✪			✪		✪	✪	✪	5
Sun, 2011[48]						✪	✪	✪	3
Yamada, 1999[49]	✪		✪	✪		✪	✪	✪	6

Table 2. NOS quality assessment of the reviewed cohort papers. Columns showed the quality items. Stars indicate positive endorsement.

Study first author, year	1a. Representativeness of the exposed cohort	1b. Selection of non-exposed cohort	1c. Ascertainment of exposure	1d. Demonstration that outcome of interest was not present at start of the study	2a. Comparability of cohorts on the basis of the design or analysis	3a. Ascertainment of outcome	3b. Was follow-up long enough for outcomes to occur	3c. Adequacy of follow up of cohorts	Total quality score (0-9)
Flores-Mir, 2006[13]	✪		✪			✪	✪		4
Dibbets, 1996[17]			✪			✪	✪		3

Table 3. Summary of findings from adolescent studies assessing the relationship between facial morphology and disc displacement

Study's first author and year	Population (patients/ problem)	Intervention (features of study design)	Comparison (control group)	Outcome
Flores-Mir, 2006[13]	79 adolescents (52 F, 27 M; m.a. 16.5yrs; range 10-20 yrs) with/without TMJ disc abnormalities	Longitudinal study (mean follow up 43 months) Bilateral TMJ MRI Lateral cephalograms to evaluate horizontal and vertical growth changes Stepwise multiple linear regression analysis to evaluate the influence of TMJ disc status and orthodontic treatment on the growth changes	2 subgroups: 1) n = 40 (orthodontic treatment group) 2) n = 39 (control group)	TMJ disc displacement associated with reduced forward growth of the maxillary and mandibular bodies and reduced downward growth of the mandibular ramus
Nebbe, 1999[14]	119 female adolescents (a.r. 10-17 yrs) with/without TMJ disorders, without history of orthodontics	Cohort study Lateral cephalograms Bilateral TMJ MRI ANOVA to determine intra-rater reliability for cephalometric variables Multiple regression analysis for association between TMJ status and facial measurements Pearson correlation coefficient	No control group	With progression of ID severity, increase in the inclination of the palatal plane, mandibular plane angle, gonial angle and total anterior facial height, reduction in sagittal length of the mandibular corpus, vertical ramus height and total posterior facial height
Nebbe, 1999[15]	70 male adolescents (a.r. 10-17 yrs) with/without TMJ disorders, without history of orthodontics	Cohort study Lateral cephalograms Bilateral TMJ MRI Multiple regression analysis for association between TMJ status and facial measurements Pearson correlation coefficient	No control group	With increasing severity of ID, reduction in the height of the posterior cranial base, decrease in vertical and sagittal dimensions of the mandible, increase in mandibular plane angle, gonial angle and total anterior facial height
Trpkova, 2000[16]	80 orthodontic female adolescents (m.a. 16 yrs; a.r. 10-17 yrs) with/without TMJ disorders	Cohort study Bilateral TMJ MRI Lateral and PA cephalograms Dahlberg's formula for measurement error 1-way ANOVA and multiple linear regression analysis to test differences	2 subgroups: 1) n = 38 (ID patients) 2) n = 42 (BN)	Bilateral TMJ ID females with greater vertical mandibular asymmetry than females with unilateral TMJ ID or normal TMJs Other facial regions without significantly different asymmetry

Footnotes: m.a.: mean age; a.r.: age range; B: bilateral; BN: bilateral normal; F: females; ID: internal derangement; M: males; MRI: magnetic resonance imaging; N: normal disk position; PA: postero-anterior; TMJ: temporomandibular joint; yrs: years.

Table 4. Summary of findings from adolescent studies assessing the relationship between facial morphology and TMJ signs and symptoms

Study's first author and year	Population (patients/ problem)	Intervention (features of study design)	Comparison (control group)	Outcome
Dibbets, 1996[17]	110 orthodontic patients (55% F, 45% M; initial m.a.: 12,5 y; final m.a.: 26,4 y)	Longitudinal study Questionnaire and TMJ clinical assessment Lateral cephalograms at the two time points Kappa statistics to measure the degree of stability of signs and symptoms over the 14-year period Linear regression analysis	No a priori grouping criterion	Signs and symptoms in children not associated with facial morphology TMD signs in adults associated with a sagittal shorter midface, already present at childhood
Pereira, 2007[18]	40 adolescent patients from public schools (20 F, 20 M; a.r. 12-18 yrs)	Case-control design Ultrasonography to determine muscle thickness Craniomandibular Index (CMI)[20] to evaluate TMD Lateral cephalograms Pearson's and Spearman's correlation coefficients Multiple regression analysis Dahlberg's formula (measurement error)	2 subgroups: 1) n = 20 (SP) 2) n = 20 (control group)	Correlation between CMI and the facial variables more significant in the symptomatic group, but no statistically significant differences in the morphological parameters between groups
Sonnesen, 2001[19]	96 children with malocclusion (51 F, 45 M; a.r. 7-13yrs)	Cohort study Helkimo Index[21] for TMD diagnosis Lateral cephalograms for facial dimensions Plaster casts to measure dental arch widths Pressure transducer for bite force Spearman correlation, multiple logistic regression analysis to evaluate associations Dahlberg's formula (measurement error)	No control group	TMJ dysfunction in connection with a marked forward inclination of the upper cervical spine and an increased craniocervical angulation Muscle tenderness associated with a long-face facial morphology and a lower bite force Headache associated with a larger maxillary length and increased maxillary prognathism

Footnotes: a.r.: age range; F: females; M: males; m.a.: mean age; SP: symptomatic patients; TMD: temporomandibular disorders; TMJ: temporomandibular joint; yrs: years

Table 5. Summary of findings from adult studies assessing the relationship between facial morphology and TMJ disc displacement

Study's first author and year	Population (patients/ problem)	Intervention (features of study design)	Comparison (control group)	Outcome
Ahn, 2006[22]	134 female patients with malocclusion without history of orthodontics (m.a. 23.6yrs; range 17-43)	Cohort study Lateral cephalograms Bilateral TMJ MRI 1-way analysis of variance (ANOVA, P<0.05), Duncan multiple comparison test (α=0.05) for comparison between groups Dahlberg's formula for measurement error	5 subgroups: 1) n = 41 (BN) 2) n = 21 (DDR; contralateral N) 3) n = 27 (BDDR) 4) n = 15 (DDR; contralateral DDNR) 5) n = 30 (BDDNR)	Skeletal Class II pattern with retrognathic mandible in subjects with TMJ ID Backward rotation of the mandible, decrease of ramus height, mandibular body length and effective mandibular length, increase of ramus inclination, articular angle, proinclination of mandibular incisors and overjet with TMJ ID progression
Bósio, 1998[23]	96 subjects (75 F, m.a. 28.7 yrs; 21 M, m.a., 24.4 yrs) with or withot TMJ disorders	Case-control design Lateral cephalometric radiography Bilateral TMJ MRI Fisher's exact test ANOVAs (P<0.05)	3 subgroups: 1) n = 32 (AV without ID) 2) n = 32 (SP without ID) 3) n = 32 (SP with ID)	More retropositioned mandible in symptomatic patients with bilateral TMJ DD than asymptomatic volunteers and symptomatic patients with no DD
Brand, 1995[24]	47 female subjects (m.a.. 32 yrs; a.r. 18-63 yrs) with or without TMJ disorders without history of orthodontics	Case-control design Cephalometric radiography Bilateral TMJ MRI Wilcoxon rank sum test for groups comparison	2 subgroups: 1) n = 24 (ID patients) 2) n = 23 (controls)	Significantly smaller length of the maxillary and mandibular bodies, but no changes in other cephalometric variables in patients with TMJ ID
Byun, 2005[25]	51 female patients with anterior open bite (a.r. 18-38 yrs) with or without TMJ disorders	Cohort study Lateral cephalometric radiographs Bilateral TMJ MRI 1-way analysis of variance (ANOVA, P<0.05), Duncan's multiple comparisons for comparison between groups	3 subgroups: 1) n = 28 (N) 2) n = 10 (DDR) 3) n = 13 (DDNR)	Skeletal Class II pattern with a retrognathic mandible in subjects with TMJ ID Facial pattern more severe as ID progresses to DDNR
Fernández Sanromán, 1998[26]	58 patients with (m.a. 22.3 yrs) /without (m.a. 23.9 yrs) dentofacial deformities (a.r. 15-45 yrs)	Case-control design Lateral cephalograms CT and MRI to assess the position of mandibular condyle and TMJ disc Helkimo Index[21] for TMJ clinical examination	2 subgroups: 1) n = 48 (dentofacial deformity group) 2) n = 10 (control group)	53% of patients diagnosed as Class II dentofacial deformity with ID and anteriorly DD, while lower incidence in the Class I and III groups (10%) Increased horizontal angle of the mandibular condyle and posteriorly seated condyle found in Class II patients when compared with the control group

		Mann-Whitney U test for group comparison		
Gidarakou, 2002[27]	88 female subjects with (m.a. 29.9 yrs)/without (m.a. 28.3 yrs) BDDR	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance to compare groups (P<0.05)	2 subgroups: 1) n = 46 (AV) 2) n = 42 (BDDR)	In the BDDR group, smaller length of both the anterior and posterior cranial base, smaller SNA and SNB angles, larger interincisal angle and upper incisor more retroclined
Gidarakou, 2004[28]	105 female subjects with (m.a. 28.6 yrs)/without (m.a. 28.3 yrs) BDDNR	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance to compare groups (P<0.05)	2 subgroups: 1) n = 46 (AV) 2) n = 59 (BDDNR)	In the symptomatic group, smaller cranial base length and facial plane angle, larger angle of convexity because of the retropositioned mandible, larger overjet, steeper mandibular plane angle, more vertical Y-axis, shorter posterior ramal height and increased angle between the mandibular and the palatal plane
Gidarakou, 2004[29]	64 female subjects with (m.a. 29.2 yrs)/without (m.a. 28.3 yrs) UDDR	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance to compare groups (P<0.05)	2 subgroups: 1) n = 46 (AV) 2) n = 18 (UDDR)	In the UDDR group, overall reduction in length of the anterior and posterior cranial base measurements and the posterior ramal height, increased cranial base angle, both upper and lower denture bases retropositioned
Gidarakou, 2003[30]	58 female subjects with (m.a. 27.4 yrs)/without (m.a. 28.3 yrs) UDDNR	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance (ANOVA) to compare groups	2 subgroups: 1) n = 46 (AV) 2) n = 12 (UDDNR)	In the UDDNR group, overall reduction in length of the anterior and total cranial base measurements, steeper mandibular plane angle and shorter posterior ramal height
Inui, 1999[31]	49 female patients with (m.a. 23.6 yrs; a.r. 17-37 yrs)/without (m.a. 25.8; a.r. 23-28 yrs) TMJ internal derangement	Case-control design PA cephalograms TMJ MRI and clinical examination Mann–Whitney U-test for groups comparison	2 subgroups: 1) n = 34 (ID group) 2) n = 15 (control group)	Mandibular lateral displacement in the ID group significantly greater than controls Degree of displacement significantly related to the cant of the frontal occlusal plane and the frontal mandibular plane, indicating the reduced vertical dimension of the posterior occlusal level and the ramus height on the mandibular displaced side
Jung, 2013[32]	460 patients with malocclusion (343 F, 117 M; a.r. 17-47 y)	Cohort study Lateral cephalograms Bilateral TMJ MRI 2-way analysis of variance (ANOVA) with Scheffe's multiple comparisons to determine differences in age Cochran–Mantel–Haenszel test Chi-square test to analyze differences between groups (P<0.05)	6 subgroups: 1) n = 111 (BN) 2) n = 71 (DDR; contralateral N) 3) n = 90 (BDDR) 4) n = 27 (DDNR; contralateral N) 5) n = 59 (DDR; contralateral DDNR) 6) n = 102 (BDDNR)	Increase in the severity of TMJ DD from skeletal Class III to skeletal Class II and from hypodivergent to hyperdivergent pattern
Muto, 1998[33]	108 subjects with either class III malocclusions (34 F, 14 M; m.a. 25 yrs),	Case-control design Clinical TMJ examination	3 subgroups: 1) n = 48 (Class III group)	Patients with signs of DD have a significantly larger gonial angle and mandibular divergence

	class I malocclusions (21 F, 9 M; m.a. 21.2 yrs), or normal occlusion (20 F, 10 M; m.a. 23.3 yrs)	Lateral oblique TMJ radiographs Lateral cephalograms 1-way analysis of variance (ANOVA) for TMD signs examination	2) n = 30 (Class I group) 3) n = 30 (control group)	
Sakar, 2011[34]	74 skeletal Class I female patients with (m.a. 29 yrs) or without (m.a. 28.2 yrs) TMJ disc displacement and without history of orthodontics	Cohort study Blateral TMJ MRI Lateral cephalometric analysis RDC/TMD[38] for TMD diagnosis Kruskal-Wallis test to assess intergroup differences and Mann Whitney-U test to identify the group showing the difference ($P<0.05$)	5 subgroups: 1) n = 12 (BN) 2) n = 16 (UDDR) 3) n = 26 (BDDR) 4) n = 12 (UDDNR) 5) n = 8 (BDDNR)	Progression of DD associated with an increase in all angular measurements related to vertical skeletal relationships and articular angle and a decrease in posterior face height to anterior face height ratio, indicating clockwise rotation of the mandible
Stringert, 1986[35]	165 subjects with (57F, 5M, m.a. 28 yrs; a.r. 16-55) or without (94 F, 9 M; m.a. 30.9 yrs; a.r. 16-55 y) TMJ ID and with or without history of orthodontics	Case-control design TMJ clinical and arthrographic assessment Lateral cephalograms Chi-square analysis and t test	2 subgroups: 1) n = 62 (ID group) 2) n = 103 (control group)	Tendency for the experimental group to be more hyperdivergent and to exhibit increased horizontal skeletal discrepancy, but little or no differences in dental and occlusal parameters are found
Yang, 2012[36]	136 female subjects (>17 yrs) without history of orthodontics	Cohort study Lateral cephalograms Bilateral TMJ MRI 2-way analysis of variance and Scheffe's multiple comparisons to analyze the between-group comparisons	3 subgroups: 1) n = 57 (BN) 2) n = 49 (BDDR) 3) n = 61 (BDDNR)	TMJ DD subjects with short ramus height and clockwise rotation of the ramus and mandible compared with those with BN
Yura, 2009[37]	94 female subjects with either skeletal open bite (m.a. 26 yrs; a.r. 14-33 yrs), healthy controls without dentofacial abnormalities (m.a. 24 yrs; a.r. 21-29 yrs), or closed lock (m.a. 21 yrs; a.r. 14-33 yrs)	Case-control design Bilateral TMJ MRI Chi-square test to assess the significance of differences	3 subgroups: 1) n = 25 (open bite patients) 2) n = 25 (volunteers with no dentofacial abnormalities) 3) n = 44 (DDNR patients with no dentofacial abnormalities)	Higher incidence of anterior DDNR in patients with skeletal open bite than in volunteers and in so affected joints higher incidence of bony change in patients with skeletal open bite than in DDNR patients with no dentofacial abnormalities

Footnotes: a.r.: age range; AV: asymptomatic volunteers; B: bilateral; CT: computerized tomography; DD: disk displacement; DDNR: disk displacement without reduction; DDR: disk displacement with reduction; DJD: degenerative joint disease; F: females; ID: internal derangement; M: males; MRI: magnetic resonance imaging; N: normal disk position; PA: postero-anterior; SP: symptomatic patients; TMD: temporomandibular disorders; TMJ: temporomandibular joint; U: unilateral; yrs: years; RDC/TMD: Research Diagnostic Criteria for Temporomandibular Disorders.

Table 6. Summary of findings from adult studies assessing the relationship between facial morphology and TMD signs and symptoms

Study's first author and year	Population (patients/ problem)	Intervention (features of study design)	Comparison (control group)	Outcome
Almăşan, 2013[39]	64 consecutive adult patients with malocclusion (>18 y)	Cohort study Lateral cephalometric analysis Helkimo Anamnestic and Dysfunction Index for TMJ clinical examination Parametric student t-test with Bonferroni correction (P<0.05), analysis of variance (ANOVA) for comparison between groups Pearson coefficient for correlation of quantitative variables	2 subgroups: 1) n = 24 (TMD patients) 2) n = 40 (control group)	Higher overjet and overbite in subjects with TMD Higher anterior open bite in Class II experimental subjects
Gidarakou, 2003[40]	88 female subjects with (m.a. 28.9 yrs)/without (m.a. 28.3 yrs) TMD symptoms with normal joints	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance (ANOVA) to compare groups (P<0.05)	2 subgroups: 1) n = 46 (AV) 2) n = 42 (SP with BN)	No significant differences between the two groups, with the exception of more retruded lower incisors in the asymptomatic group
Hwang, 2006[41]	111 malocclusion patients (61 F, 50 M; m.a. 23 yrs)	Cohort study Lateral cephalograms TMJ clinical evaluation Two-sample *t* test to examine the differences between groups	2 subgroups: 1) n = 56 (SP) 2) n = 55 (control group)	Hyperdivergent facial profile, more lingual tilting of the maxillary incisors and steeper inclined occlusal plane in subjects with TMJ disorders

Footnotes: AV: asymptomatic volunteers; B: bilateral; BN. Bilateral normal; F: females; M: males; MRI: magnetic resonance imaging; SP: symptomatic patients; TMD: temporomandibular disorders; TMJ: temporomandibular joint; yrs: years

Table 7. Summary of findings from adult studies assessing the relationship between facial morphology and TMJ osteoarthritis/osteoarthrosis

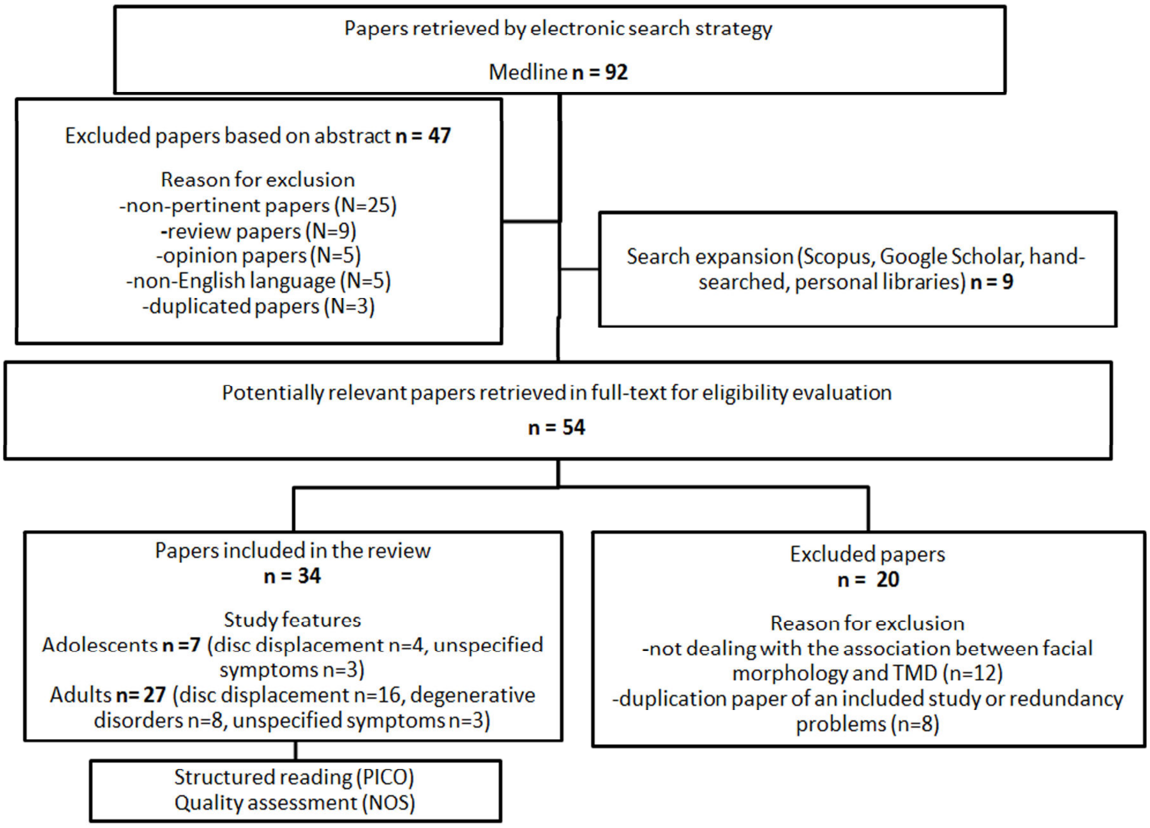
Study's first author and year	Population (patients/ problem)	Intervention (features of study design)	Comparison (control group)	Outcome
Bertram, 2011[42]	68 consecutive patients with TMJ arthralgia (62 F, 6 M; a.r. 18-49 yrs)	Cohort study Cephalometric evaluation of mandibular morphology Bilateral TMJ MRI Univariate analysis of variance, chi-square analysis for comparison between groups Logistic regression analysis for association between selected MRI and cephalometric parameters	No control group	Significant increase in the risk of horizontal mandibular and vertical ramus deficiencies in BDDNR with OA patients
Cho, 2009[43]	83 female subjects with TMJ osteoarthritis (m.a. 39 yrs) or without TMD (m.a. 39.1 yrs) (a.r. 20-67 y)	Case-control design Panoramic radiography of the mandible Bilateral TMJ CT Student's t test for groups comparison	2 subgroups: 1) n = 39 (OA patients) 2) n = 44 (controls)	Significantly shorter condylar and ramus height in the OA than control group Larger gonial angles and more distally inclined condylar head in the OA than control group
Estomaguio, 2005[44]	39 female orthodontic patients with signs and symptoms of TMJ disorders (a.r. 14-30 y)	Cohort study Bilateral TMJ CT Lateral cephalograms Unpaired t-test for comparison between groups	2 subgroups: 1) n = 18 (no bone change group) 2) n = 21 (bilateral bone change group)	Bilateral bone change group: mandibular retrusion and rotation, short ramus height, long lower anterior facial height and compensatory adaptation in the upper and lower incisors
Gidarakou, 2003[45]	75 female subjects with (m.a. 30.3 yrs)/without (m.a. 28.3 yrs) BDJD	Case-control design Bilateral TMJ MRI Lateral cephalograms Analysis of variance to compare groups ($P<0.05$)	2 subgroups: 1) n = 46 (AV) 2) n = 29 (BDJD)	In the symptomatic group: retrusion of the maxilla, clockwise rotation of the mandible, protruded upper incisors, retroinclined lower incisors, excessive overjet
Ioi, 2008[46]	59 female subjects with TMJ osoetaorthritis (m.a. 24.7 yrs) or healthy controls (m.a. 23.6 yrs)	Case-control design Dental panoramic and transcranial TMJ X-rays Lateral cephalometric radiographs Unpaired t-test to compare groups Dahlberg's formula for measurement error	2 subgroups: 1) n = 34 (OA group) 2) n = 25 (control group)	TMJ OA group: significantly larger cranio-cervical angles, more posteriorly rotated mandibles, shorter posterior facial height and more retroinclined lower incisors than control group, leading to skeletal class II relationship
Krisjane, 2012[47]	117 malocclusion patients with either skeletal class II (m.a. 20.3), class III (m.a.	Case-control design Lateral cephalograms	3 subgroups: 1) n = 45 (Class I group)	Osseous changes more prevalent in the group of patients with skeletal and dental class II relationship

	21.3), class I (m.a. 23.5) morphology	Bilateral TMJ CBCT RDC/TMD for TMD diagnosis Pearson chi-square test for differences in prevalence of changes ANOVA analysis for the relationship between age group and number of changes	2) n = 28 (Class II group) 3) n = 44 (Class III group)	
Sun, 2011[48]	232 patients with or without TMJ osteoarthritis seeking orthodontic treatment (189 F, 43 M; a.r. 15-25 yrs; m.a. 20.2 yrs)	Cohort study Lateral cephalograms Panoramic, transcranial and transpharyngeal radiography for TMJ assessment Student t test and chi-square analysis to evaluate differences between groups	2 subgroups: 1) n = 113 (OA group) 2) n = 119 (control group without OA)	OA group with shorter posterior ramus height and shorter condyles, smaller SNB angle and larger ANB angle, smaller facial plane angle and larger angle of convexity, steeper mandibular plane angle and more vertical Y-axis
Yamada, 1999[49]	29 orthodontic patients with condylar bony changes (23 F, 6 M; a.r. 11-30 y)	Cohort study Bilateral TMJ CT and MRI Lateral and PA cephalograms 1-sample t test	Control group from general population	In the study sample mandibular retrusion and rotation, short ramus height, long lower anterior facial height with compensatory adaptation in the lower incisors

Footnotes: a.r.: age range; AV: asymptomatic volunteers; B: bilateral; CT: computerized tomography; DDNR: disk displacement without reduction; DJD: degenerative joint disease; F: females; M: males; MRI: magnetic resonance imaging; OA: osteoarthrosis/osteoarthritis; PA: postero-anterior; TMD: temporomandibular disorders; TMJ: temporomandibular joint; yrs: years

FIGURE LEGENDS

Figure 1. Flow-chart of the search strategy.


Papers retrieved by electronic search strategy
Medline n = 92
Excluded papers based on abstract n = 47
Reason for exclusion
-non-pertinent papers (N=25)
-review papers (N=9)
-opinion papers (N=5)
-non-English language (N=5)
-duplicated papers (N=3)
Search expansion (Scopus, Google Scholar, hand-searched, personal libraries) n = 9
Potentially relevant papers retrieved in full-text for eligibility evaluation
n = 54
Papers included in the review
n = 34
Study features
Adolescents n =7 (disc displacement n=4, unspecified symptoms n=3)
Adults n= 27 (disc displacement n=16, degenerative disorders n=8, unspecified symptoms n=3)
Excluded papers
n = 20
Reason for exclusion
-not dealing with the association between facial morphology and TMD (n=12)
-duplication paper of an included study or redundancy problems (n=8)
Structured reading (PICO)
Quality assessment (NOS)