An Evaluation of the Correlation Between Temporomandibular Disorders Defined by Joint Vibration Analysis Both with Sleep Disorder Breathing and Patient Characteristics

A. Robinson, P. Reher, and N. Doan

Abstract Limited research exists on the correlation between sleep disorder breathing and TMD. The aim of this study is to assess the relation between TMJ noises generated using Joint Vibration Analysis (JVA) and the most common subtype of TMD; TMD and SDB, and variables amongst patients and TMD**.** This study is a 10-year retrospective analysis of 68 patients. Patients were selected for the study if they possessed a full set of dental records comprising of demographics, cone beam computed tomography (CBCT), and JVA data. Based on a clinical diagnosis of SDB, patients were divided into two groups, patients with SDB (n = 37) and those without SDB (n = 31). JVA was used to diagnose patients with TMD (n = 56) and those without TMD (n = 12) as well as to identify the most common subtype of TMD. SDB and non-SDB patient groups were compared to each other in order to identify whether a link concerning SDB and TMD and SDB versus other TMD subtypes. Finally, a multivariant analysis was done in order to identify a correlation between patient characteristics and TMD using Graph Pad Prism v8.2.0. The analysis of results indicated that ligamentous laxity was the most common diagnosis of TMD defined by JVA. No statistically significant association identified between SDB and TMD cohort (p = 0.7598); TMD subtypes in patients with SDB. However, multivariant analysis of patient characteristics below average patient oral hygiene was significantly associated with TMD (p = 0.0309). JVA successfully identified ligamentous laxity as the most common diagnosis of TMD. Due to limitations in this patient cohort, an association between TMD and SDB was not able to be established in this analysis. The correlation between TMD and SDB requires further research. If an association does exist, JVA represents a novel tool for the early identification of TMD, which may lead to earlier diagnosis and intervention for SDB.

Keywords JVA · CBCT · Sleep-disordered breathing · TMD

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1 Introduction

SDB has become increasingly more common in the general community. Numerous illnesses are covered under the umbrella of SDB, and its gravity varies from snoring to sleep apnea. The more severe disorders are characterized by atypical displays of respiration and changes in oxygen saturation during sleep and are associated with adverse outcomes across multiple organ systems. SDB patients commonly report noises in their TMJ suggestive of underlying TMD. Multiple papers have identified an association between TMD and JVA. However, currently, little research has been done in identifying a link between SDB and TMD. The aim of this study is to identify the most common subtype of TMD diagnosed by BioPak software through JVA. Secondly, this study aims to investigate whether an association exists between SDB and TMD and whether certain TMD subtypes have a greater association with SDB. Finally, the study will look at which variables amongst patients are associated with a higher likelihood of TMD. If an association between SDB and TMD exists, the JVA device could be used to identify at-risk patients and offer early intervention.

2 Literature Review

2.1 Definition and Pathophysiology of Sleep Disordered Breathing

During sleep for healthy patients, the air is seen to move in and out of the lungs at a consistent rhythm. In patients who suffer SDB, this air movement is occasionally reduced or stopped completely. Sleep-disordered breathing indicates to brief, frequently cyclical, stops in breathing pattern (apnoeas) or temporary or persistent reductions in-breath amplitude (hypopneas) [1]. There are two main types of SDB which are demonstrated in sleep apnea (SA).

- Obstructive sleep apnoea (OSA) can be characterized by decreases or pauses of airflow in sleep, notwithstanding continuing respiratory effort. It is owing to upper airway impediment.
- Central sleep apnoea is characterised by recurring crescendo-decrescendo breathing exertion and airflow in alertness or sleep, exclusive of upper airway blockage.

The upper airway is a complicated arrangement needed to accomplish multiple intricate motor behaviours. Partly, the hyoid bone which is an important attaching location for pharyngeal dilator muscles is to blame for upper airway obstruction in sleep as it is not firmly attached to skeletal structures [1]. Hence the human pharynx has no firm backing excepting for the extreme upper and lower ends.

Reports by means of computer tomography (CT), nasal pharyngoscopy and magnetic resonance imaging (MRI) have revealed that the retropalatal region of the

oropharynx is the usual utmost site of airway failure in OSA [1]. However, airway tapering is an active development that differs noticeably amongst patients and can also include the retroglossal and hypopharyngeal areas (see Fig. 1) [2].

Expansion of soft tissue, including the soft palate and tongue, around the upper airway (UA), renders drastically to pharyngeal airway contraction in the anterior–posterior plane in many cases of OSA (see Fig. 2) [5]. While thickening of the lateral pharyngeal partitions has been indicated to be the main location of airway concession in the lateral dimension (see Fig. 3) [3]. As well as this, OSA individuals exhibited retroposed and undersized lower jaws, inferiorly positioned hyoid bones, lengthier soft palates, broader uvulas, and greater slenderer hard palates [6].

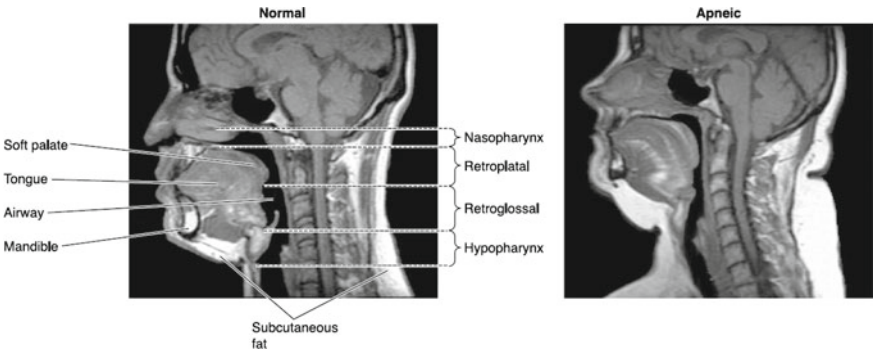

Fig. 1 Picture of midsagittal magnetic resonance (MRI) in a typical patient (left) and a subject with advanced OSA (right). Underlined are the four upper airway areas and upper airway soft tissue [3, 4]

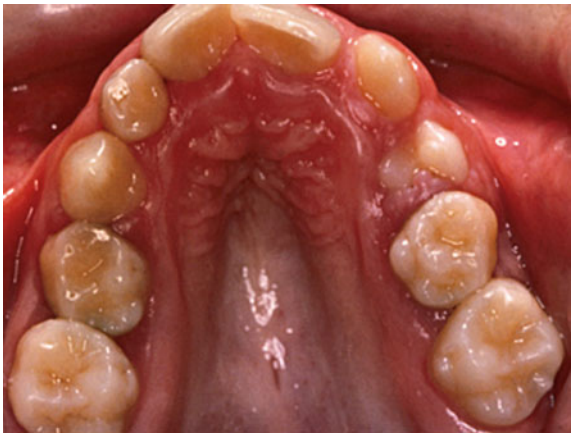

Fig. 2 Palate with a high and narrow maxillary arch in a subject has obstructive sleep apnoea. The tongue cannot fit into the narrow palate. Therefore, the tongue tends to move backwards when the patient is supine, blocking the airway [7, 8]

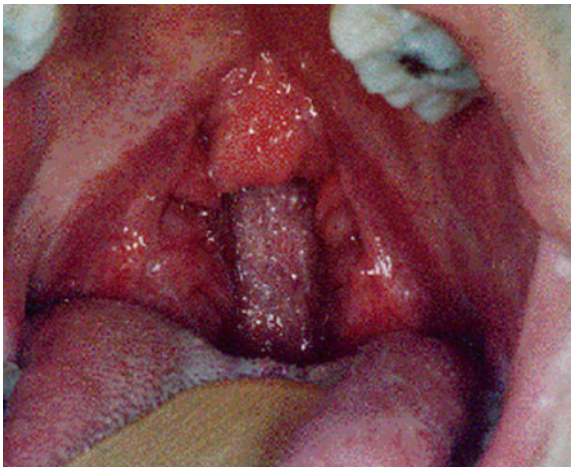

Fig. 3 This photograph is from a snoring patient in whom obstructive sleep apnea was excluded by polysomnography. The oropharyngeal narrowing is present in the lateral dimension due to residual tonsillar tissue [9, 10]

2.2 Epidemiology

SDB is a serious condition and is now recognized to have serious adverse consequences [11]. It can affect a person's ability to safely perform daily activities, including disproportionate daytime somnolence, behaviour and cardiovascular illness, and death. Approximately 25% of adults are at risk for sleep apnea of some grade [12].

OSA is currently the very usual sleep-related breathing disorder. It is more prevalent among older men and postmenopausal women; however, it also has been shown in children [13, 14]. The presence of OSA has also been shown to vary with race. OSA is farther widespread in African Americans age less than 35 when contrasted to Caucasians in the same age bracket [15]. It was also noted that OSA prevalence in Asia is similar to the United States, despite lower rates of obesity [16].

Multiple reports have shown that the occurrence of OSA seems to be on the rise, whether this is due to increased awareness and diagnosis of OSA or obesity is unclear [12, 17]. One study estimated the prevalence of OSA between 1990 and 2010 to have increased from 11 to 14% in adult males [12].

2.3 Risk Factors and Diagnosis

Many risk factors are linked with OSA and include Older age [18, 19], Male gender [15, 20], Obesity [1] and body mass index (BMI) [21], Craniofacial and upper airway anomalies [10, 22], Smoking [22], Big neck circumference [23].

In general, patients who suffer from OSA will complain of daytime sleepiness, or their partner will report loud snoring, choking, or interruptions in breathing while sleeping. The diagnosis of OSA is established both on the existence or lack of related symptoms, as well as the occurrence of respiratory incidents during sleep. The ideal standard diagnostic test for the rate of breathing incidents in sleep is in-laboratory polysomnography (PSG).

The most common variety of evaluation tool used in the diagnosis of OSA, which is readily available for clinicians is the STOP-Bang questionnaire (see Table 1). This tool is often used by clinicians preoperatively to assess the risk of undiagnosed OSA [24].

Table 1 STOP-Bang questionnaire [9, 25]

STOP-Bang questionnaire		
Yes	No	**Snoring?** Do you **snore loudly** (loud enough to be heard through closed doors, or bed partner elbows you for snoring at night?)
Yes	No	**Tired?** Do you often feel **tired, fatigued or sleepy** during daytime? (such as falling asleep during driving?)
Yes	No	**Observed?** Has anyone **observed** you **stop breathing** or **choking/gasping** during your sleep?
Yes	No	**Pressure?** Do you have or are being treated for **high blood pressure?**
Yes	No	**Body mass index more than 35 kg/cm^2?**
Yes	No	**Age older than 50 years old?**
Yes	No	**Neck size large? (measure around Adam's apple)** For male, is your shirt collar 17 inches or larger? For female, is your shirt collar 16 inches or larger?
Yes	No	**Gender = male?**
Scoring criteria:		
Low risk of OSA: Yes to 0–2 questions		
Intermediate risk of OSA: Yes to 3–4 questions		
High risk of OSA: Yes to 5–8 questions		

2.4 Understanding TMD and JVA

TMDs are common; however, they are not easily classified. Substantial morbidity results from patients who suffer from TMD. It is estimated in the US that for each 100 million working individuals, TMD will result in 17.8 million working days lost yearly [26].

The pathogenesis of TMDs is multifactorial with the greatest frequent being temporomandibular joint (TMJ) damage. Trauma to the TMJ ligaments, articular cartilage, disc, and bone leads to a disparity between free radicals and antioxidants in the body, recognized as oxidative stress. This, in turn, leads to free radical generation in the intra-radicular space and subsequent synovial fluid inflammation, producing cytokines that cause degenerative TMJ disease. The initial joint trauma leading to this degeneration can result from external injuries to the jaw, or bruxism [27].

The major clinical manifestations of TMD revolves around the two distinct elements which contribute to TMD. These being muscle dysfunction and specific problems within the TMJ. Thus, the major symptoms are a pain in the muscles of chewing or pre-auricular zone, joint noises, and limitation in jaw function [28].

JVA utilizes accelerometers to capture pulsations result from movement of two irregular sides, being in this instance the disc and condyle surfaces (see Fig. 4). In theory, joints in the right biomechanical connexion should make a very minute rubbing, and hence slight vibration which can be detected by JVA [29]. Changes in the two irregular surfaces, for example, those produced by degeneration, tear of the disc, or displacement of the disc, commonly create rubbing and hence vibration

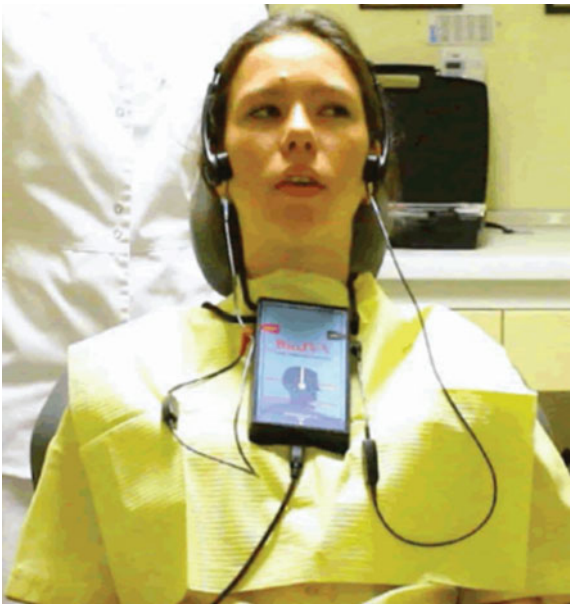

Fig. 4 Joint vibration analysis procedure [25, 34]

[30]. It was hypothesized that distinctive conditions might yield diverse patterns of vibration [31].

The most broadly applied tool for diagnosis of TMD, The Research Diagnostic Criteria aimed at temporomandibular disorder (RDC/TMD), uses TMJ sounds for patient diagnosis [32]. The TMJ noise kinds employed in RDC/TMD diagnosis are identified by particular measures of these noises by palpation and auscultation [30]. Traditionally the diagnostic accuracy of TMJ sounds is questionable due to the inherent inconsistency of joint noises and the trivial inter-examiner consistency. The advent of objective tools to measure and record TMJ sounds resulted in the development of the JVA.

The analysis of vibrations detected by the JVA of the TMJ is a measurable procedure that gauges the intensity and frequency dispersal of vibratory waves emitted from the joint during its full range of movement [33]. There are two companies, BioResearch and Myotronics, that presently promote devices that can be employed for appraisal of JVA data. The US Food and Drug administration accepts the BioResearch advertised device for the ensuing indications:

1. To trace and exhibit sound/noises from the TMJ
2. Help the practitioner in the study of joint sound/noise by permitting him/her to realise the wave-form in several typical plans
3. To aid the practitioner in equating a patients' existing normal graphs to preceding records before, during and after usage.

2.5 TMD Diagnosis Subcategories as Defined by JVA

The analysis of TMJ joint noises generated using JVA is the focus of this study, with the conditions of TMD diagnosed into the following subgroups as determined by the JVA flow chart (see Fig. 5).

1. Disc displacement with reduction (DDR)
2. Disc displacement without reduction (DD)
3. Degenerative joint disease (DJD)
4. Ligamentous laxity (LL)
5. Deliver mathematical standards that can be utilized to calculate the objective features of the sounds/vibrations, permitting between-patient contrasts by the practitioner [33]. The reliability of the vibrations captured by JVA has been evaluated in previous studies. All variables displayed decent to outstanding consistency throughout various sessions and through diverse dates [30]. Hence JVA may well provide a relatively quick, non-invasive, and easily repeatable technique to record the health of the TMJ.

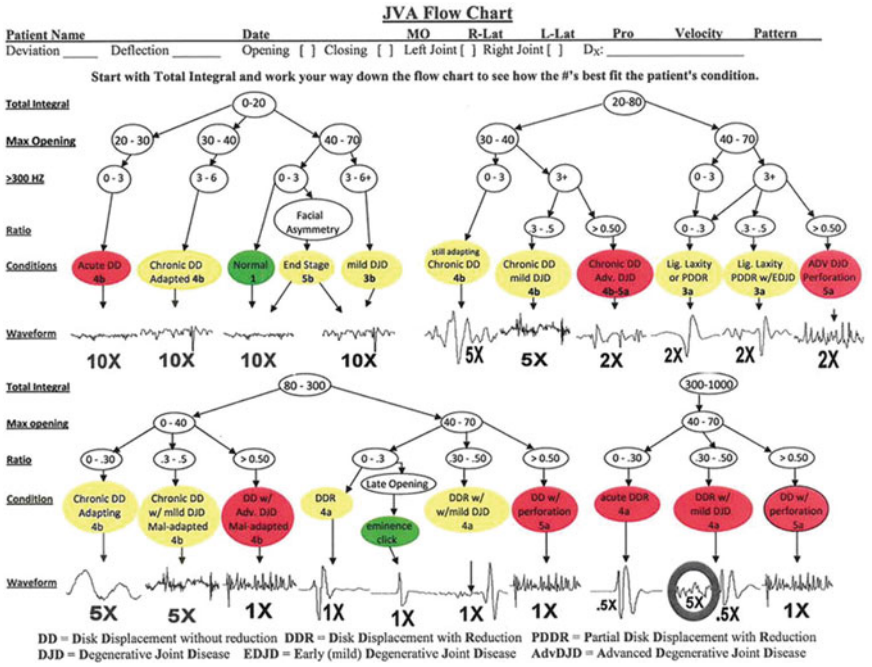

Fig. 5 Joint vibration analysis flow chart [17, 35]

2.6 Healthy Relationship Within TMJ and Association Between SDB and TMD

It is best to first understand a healthy relationship within the TMJ joint capsule on opening and closing before discussing dysfunction (see Fig. 6). There are two different activities, rotation and translation, which happen in the TMJ throughout opening and closing. The initial stage of mandibular opening, being turning of the mandibular condyle inside the glenoid fossa, is initiated by the suprahyoid muscles. The additional opening is because of a frontward translation, guided by the lateral pterygoid muscle, of the condyle alongside the posterior angle of the articular prominence. Finally, the action of mandibular closure is directed by the temporalis, masseter, and medial pterygoid muscle groups. During temporomandibular articulation, a fibrocartilaginous disc divides the condyle and glenoid fossa from straight interaction and apportions the joint area into inferior and superior zones [36].

The correlation between TMD and SDB is contentious. This is contributed by the lack of consistency in diagnostic aspects of both disorders. In support of this association, it has been found that a bulk (>50%) of subjects with TMD complain of deprived sleep characteristic [38]. Additionally, Smith et al. noted that 43% of the patients with TMD in their study had evidence of sleep disorders [39]. Furthermore,

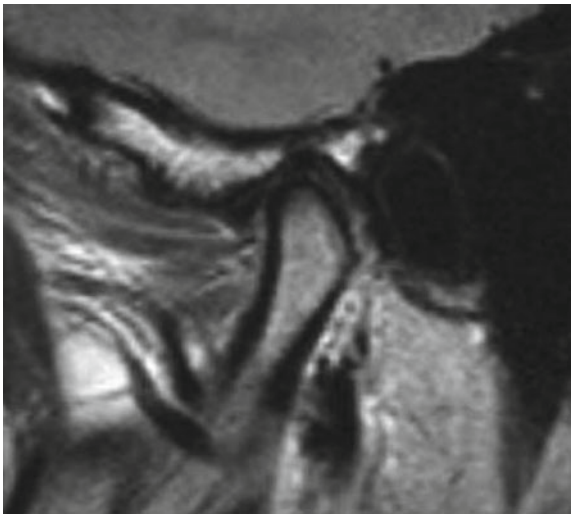

Fig. 6 Magnetic resonance images show the healthy TMJ disc position. The posterior band of the disc is located above the apex of the condylar head (at the 12 o'clock position) with the mouth closed [24, 37]

Dubrovsky et al. [40] using PSG on patients with TMD, found a pattern of sleep stage alterations as well as an increase in respiratory effort-related arousals [4, 40].

On the other hand, most previous research has focused only on the relationship between sleep bruxism and TMD. Bruxism is defined by the American Academy of Sleep Medicine, as an oral motor complaint categorized by sleep-related crunching and/or clenching of the teeth [8]. Alterations in the pattern of sleep, micro-arousal phenomena, that may be caused by SDB appear to show the main role in bruxism [41]. Of entire the parafunctional activities of the jaw system, bruxism is contemplated to be a major risk feature for TMD [42]. Manfredini et al. [42] carried out a systematic review noted that solid backing for the connection concerning bruxism and TMD only derived from reports which utilized a scientific bruxism analysis, whereas other studies which adopted diagnostic modalities failed to confirm the association [42]. Current evidence can therefore only support a weak association between TMD and bruxism, and hence SDB. This study aims to explore this gap in the literature.

3 Methodology

3.1 Study Design

Aims

The aims of this study are:

1. To analyze and quantify TMJ noises generated using JVA to determine the most common subtype of TMD diagnosed by BioPak software.
2. To analyze whether an association exists between TMD and SDB and whether certain TMD subtypes have a greater association with SDB.
3. To identify which variables amongst patients are associated with a higher likelihood of TMD.

Hypotheses

1. I hypothesize that JVA will be able to determine the most common subtype of TMD.
2. I hypothesize that there will be an association between TMD and SDB and that certain TMD subtypes will have a greater association with SDB.
3. I hypothesize that certain patient characteristics will be associated with TMD.

3.2 Methods

The design of this study is a cross-sectional retrospective study. Patients were selected from private dental practice in Brisbane, with data expanding from 2008 to 2018. The study sample was completed by methods of convenience sampling where subjects over the age of 18 that had an existing JVA and CBCT with adequate health records were randomly selected. Participants voluntarily gave informed consent in accordance with human ethics approval from Griffith University (Ref No: 2017/626). The randomization the indiscriminate consignment of study subjects to exposure groups to stopping any associations between exposure and confounders. Participants willingly provided informed consent in line with human ethics approval from Griffith University (Ref No: 2017/626). The study population consists of 68 individuals with age ranging from 22 to 85 years of age, of which 47 were female, and 21 were male. The attempt was made to match for age and sex. However, due to the small sample size, this was not possible. A power analysis has shown that a full sample of 270 participants would be required to identify sizeable outcomes (80% chance), built on a t-test at 5% level of significance. However, due to available data and randomization, no further participants were included.

In addition, the selected CBCT scans were acquired in a vertical direction only as this were the most common capturing position. This may affect the outcomes of the collected data.

In addition, patients gave informed consent for data collection to be used in further research. A full set of dental records comprising of demographics, CBCT, and JVA data. If this data was not available, then patients were excluded. Based on a clinical diagnosis of SDB as determined by the primary examiner, patients were divided into two groups, patients with SDB (n = 37) and those without SDB (n = 31). JVA was used to diagnose patients with TMD (n = 56) and those without TMD (n = 12) as well as to identify the most common subtype of TMD. SDB and non-SDB patient groups

were compared to each other in order to identify whether an association between SDB and TMD exists. Further subgroup analysis of TMD subtypes was carried out to ascertain whether certain TMD subtypes were more strongly associated with SDB compared to other TMD subtypes. Finally, a multivariant analysis was done in order to identify a correlation between patient characteristics and TMD. The data set was analysed using Graph Pad Prism v8.2.0 (GraphPad Software, Inc., La Jolla, CA).

3.3 Data Collection and Statistical Analysis

The subsequent data (2008–2018) were gathered for entire participants from demographic information (age, gender, ethnicity), smoking standing, physical features and characteristics linking to sleep and temporomandibular joint disorders. These cofounding factors were inferred to take into account of SDB risk factors, for example, age, obesity, sex, family history, craniofacial anomalies, and smoking history.

Furthermore, we also gathered inspection statistics documented by an oral surgeon skilled in the assessment of sleep disorders. This comprised of vital signs, height, weight, and neck perimeter dimensions, palpitation findings of muscle and joint, joint vibration analysis (JVA), a TMD planned questionnaire, the incidence of micrognathia, tongue shape evaluation (scalloped, above occlusal plane), the occurrence of tori, uvula changes and Mallampati's score. To identify patients with possible TMD, the Diagnostic Criteria for Temporomandibular Disorders for Clinical and Research Applications was also employed.

Continuous variables are shown as mean ± standard error of the mean (SEM) if discovered to keep on a Gaussian distribution consistent with a D'Agostino-Pearson omnibus normality test, or as median ± lower and upper quartiles, if seen to track a non-Gaussian distribution. Normally distributed variables were equated by means of Student's t-test and non-normally distributed variables by means of Mann–Whitney U test. Categorical variables are expressed as percentages. A Chi-square analysis was done to equate categorical variables.

A p-value of ≤ 0.05 was regarded as statistically significant for all investigates. Of the statistically significant data set, an odds ratio and confidence interval using Baptista-Pike method was calculated.

Entire studies were accomplished by means of Graph Pad Prism v8.2.0 (GraphPad Software, Inc., La Jolla, CA).

3.4 Results

In patients with TMD, there is a statistically significant difference in diagnosis as defined by JVA. The most common diagnostic criteria in this patient population were LL, followed by DDR, followed by LL + DDR, followed by DD, with the least

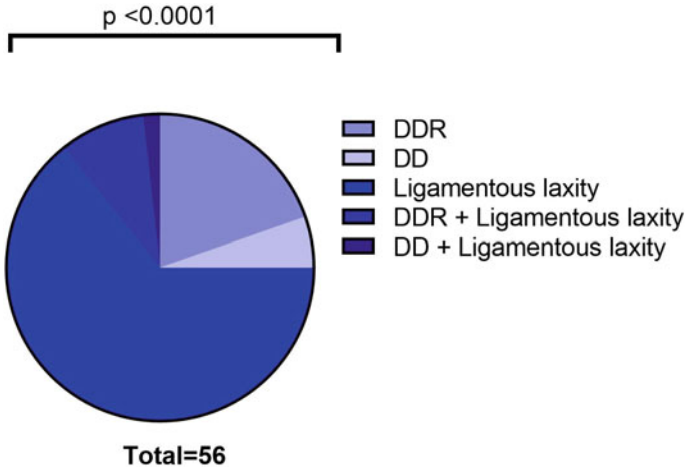

Fig. 7 Pie chart showing the most common subtype of TMD as defined by JVA

common diagnostic criteria being DD + LL (64.3% vs. 19.6% vs. 8.9% vs. 5.4% vs. 1.8%; $p < 0.0001$; see Fig. 7).

Analysis for an association exists between TMD and SDB and whether certain TMD subtypes have a greater association with SDB

In patients with SDB, there was no statistical significance between those diagnosed with TMD by JVA versus those without a diagnosis of TMD ($p = 0.7598$). Furthermore, in a subgroup analysis of TMD subtypes, there was no statistical significance between TMD subtypes and the likelihood of SDB ($p = 0.8010$; see Fig. 8).

Identification of which variables amongst patients are associated with a higher likelihood of TMD

In a multivariant analysis comparing patient characteristics between TMD and non-TMD groups, there were no statistically significant differences between TMD and non-TMD groups except for patient oral hygiene evaluation. There was a statistically significant percentage of patients with average or below average oral hygiene in the TMD group versus the non-TMD group (above average = 7.14%, average = 58.93%; below average = 33.93% in TMD group vs above average = 33.34%; average = 33.33%; below average = 33.33% in non TMD group; $p = 0.0309$; see Fig. 9). An odds ratio and confidence interval using Baptista-Pikes' method for oral hygiene was calculated (OR = 6.5; CI 95% = 1.569–25.08) (Table 2).

Highlights

SDB patients tend to have the following features: sizable neck perimeters, Mallampati Class II and III, the inadequacy of cervical motion, forward head posture, incompetent lips, nasal deviance, skeletal Class II, small jaw/micrognathia, pain on palpation of chewing muscles, TMJ noises and clinical indication of TMD.

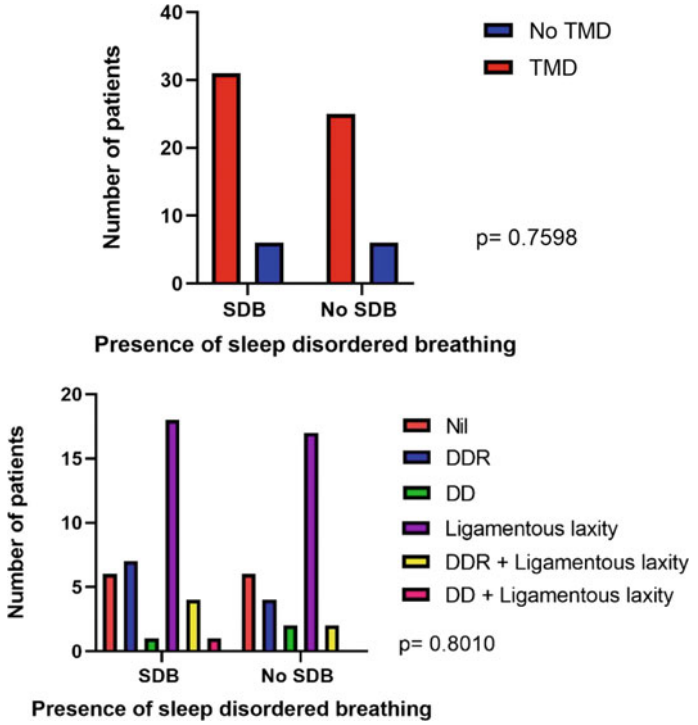

Fig. 8 No statistical significance between SDB and TMD. Furthermore, there was no statistical significance in the TMD patient population groups and SDB

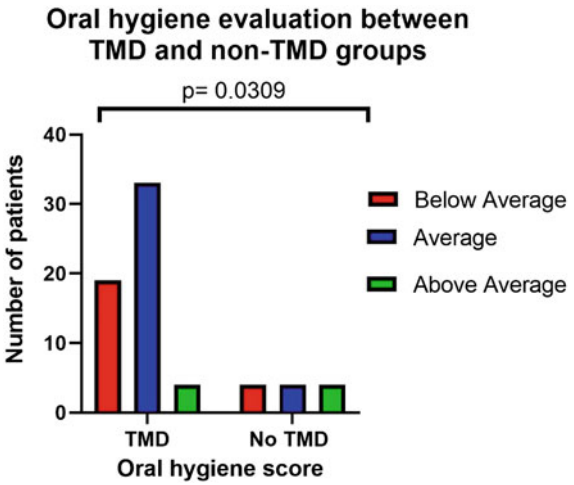

Fig. 9 Statistically significant percentage of patients with average or below average oral hygiene in the TMD versus non-TMD group

Table 2 Correlation between patient characteristics and TMD as defined by JVA

Patient characteristics		TMD	No TMD	*p*-value
Gender (% of female)		66.07	83.33	0.3169
Age		63.82 (53.98–69.68)	64.10 (54.71–74.72)	0.981
Weight		162.12 (54–81.25)	73 (52.75–76.5)	> 0.9999
Height		162.11 (±2.99)	161.75 (±2.99)	0.9052
Neck circumference > 40 cm		32.14%	25%	0.7416
BMI > 30		35.71%	33.33%	> 0.9999
Smoker		14.29%	8.33%	> 0.9999
Forward head posture		83.93%	66.67%	0.2223
Lip incompetence		41.07%	25.00%	0.3481
Dark circles under eyes		84.31%	15.69%	0.4773
Nasal deviation		71.43%	50.00%	0.182
Skeletal profile				
	Class 1	51.79%	50.00%	0.4316
	Class 2	37.50%	50.00%	
	Class 3	10.71%	0.00%	
Micrognathia		25.00%	16.67%	0.7171
Mn Range of Motion < 35 mm		1.79%	0.00%	> 0.9999
Dental classifications				
	Class 1	55.36%	66.67%	0.4767
	Class 2	33.93%	33.33%	
	Class 3	10.71%	0.00%	
Periodontal status				
	None	21.43%	33.33%	0.6765
	Mild	48.21%	41.67%	
	Moderate	30.36%	25.00%	
	Severe	0.00%	0.00%	
Oral removable prosthetics		5.36%	16.67%	0.2107
Limited cervical range of movement		35.71%	16.67%	0.3113
Professional dental oral hygiene evaluation				
	Below average	33.93%	33.33%	0.0309*
	Average	58.93%	33.33%	

(continued)

Table 2 (continued)

Patient characteristics		TMD	No TMD	*p*-value
	Above average	7.14%	33.33%	
Mallampti Classification	Class 1	39.29%	41.67%	0.9622
	Class 2	39.29%	41.67%	
	Class 3	19.64%	16.66%	
	Class 4	1.78%	0.00%	

4 Discussion

JVA is the first device that can absolutely quantify TMJ noises on opening and closing. JVA demonstrates several advantages over traditional methods of examination of the TMJ for symptoms of TMD. These advantages include not having to rely on inconsistent inter-examiner reliability, being able to pick up vibrations far below the frequency of human hearing, offering an absolute and simplified method of quantification, the ability to diagnose different signatures of vibratory waves within the joint capsule, and greater reproducibility of results. JVA is able to quantify vibration within the TMJ capsule and measure intensity and frequency distributions of vibratory waves that are stemming from the TMJ. Given JVAs proposed advantages, it is of particular interest in being able to more reliably diagnose patients with TMD in general dental surgery [33].

Determination of the most common subtype of TMD diagnosed by BioPak software

After acquiring data from all 68 patients involved in the report, 12 of the 68 subjects were not included in the analysis due to not being diagnosed into a subcategory of TMD defined by JVA BioPak software. Of the remaining 56 patients diagnosed with having vibratory waves indicative of TMD detected by JVA, the most common diagnosis was LL (64.3%).

LL of the TMJ is defined as larger than usual range of motion in the joint and suggests joint instability [43]. As indicated by the RDC/TMD, LL can be divided into two subcategories based on the severity of symptoms: these being subluxations and locations [44]. There are multiple etiological predictors of TMD development that have been postulated, one of which is joint hypermobility, also known as LL. In a clinical paper published in 2012, Ogren et al. indicated that general joint hypermobility is an imperative etiological aspect for the progress of TMD [45]. The findings in this study agree with this and suggest LL is the main pathological driver of TMD. This is an important correlation as LL may be considered as an early predictor and a significant factor in the development and advancement of TMD. Further research is warranted to identify the pathogenesis of LL as well as the role of therapeutic interventions.

Finding the association exists between TMD and SDB and whether certain TMD subtypes have a greater association with SDB

The data acquired from the patient cohort was analyzed to look for a correlation between patients with symptoms of SDB and prevalence of TMD diagnosed by JVA showed no statistical significance found between those patients with symptoms of SDB diagnosed with TMD defined by JVA versus those without a diagnosis of TMD ($p = 0.7598$).

Additionally, in a subgroup analysis of TMD subtypes, there was no statistical significance between TMD subtypes and the likelihood of SDB. It was hypothesized that varying degrees of severity of TMD would show a greater correlation in incidences of patients with symptoms of SDB, but this was not shown in this study.

The correlation between SDB and TMD is contentious. Smith et al. noted that 43% of patients that had diagnosed TMD had two or more sleep disorders [46]. Furthermore, [39] Dubrovsky et al. using polysomnographic data were able to determine that patients with TMD have a mild degree of sleep disturbances and a mild increase in upper airway resistance during sleep [39]. Instead, in a systematic review, Manfredini et al. were only able to establish a weak correlation between SDB and TMD [42]. In my patient cohort, I was not able to identify a correlation between SDB and TMD.

Results from this study indicate that an association between TMD and SDB does not exist. However, as discussed further below, this study had multiple limitations that impact this conclusion. Additionally, SDB is a complex process, with TMD possibly representing one part of multifactorial disease.

The importance of determining an association between TMD and SDB should not be understated. If a correlation is ascertained, then symptoms of TMD could lead the patient to a prompter diagnosis of SDB. This has ramifications in the overall health of the patient.

Further research is required to better ascertain a clear association between TMD and SDB. Patients with TMD and healthy controls should be tested using PSG as the standard gold diagnosis of SDB. Those patients with a confirmed diagnosis of SDB determined by PSG require JVA. A true healthy control group with no diagnosis of SDB and no TMD is required for adequate analysis.

Larger group analysis is warranted to not only establish whether a link does exist but also to use novel JVA technology in order to well comprehend TMDs character in the pathogenesis and treatment of SDB.

Identification of variables amongst patients that are associated with a higher likelihood of TMD.

The data acquired was analyzed in a multivariant analysis to look for correlations between different patient characteristics and TMD diagnosed by JVA. In this patient cohort, poor oral hygiene was significantly associated with TMD ($p = 0.0309$). This association was further confirmed by using Baptista-Pike method for odds ratio calculation; poor oral hygiene was again significantly associated with TMD (OR = 6.500, CI 95% = 1.569–25.08). The association between TMD and poor oral hygiene is an interesting finding of this study which, to my knowledge, has not

been identified in prior literature. Poor oral health has significant ramifications on cardiovascular health and wellbeing, possibly through the elevation of cholesterol and resulting inflammation [47]. The current understanding of TMD is that of an inflammatory process driven by trauma to the TMJ. This initial trauma can result from external injuries and/or internal derangement (bruxism). The trauma leads to oxidative stress and hence free radical generation in the intra-radicular space and subsequent synovial fluid inflammation. This, in turn, produces cytokines which through a number of actions results in the degeneration of the TMJ and resulting TMD [48].

It is known that gingivitis and its more sinister infection periodontitis is also an inflammatory disease which tends to be a direct result of dental plaque build-up associated with poor oral hygiene. The inflammatory nature of gum disease is modulated through the production of interleukins, prostaglandins, and matrix metalloproteinases [49]. An isolated disturbance in the homeostatic equilibrium of the human body should not be considered as a secluded spectacle and hence limited in its area of impact [50]. Hence, the modulators of the inflammatory reaction of gum disease are not likely to remain confined to the initial area of onset. It could, therefore, be postulated that this inflammatory process could contribute to the pathogenesis of TMD. Further larger group analysis is warranted with more formal quantification of oral hygiene to assess if this result is replicable. If replicated, this could have significant ramifications to our understanding of TMD as well as the potential for preventative and targeted therapies.

Limitations

The data from this study do not back the original hypothesis. As such, it is important that the limitations of this study are looked at. Firstly, the report was constrained by a lesser subject size, particularly in the non-TMD group. Furthermore, the other limit of this report was the absence of a true healthy control group. Ideally, a true healthy control group would have been confirmed using PSG as the gold standard for diagnosing patients with symptoms indicative of SDB.

A further limitation is that the patient cohort that was analyzed had a wide range of dental disease which would affect occlusion and hence TMJ stability. The study was also limited by the method of diagnosing patients with SDB, which did not follow the gold standard of PSG. Moreover, finally, the study was limited by having only one examiner involved in taking the JVA data. As such, there was no inter-examiner agreement and hence the potential for information bias.

Confounding factors that affect the accuracy of JVA measurements can include the stress of the patient on the day of the measurement, ability to understand the language command given by the examiner, psychological factors of the patient, and experience of the operator. The rationale of randomization the indiscriminate consignment of study subjects to exposure groups to stopping any associations between exposure and confounders. This lessens the potential for confounding by creating clusters that are objectively analogous with regards to recognized and unrecognized confounding variables. Within the context of this study, matching does not

completely solve the problem of confounding but might be useful in particular situations to the small sample controls.

A drawback of this study conveys to its sample size, as power analysis shown that a full sample of 270 participants would be required to identify sizeable outcomes (80% chance), built on a t-test at 5% level of significance. Additional limitation pertains to the information that the entire CBCT scans were acquired in a vertical direction. This may affect the collected data as the anteroposterior measurements of the oropharyngeal airway reduced respectively, with the highest contractions happening fat the soft palate.

5 Conclusion

In this study JVA was demonstrated as an innovative and objective tool in the diagnosis of TMD, JVA identified that LL (64.3%) was the most common disorder of the TMJ which is considered an early etiological factor in the deterioration of TMD. A relationship between SDB and TMD was not able to be identified, suggesting that TMD plays only a small role in the pathophysiology of SDB. However, this study has multiple limitations which include; a small patient cohort, the lack of a healthy control group, a wide range of patient dental health status, and other confounding factors. A significant link between TMD and poor oral hygiene was identified. This finding raises interesting questions regarding the pathophysiology and pathogenesis of TMD and warrants further research, especially in early identification of both SDB and TMD.

Conflict of Interest The authors have no conflict of interest to declare.

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