Systematic Review of Reliability and Diagnostic Validity of Joint Vibration Analysis for Diagnosis of Temporomandibular Disorders

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Aims: *To conduct a systematic review of papers reporting the reliability and diagnostic validity of the joint vibration analysis (JVA) for diagnosis of temporomandibular disorders (TMD).* ***Methods:*** *A search of Pubmed identified English-language publications of the reliability and diagnostic validity of the JVA. Guidelines were adapted from applied STAndards for the Reporting of Diagnostic accuracy studies (STARD) to evaluate the publications.* ***Results:*** *Fifteen publications were included in this review, each of which presented methodological limitations.* ***Conclusion:*** *This literature is unable to provide evidence to support the reliability and diagnostic validity of the JVA for diagnosis of TMD.* J OROFAC PAIN 2013;27:51–60. doi: 10.11607/jop.972

Key words: joint vibration analysis, temporomandibular disorders, temporomandibular joint, systematic review

The use of diagnostic instruments such as the joint vibration analysis (JVA) in the diagnosis of temporomandibular disorders (TMD) has been a topic of controversy for many years. With the latest debate on TMD diagnosis and treatment at the 2011 open Clinical and Science Forums reported in the American Dental Association news,[1] the idea among clinicians that this instrument provides valuable diagnostic information still prevails. The American Association for Dental Research policy statement indicates that "The choice of adjunctive diagnostic procedures should be based upon published, peer reviewed data showing diagnostic efficacy and safety."[2] The efficacy of diagnostic modalities is assessed by reliability and validity as the principal criteria.

Reliability is the extent to which an observation is reproducible. One tests if the observation per se, such as vibration, is stable over time and can be measured in a reproducible manner. Reliability is demonstrated by an acceptable level of the intraclass correlation coefficient among other statistic tools.[3] *Diagnostic validity* is the capability to correctly identify cases and controls. It is demonstrated by acceptable levels of sensitivity and specificity. For the presence of disc displacement, it is tested using magnetic resonance imaging as the reference standard.[4] Reliability and validity are two major concepts that are fundamental principles and must be tested using research designs with strong foundations. As a methodological principle, the reliability must be demonstrated first, followed by diagnostic validity.

JVA is based on principles of motion and friction. When surfaces rub together, they cause vibration. The greater the surface roughness, the greater the vibration, and this vibration can be captured by

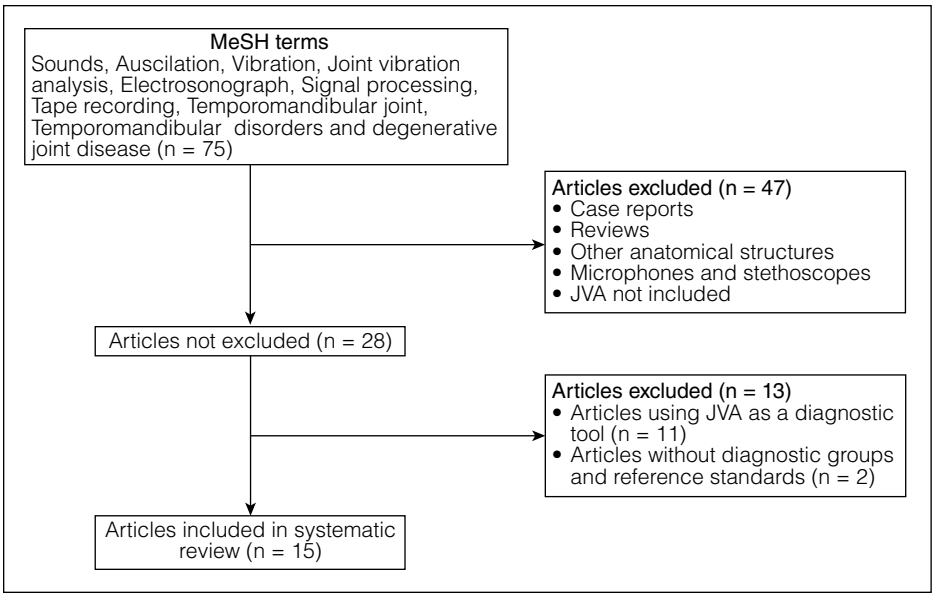

Fig 1 Flow chart for inclusion and exclusion of studies in the systematic review of reliability and diagnostic validity of JVA. MeSH terms used to search potential articles are included.

accelerometers. Human joints have surfaces that rub together in function. In theory, smooth, lubricated surfaces in a proper biomechanical relationship should produce little friction and little vibration.[5–9] But surface changes, such as those caused by tissue degeneration, tears, or displacements of the disc, are thought to produce greater friction and greater vibration.[10] It has been suggested that different disorders can produce different vibration patterns or "signatures" in the joint.[11–13] In the temporomandibular joint (TMJ), computer-assisted analysis of vibrations has been reported to identify patterns thought to differentiate among various TMD.[11–14]

Vibration analysis of the TMJ is a quantitative process that measures the absolute intensity and frequency distribution of vibratory waves emanating from the joint as it is exercised throughout its full range of motion. Tissue vibrations are recorded down to the level of approximately 1 μm.

Two companies currently market instruments that are used for the assessment of JVA: BioResearch and Myotronics. The instrumentation marketed by Myotronics is presented on their website as the K7 evaluation system, although the website shows a K-7 ESG Electrosonograph. No specifications were found on the US Food and Drug Administration website[15] for this component. The US Food and Drug Administration approves the BioResearch-marketed device under the premarket notifications 510(k). According to the report, this two-channel JVA amplifier has the following indications:

a. To record and display sounds/vibrations from the TMJ
b. To aid the clinician in analysis of a joint sound/vibration by allowing him/her to see the waveform in various standard plots
c. To aid the clinician in comparing a patient's current standard plots to previous recordings before, during, and after treatment
d. To provide numerical values that can be used to quantify the physical characteristics of the sounds/vibrations, allowing intrapatient comparisons (only) by the clinician[16]

Due to the controversies in the use of electronic devices for the diagnosis of TMD and the methodological limitations of the existing body of literature, the current American Association for Dental Research policy statement reports that none of the current technological devices shows the sensitivity and specificity required to separate normal subjects from TMD patients, nor can they distinguish among types of TMD. [22]

The reliability and diagnostic validity of the JVA have been evaluated in previous published studies, but the outcomes of these studies vary and have never been synthesized in a systematic review. Thus, the aim of the present study was to conduct a systematic review of papers reporting the reliability and diagnostic validity of the JVA for diagnosis of TMD.

Materials and Methods

This systematic review was limited to publications for evaluating the reliability and diagnostic validity of the JVA. PubMed was searched using the following MeSH terms (TMJ OR TMD) AND (tape recording OR joint vibration analysis OR electrosonograph OR signal processing) AND (sounds OR vibrations OR auscultation). The search was limited to English-language publications and had no publication date limits. The last search was conducted on May 8, 2012. Seventy-five articles were retrieved from PubMed. Abstracts without subsequent publications were excluded.

Two reviewers independently read the full content of all publications. Case reports, reviews, and theoretical papers were excluded, as were articles that used other anatomical structures or other instruments such as microphones. The potential articles[17–30] were then distributed among the four reviewers and each article was read by at least two reviewers in full text. Articles that used JVA only as the diagnostic tool were excluded because they did not compare the JVA to a reference standard, and those that had only one diagnostic group or lacked reference standards were also excluded. The STAndards for the Reporting of Diagnostic accuracy studies (STARD) guidelines[31] were adapted to evaluate the publications. The initial number of articles using the search terms described above and the consequential reasons of reduction leading to the final literature core are presented in Fig 1.

Results

After the standardized review was performed, 15 publications were included (Table 1). Several methodological limitations were present in these 15 studies. First, there was a lack of blindness and, consequently, classification bias is possible.[19–22,24,26,28] Second, a nonvalidated classification system of disease progression was often adopted.[19–22,24] Third, different imaging techniques were used as reference standards to identify the control and test groups within the same study. For example, computerized tomography was used to determine normal status of the TMJ including disc position, whereas arthrography was used to determine the joint status for the symptomatic patients.[22] Fourth, the presence of joint sounds per se was often considered as a pathological status and used as a reference standard.[17,18,23,30,32] Finally, some articles used the JVA, instrument of interest, as the reference standard even though its diagnostic validity has not been proven.[17,18,25,27,29]

Reliability of the phenomenon (vibration) was evaluated by only one study, which found a large range of reliability values of joint sounds during vertical range of motions, and for which the time interval between the three recordings was not reported.[23] In contrast, there were 14 articles on validity, that is, sensitivity and specificity. The reported sensitivity ranged from 50% to 100% and the reported specificity ranged from 59% to 100%, but both of these are questionable due to various methodological limitations.

Discussion

The main finding of this systematic review was that this body of literature is currently unable to provide convincing evidence to support the reliability and the diagnostic validity of the JVA in the diagnosis of TMD.

The strengths of this study are *(1)* it included a comprehensive search of the electronic database; *(2)* reliability and diagnostic validity of the JVA to diagnose TMD was examined; and *(3)* the STARD criterion[31] was used to evaluate the potential publications. The objective of the STARD initiative is to improve the accuracy and completeness of reporting of studies of diagnostic accuracy in order to allow readers to assess the potential for bias in the study (internal validity) and to evaluate its generalizability (external validity). The STARD statement consists of a checklist of 25 items and recommends the use of a flow diagram that describes the design of the study and the flow of patients.[31] Thus, to the authors' knowledge, this is the first systematic review of studies on JVA in which the STARD guidelines were used.

The possible study limitations are *(1)* the articles included in this study were limited to the English language and *(2)* some articles may not have been identified through the search process. However, the study used a broad search strategy that included manufacturers' websites and citations in the references. These did not reveal any additional articles.

There were two general problems with the quality of studies included in this review. First, results from the studies were not reported using the STARD checklist.[31] Moreover, these studies did not use standardized and well-described diagnostic criteria for disease classification and/or the appropriate imaging as reference standards.

Hence well-designed research will be required to provide evidence for the reliability and diagnostic validity of JVA if it is to have applicability in clinical practice.

Table 1 Summary of Methodological Characteristics of the Included Studies

Study	Aim	Demographics	Diagnostic groups
Brown et al[25] (1998)	Validation of the JVA in conjunction with the clinical examination and history questionnaire in TMD patients	25 subjects from university research clinic Sex: 16 (64%) female 9 (36%) male Mean age: Female 36.5 y Male 33.4 y	Control group: n = 11 asymptomatic 4 female, 7 male Test group: n = 14 symptomatic 12 female, 2 male
Christensen et al[17] (1992)	Comparison of self-reported TMJ sounds and severity to electronic vibrations; evaluation of anterior guidance angles to occurrence of TMJ vibration	20 subjects Sex: 10 (50%) female 10 (50%) male Mean age: Control: 25 ± 2 y Test: 28 ± 8 y	Control group: n = 9 negative EVG with self-report sounds 3 female, 6 male Test group: n = 11 positive EVG with either ± self-report of sounds 7 female, 4 male
Christensen and Orloff[18] (1992)	Evaluation of TMJ vibration reproducibility based on three recordings within 3-min intervals	6 subjects Sex: 1 (17%) female 5 (83%) male Mean age: 41 ± 5 y	Control group: n = 3 subjects (only 1 TMJ per subject) Test group: n = 3 subjects with TMJ noise
Garcia et al[26] (2000)	Evaluation of total energy, > / < 300 Hz, width and frequency peak of vibrations in individuals with capsulitis and/or sinovitis and retrodiscitis	20 subjects Sex: 14 (70%) female 6 (30%) male Mean age: Control: 20 y Test: 40 y Age range: Control: 18–21 y Test: 32–61 y	Control group: n = 10 5 female, 5 male Test group: n = 10 9 female, 1 male
Honda et al[28] (2008)	Investigation of bony changes in condylar surfaces in disc displacement without reduction, if changes limit disc and condyle motion and produce joint sounds	37 joints in 28 patients Sex: 27 (96%) female 1 (4%) male Mean age: Pathological bone changes (PBC) group: 50.2 ± 17.3 y Adaptive bone changes (ABC) group: 46.1 ± 15.3 y	Control group: n = 0 No healthy subjects Test group: n = 24 with PBC n = 13 with ABC
Hwang et al[30] (2009)	Six-month examination of TMJ sounds	20 dental students Sex: 2 (10%) female 18 (90%) male Mean age: 22.4 y	Control group: n = 10 with normal TMJs 10 female 0 male Test group: n = 10 with anterior disc displacement 2 (20%) female 8 (80%) male

Reference and index test	Statistical methods and results	Authors' conclusion	Limitations
Reference: Consensus diagnosis of 3 clinicians using RDC, TMJ Scale, mandibular position indicator, computerized axiography, and JVA Index: JVA & RDC	Reliability: Not reported Validity: Not reported	JVA in combination with clinical examination increases accuracy of the diagnosis	Diagnostic groups do not have operational definitions or clinical criteria; JVA is included in the proposed reference standard; no reliability or validity evidence reported for the proposed consensus diagnosis
Reference: EVG Index: Self-report sounds	Reliability: Not reported Validity: Sen = 50% Spec =100%	Self report unable to reliably detect early symptoms of TMJ dysfunction but able to detect late symptoms of TMJ dysfunction and possibly disease	No reliability tested; TMJ sounds considered a pathological state; calculation of validity was estimated using EVG as the reference standard
Reference: Palpation & auscultation for TMJ sounds and EVG Index: TMJ sounds	Reliability: ICC range from 0.75 to 1.0 Validity: Not reported	EVG is superior diagnostic aid in the examination of patients with TMJ pathology and dysfunction	TMJ sounds considered as pathological state; data presented as one value per subject; in the control group only one joint used; selection bias as the EVG was used to select TMJs; ANOVA model incorrectly used, each subject is taken as a group for comparison
Reference: History & clinical examination & transcranial radiography Index: JVA	Reliability: Not reported Validity: Not reported	Total amount of energy has different ranges among the groups; total vibration energy higher in the symptomatic group	No reliability or validity evidence for the proposed consensus diagnosis; examiner was not blind to group status; no clinical criteria to differentiate among the capsulitis group; age and groups confounded
Reference: MRI & radiographic examination Index: JVA	Reliability: Not reported Validity: Not reported	Median frequency; mean values of energy power over 300 were evaluated and no statistical differences between the groups were found	No reliability; no diagnostic validity of the JVA tested; no group with healthy joints; no examiner reliability rating to determine the bone status
Reference: Sounds upon palpation Index: JVA	Reliability: Not reported Validity: Not reported	Groups varied in ratio > 300/< 300 before & after 6 months; similar patterns in frequency spectrum at same location that joint sounds occurred before and after the 6-month recording	Diagnostic validity not evaluated and diagnostic grouping based on clinical examination, based on the presence of sounds upon palpation; considered joint sound to be pathological

Table 1 Summary of Methodological Characteristics of the Included Studies (cont.)

Study	Aim	Demographics	Diagnostic groups
Ishigaki et al[21] (1993)	Evaluation of sensitivity and specificity of joint vibration analysis in patients with and without internal derangement	309 joints imaged in 213 patients with TMJ pain, sounds, and limited range of motion Sex: 14.2% female 85.8% male Mean age: not provided	Control group: n = 88 joints without internal derangement Test group: n = 221 joints with internal derangement
Ishigaki et al[22] (1993)	To establish the vibration energy threshold among symptomatic and asymptomatic TMJs with normal imaging	10 clinically normal and asymptomatic volunteers Sex: 8 (80%) female 2 (20%) male Mean age: 30.8 ± 8.6 y	Control group: n = 20 joints asymptomatic normal by CT Test group: n = 83 joints symptomatic with normal arthrograms
Ishigaki et al[20] (1993)	Evaluation of sensitivity and specificity of joint vibration in patients with disc displacement with and without reduction	247 participants Sex: Not provided Mean age: NID group: 31.6 y MDR group: 30.4 y MD group: 29.1 y	Control group: n = 83 joints symptomatic with normal arthrograms Test group: n = 102 joints with displacement with reduction: 29 MDR–early 73 MDR–late n = 70 joints with disc displacement without reduction: 9 MD–incomplete 61 MD–complete
Ishigaki et al[19] (1993)	Evaluation of sensitivity and specificity of joint vibrations in patients with DJD and/or perforation of the disc	125 participants Sex: 103 female 22 male Age range: 52.2 ± 19.2 y to 28.5 ± 9.8 y among the groups	Control group: 83 joints with normal TMJ imaging 63 female 20 male Test group: n = 42 joints with DJD and/or perforation 40 female 2 male 4 MD-DJD 23 MDP 9 MDP-DJD 6 Perforation

Reference and index test	Statistical methods and results	Authors' conclusion	Limitations
Reference: Arthrography Index: JVA	Reliability: Not reported Validity: I(T) = 1.76 Sen = 85% Spec = 66% I(T) = 2.90 Sen = 75% Spec = 76%	JVA better than patient's awareness of sounds or doctor's assessment of sounds	No reliability; no healthy individuals; lack of blindness of examiners; possible referral bias; lack of clarity to determine the cutoff of the total integral as an outcome measure; lack of clinical criteria for diagnostic classification
Reference: Bilateral CT for control group & arthrography for symptomatic subjects Index: JVA	Reliability: Not reported Validity: I(T) = 2.06 Sen = 82.4% for internal derangement group Spec = 75% for non-internal derangement group	Symptomatic subjects have higher energy above 300 Hz & show significantly higher total energy than controls	Different reference standard for both groups; change in the I(T) cutoff accounts for new values of sensitivity and specificity; no blindness of the examiner to the joint status; lack of clinical criteria for diagnostic classification; no group with internal derangement in this paper; no 2x2 table showing calculations of sensitivity and specificity and unclear what reference standard was used for the calculation
Reference: Arthrograms & videofluoroscopy Index: JVA	Reliability: Not reported Validity: I(T) = 2.06 cutoff Sen: Early reduction group = 97%; Late reduction = 92%; Incomplete displacement without reduction = 78%; Complete = 57% Spec = 75%	The level of vibration is related to the level of displacement	No blinding; no reliability; elimination of patients with multiple pathologies; lack of clinical criteria for diagnostic classification, especially under the early and late displacement and complete and incomplete reduction
Reference: Arthrography Index: JVA	Reliability: Not reported Validity: I(T) = 2.06 as cutoff Control group: Spec = 75% for NID group Test group: Sen = 80.2% for ID &/or DJD group: MD-DJD =100% MDP = 87% MDP-DJD = 88.9% Perforation = 100% Spec = not given	DJD showed higher vibration energy above 350–450 Hz; perforation higher vibration energy between 100–150 Hz & 300–450 Hz; presence of perforation did not affect characteristic of vibration in DJD	No blinding; no reliability; lack of explanation for group selection in order to calculate sensitivity and specificity

Table 1 Summary of Methodological Characteristics of the Included Studies (cont.)

Study	Aim	Demographics	Diagnostic groups
Ishigaki et al[24] (1994)	Classification of patients by EVG patterns	297 joints Demographics not provided	9 diagnostic groups: 83 NID; 29 MDR-early; 73 MDR-late; 9 MD-incomplete; 61 MD-complete; 4 MD-DJD; 23 MDP; 9 MDP-DJD; 6 perforation
Mazzetto et al[29] (2008)	Analysis of joint noise characteristic in groups formed according to joint dysfunction classification provided by EVG	72 participants Demographics not provided	8 groups based on EVG
Radke et al[27] (2001)	Evaluation of wavelet of vibrations can separate disc displacement with reduction vs normal joint by blinded observers	124 patients Demographics not provided	Control group: n = 28 with at least one normal joint Test group: n = 28 with at least one joint with reducing displaced disc
Tallents et al[23] (1993)	Evaluation of joint sounds reproducibility and their association to internal derangement in asymptomatic subjects	50 asymptomatic volunteers with negative history of signs or symptoms of TMJ Demographics not provided	Control group: Normals Test group1: Disc displacement with reduction Test group 2: Disc displacemnt w/o reduction
Huang et al[33] (2011)	Explore diagnostic value of JVA and compare TMJ vibrations in ADDWR	47 patients Sex: 29 (62%) female 18 (38%) male Mean age: not provided	Control group: n = 26 with normal TMJs 16 female 10 male Test group: n = 21 with anterior disc displacement 13 (62%) female 8 (38%) male

ADDWR, anterior disc displacement with reduction; ANOVA, analysis of variance test; CT, computerized tomography; DJD, degenerative joint disease; EVG, electrovibratography; ICC, interclass correlation coefficient; I(T), total integral; JVA, joint vibration analysis, SonoPAK, BioResearch Inc, Milwaukee, Wisconsin, USA; MD, meniscal displacement; MD-DJD, meniscal displacement associated with degenerative joint disease; MDP, meniscal displacement without reduction associated with perforation; MDP-DJD, meniscal displacement without reduction with perforation associated with degenerative Joint Disease; MDR, meniscal displacement with reduction; MRI, magnetic resonance imaging; NID, no internal derangement; NPV, negative predictive value; PPV, positive predictive value; RDC, Research Diagnostic Criteria; Sen, sensitivity; Spec, specificity; TMJ, temporomandibular joint; TMD, temporomandibular disorders.

Reference and index test	Statistical methods and results	Authors' conclusion	Limitations
Reference: Arthrography & video-fluoroscopy Index: JVA	Reliability: Not reported Validity: MDR-early & MDR-late: Sen = 79% Spec = 76.2% MD-incomplete: Sen = 85.7% Spec = 79.9% MD-complete: Sen = 77.1% Spec = 59% DJD &/or perforation: Sen = 76.3% Spec = 77.9%	Vibration analysis could be clinically useful as a screening examination for TMD patients	No reliability, use of diagnostic groups without criteria or operational definition
Reference: EVG Index: EVG	Reliability: Not reported Validity: Not reported	Analyzing noise by using EVG suggests type of joint dysfunction; may help to establish a diagnosis & treatment plan	EVG used to form groups and used as the reference standard; nonvalidated diagnostic classification based on JVA
Reference: Clinical exam, tomographic radiograph, JVA Index: EVG wave forms used by 7 blinded observers	Reliability: Not reported Validity: Not reported None— compared to probability of sorting forms by chance	Wavelet transforms can be used to separate normal from displaced disc; no evidence of high variability in disc displaced group	Assumes reliability of JVA; used JVA to determine diagnoses for disc displacement (reference standard); same phenomena (vibrations used to compute wavelets) used in the index test
Reference: MRI and clinical examination (audible & palpable sounds) Index: JVA	Reliability: Average ICCs for > 300 Hz/ < 300 Hz 0.49 Median frequency 0.64 Peak frequency 0.5 Validity: Not reported	Inaudible joint sounds do not aid in staging of internal derangement; sound events present were not reproducible	No validity estimates provided; time interval to assess reliability is not known; large range of ICCs
Reference: MRI and clinical examination Index: JVA	Reliability: Not reported Validity: I(T) Sen = 85.7% Spec = 84.6%	All parameters of JVA in ADDWR higher than controls; different pathological stages of disc displacement show different TMJ vibrations; JVA may be helpful to identify process of pathological TMJ sounds	No reliability reported; lack of blindness of examiners; lack of clarity as to the cutoff of the total integral as an outcome measure; lack of clinical criteria for diagnostic classification; no MRI used on control group

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