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Clinical presentation of two phenotypes of tooth wear patients

Wedad Hammoudi[a,b,*], Mats Trulsson[b,c], Jan-Ivan Smedberg[a,b], Peter Svensson[b,c,d]

[a] Dept. of Prosthetic Dentistry, Folktandvården Eastmaninstitutet, Stockholm, Sweden
[b] Dept. of Dental Medicine, Karolinska Institutet, Stockholm, Sweden
[c] Scandinavian Centre for Orofacial Neuroscience (SCON), Denmark
[d] Section of Orofacial Pain and Jaw Function, Department of Dentistry and Oral Health, Aarhus University, Aarhus, Denmark

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ABSTRACT

Objective: To assess the clinical presentation of wear lesions in two phenotypes of tooth wear (TW) patients based on distribution and morphological features of wear.

Materials and methods: 103 patients (mean age = 43.1 years) were divided into two groups based on cluster analysis; cluster A (61 patients) and cluster B (42 patients). The distribution of wear lesions, scores of presence or absence of 10 defined morphological TW criteria and number of teeth fulfilling each criteria were compared between groups. Intra- and inter-examiner reliability of the 10 TW criteria was determined by Cohen's kappa and intraclass correlation coefficient.

Results: While cluster A had more wear in maxillary anterior teeth and mandibular molars compared with the same opposing tooth groups ($p < 0.001$, $p < 0.007$ respectively), there were no differences for cluster B. Cluster A was characterized by higher prevalence of 4 chemical morphological criteria and the highest number of teeth affected by one chemical criteria, whereas cluster B had a higher prevalence of one mechanical criteria and higher number of teeth affected by an additional mechanical criteria. Both intra- and inter-examiner values for the defined TW criteria were fair to excellent.

Conclusion: The results may indicate a more chemical background for TW in cluster A and mechanical background in cluster B. Furthermore, clinicians may use certain clinical features of TW to distinguish between individuals who belong to a specific TW cluster with a presumed chemical or mechanical etiology. These preliminary findings need to be confirmed in future studies.

1. Introduction

Despite the decline of tooth loss in the 20th century, tooth wear (TW) is gaining more and more attention in the long-term health of the dentition and presents a growing concern to the clinician. The prevalence of TW has been reported to range between 10–80% in children and 4–82% in adults [1]. The reported wide range in the prevalence of this condition is possibly due to the lack of international standardisation and differences between applied TW terminology, indices and classification, which in turn contribute to difficulties in the comparability of research findings [2,3]. However, TW seems to increase with age and is more prevalent in men than in women [4,5]. A recent genome- wide association study in a sample of the Northern Finland Birth Cohort 1966 (n = 1962) suggested that the individual and gender variance of erosive wear severity may have a genetic component [6]. To provide the best preventive and therapeutic measures, patient-related risk factors must be primarily investigated and then coupled with the evident signs of wear observed during the clinical examination [1].

The majority of the proposed classification systems for TW have been mainly based on the presumed underlying etiological factors where the groups of TW patients are defined a priori [7–10]. Unlike clustering procedures where patients are assigned according to datasets into different groups known as clusters or partition [11]. Cluster analysis is an exploratory statistical method that may reveal novel groupings, some otherwise are hidden within a complex dataset, depending on the similarity of the objects for a set of specified characteristics [12]. The patients who belong to the same cluster are more similar to each other than those who belong to other clusters [13]. This mathematical approach has been used for decades by researchers in various medical fields since statistical categorization of conditions/diseases parameters is considered a reasonable method to discover otherwise under-appreciated pathological patterns [14]. Such approach enables the profiles of these groups to be studied separately and form bases for disease classification that often contributes to establish tools for therapeutic

* Corresponding author at: Folktandvården Eastmaninstitutet, Dept. of Prosthetic Dentistry, Box 6031, S-102 31 Stockholm, Sweden.
E-mail addresses: wedad.hammoudi@sll.se, wedad.hammoudi@ki.se (W. Hammoudi).

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options [14]. Those modelling tasks can be either performed in an unsupervised or supervised manner.

Several clinical features were reported by different authors and regarded as diagnostic tools for different types of pathological TW [15,16]. TW lesions with a proposed mechanical cause, such as attrition, have occluding surfaces that match in excursive jaw movements and, usually, to similar degrees of wear in both arches [17]. TW with proposed chemical causes (erosion) can change the original tooth morphology by flattening the convex areas, development of occlusal concavities and an intact palatal border of enamel along the gingival margin [18,19]. TW with abrasive lesions may typically be located at cervical areas of teeth and are more wide than deep [20,21].

A two-step cluster analysis which was developed by Chiu et al. (2001) was used in a recent study and considered as a new mathematical method or statistical approach to study patients with TW [22]. Data sets were grouped based on similarity of responses to several variables. The selected variables had sufficient predictive power for segmentation and made it possible to offer a relevant description of the characteristics of the members of the clusters [22]. Selection of the final cluster solution was based on both objective and self-reported measures. Two clusters could be identified with the use of a unsupervised approach: cluster A and cluster B. Compared with cluster A, participants in cluster B showed higher prevalence of presumed mechanical factors and diseases affecting saliva. Although it is known that the processes of chemical and mechanical TW clinically do not occur independently, the recent study indicated a substantial overlap but also some differences that allowed a tentative separation of TW patients into two clusters [22]. It could be argued that the presented method may help in better targeting appropriate treatment and studying typologies of TW patients. Studies which examine differences in the clinical presentation of TW lesions in these proposed clusters may support the clinical value of a differentiation of patients into at least two clusters.

The aim of this study was to assess the clinical presentation, in regard to the distribution and the morphology, of wear lesions in two phenotypes of TW patients established in our recent study [22]. The null hypothesis was that the clinical presentation of the worn dentition in two phenotypes of TW patients would not differ in terms of specific distribution and morphology of wear lesions. A second aim was to establish tentative criteria for TW and to test for intra- and inter-examiner reliability of these criteria.

2. Materials and methods

2.1. Patients

Data was collected from a cross-sectional study of 125 patients, aged 17–65 years (mean age 43.1 years) and have been reported in details in Hammoudi et al. (2019). In brief, patients were selected on the basis of the presence of extensive TW which corresponded > grade 2 according to the Smith and Knight Tooth wear index. A total of 34 variables related to demographic information (age, gender, body mass index, snuff use, medical history), presumed risk factors for chemical TW (history of gastric reflux and conditions involving intrinsic acids, previous conditions of dietary alterations like bulimia nervosa and anorexia nervosa, weight loss and gain, acidic diet, frequent alcohol intake, wine testers/club- and restaurant workers, acidic medication), presumed risk factors for mechanical TW (self-report of sleep bruxism, self-report of awake bruxism, nail/lip/cheek/pencil biting, working in a dusty environment, heavy labour like builders/carpenters/truck drivers, heavy sport exercisers/body builders), presumed risk factors affecting saliva (diseases like asthma/depression/diabetes mellitus/hypertension, drugs affecting salivary protection, sports enthusiast), perceived stress scale scores (PSS-scale), saliva measures (salivary flow rates, pH and buffer capacity), jaw muscle activity during sleep measured by a single-channel electromyographic (EMG) device (total number of EMG grinds, number of EMG grinds/h, EMG intensity, total number of EMG bursts, number of EMG bursts/h, average EMG burst duration, total number of EMG episodes, number of EMG episodes/h, Number of nights) and the presence of torus mandibularis were collected from all participants. An unsupervised two-step cluster analysis was applied to investigate possible variations in TW phenotypes. The procedure of variable selection and cluster discovery resulted in exclusion of 22 cases due to incomplete data concerning PSS-scale, salivary and/or EMG measurements and only 103 cases were included in the final analysis. Variables that could provide a sufficient predictive power for segmentation or differentiation between the study members could be identified by running different cluster models and were included in the final analysis (self-report of sleep bruxism, self-report of awake bruxism, diseases affecting saliva like asthma/depression/diabetes mellitus/hypertension, heavy sport exercisers/body builders, heavy labour like builders/carpenters/truck drivers, salivary buffering capacity, working in a dusty environment, age, sports enthusiast, torus mandibularis, median number of EMG episodes/h, acidic diet, non-stimulated saliva, PSS-scores, median number of EMG grinds/h, history of gastric reflux and conditions involving intrinsic acids). The remaining variables were excluded either because they impaired the quality of the cluster model or had low frequencies. Consequently, the final cluster model comprised 103 cases and 16 variables. The analysis revealed two relatively distinct groups of TW patients; 61 cases belonged to cluster A whereas 42 cases belonged to cluster B. Cluster membership was mainly ruled by several presumed mechanical risk factors and diseases affecting saliva. Compared with the numerically largest cluster, cluster B, had the highest percentage of presumed mechanical risk factors, sleep bruxism self-reports (A 1.6%, B 92.9%, $p \leq 0.001$), awake bruxism self-reports (A 45.9%, B 85.7%, $p \leq 0.001$), heavy sport exercises (A 1.6%, B 21.4%, $p = 0.001$); and highest percentage of diseases affecting saliva (A 13.1%, B 47.6%, $p \leq 0.001$). A remarkable finding was the lack of significant differences between clusters in many other presumed risk factors for mechanical and chemical TW [22].

In summary, the current study included data from the 103 patients who were clustered into two groups with relatively distinct profiles. Prior to study start, an approval from the Regional Ethical Review Board, Stockholm, Sweden was obtained (No 2012/263-31/2), and an informed consent was signed by each participant.

2.2. Photographs and study casts examination

Intra-oral photos were taken by the same investigator with the use of one digital camera (Nikon D80/ Nikon Corporation, Tokyo, Japan) with a ring flash. All photos were taken in 2 rooms with standardized consistent lighting and exposure while the patients were sitting in an upright position. Each patient had at least 9 views. The camera was kept parallel to the tooth surfaces when taking the following views; retracted front view with the teeth in occlusion, retracted right and left in occlusion, close-ups for the maxillary and mandibular anterior teeth. A photographic black background board was used when taking the close-ups views. Left and right lateral mirror views and occlusal upper and lower full-arch mirror views were also taken. The mirrors were held by a dental assistant and the camera was kept at a shallow angle to the mirror when taking these views. Complementary close-up views were taken in patients who had difficulties for some of these views in order to ensure the identification of TW lesions. All photos were stored digitally. Alginate impressions (Blueprint Xcreme alginate, Densply) and study casts were collected. The study casts were wrapped separately in soft paper and stored in a box, between the sessions.

A study manual, consisted of 10 morphological TW criteria that were represented by 6 clinical photos, was constructed. The included morphological features were derived from clinical experience and extensive review of literature [17,23–26]. The study manual was used to register the presence or absence of the 10 defined morphological criteria (Table 2) and the number of teeth fulfilling each criteria in each patient (Table 3). The registration was performed by two observers

(WH and J-I S) who together went through all collected study casts and clinical photos, discussed the presence or absence of the criteria and the number of teeth affected by those criteria in each patient and came to an agreement. Only criteria that were considered obvious dental wear defects were recorded and scored. That was to avoid exaggerating the amount of pathological TW in the study population. The process was performed during three 8 -hs sessions within the same week. The examination took place in a meeting room with 2 large screens and standard lighting conditions.

Later, the same observers went separately through the study casts and photos of 41 randomly selected patients in order to assess the intra- and inter-observer reliability. Between and within the sessions, the two observers were blinded to the outcome of the other observer's examination as well as to their own previous observations. The time elapsed between the two registrations was 2 months for the first observer and 3 months for the second observer. Both observers were recalibrated on the same day before thier second registration with the use of study casts and photos for 5 participants who were not included in the second registration.

2.3. Statistics

Simple t-tests were used to compare age, total number of maxillary and mandibular teeth, and the number of maxillary and mandibular teeth with TW > grade 2 between the study participants in the two clusters. Chi square test was used to compare the gender in the two clusters.

Analysis of the distribution of TW > grade 2 revealed no differences between the number of teeth belonging to the same tooth group on the left or right side of the dental arches. The percentage of patients in each cluster with extensive TW in seven maxillary and mandibular tooth groups; central incisors, lateral incisors, canines, first premolars, second premolars, first molars and second molars was registered. For each tooth group, the number of patients with TWI > grade 2 on one or both of the two teeth in the same dental group were calculated. To facilitate the interpretability of the distribution of extensive wear lesions, data was presented as three pairs of maxillary and mandibular tooth groups. The first group was the anterior teeth and consisted of the central incisors, lateral incisors and canines. The second group was the premolars, consisting of the first premolars and second premolars. The third group was the molars and consisted of the first molars and second molars. McNemar tests were used to compare the differences in wear distribution in the three maxillary and mandibular tooth groups in each cluster.

Simple binary logistic regression models were used to analyze the relationship between the presence of different morphological criteria in participants who belonged to the 2 clusters. The average number of teeth per patient with the defined morphological criteria within the 2 clusters was compared by Mann-Whitney tests.

The reliability of scoring the presence or absence of the 10 morphological features was assessed by the calculation of the intra- and inter-observer agreement by linear weighted Cohen's kappa. Intra-class correlation coefficient (ICC) was used to examine the intra- and inter-examiner reproducibility of scoring the average number of teeth per patient with the defined morphological criteria. Significance level was set at $p < 0.05$ and IBM SPSS version 22 was used.

3. Results

3.1. Characteristics of study participants

Demographic characteristics, number of teeth as well as number of teeth with extensive TW in all study participants and in each generated cluster are described in Table 1.

A total of 103 patients (women = 23 [22.3%], men = 80 [77.7%]) were clustered into two subgroups; cluster A consisted of 61 patients (women = 14 [23.0%], men = 47 [77.0%]) and cluster B (women = 9 [21.4%], men = 33 [78.6%]). Mean age, range and SD for the study cohort, cluster A, and cluster B was 43.1 years (range 14–65, SD 10.2), 41.1 years (range 17–63, SD0.2), 46.0 years (range 27–65, SD 9.7) respectively. Individuals in cluster A were younger than in cluster B ($p =$ 0.015).

Individuals in cluster B had significantly fewer maxillary teeth compared with cluster B ($p < 0.001$). Yet, no significant differences could be found concerning the number of teeth with extensive TW.

3.2. Distribution of extensive tooth wear

Fig. 1 demonstrates the distribution of extensive TW in the 2 clusters represented by calculation of the percentage of individuals with TW > grade 2 and with respect to three maxillary and mandibular tooth groups. Individuals in cluster A showed a higher percentage of extensive TW in the maxilary anterior teeth and the mandibular molars tooth groups compared with the same opposing teeth groups ($P < 0.001$, $P < 0.007$ respectively). No significant difference was detected between the maxillary and mandibular premolars in cluster A ($P = 1.000$). On the other hand, participants in cluster B were characterized by having no significant differences between all three maxillary and mandibular tooth groups (anterior teeth group $p = 0.219$, Premolars $P = 0.092$, Molars $P = 1.000$).

3.3. Presence or absence of defined morphological TW criteria

In Table 2, the clusters are compared with respect to the distribution of the defined morphological TW criteria. While individuals in cluster A had a higher prevalence of the defined criteria number 1, 2, 4 and 5, individuals who belonged to cluster B had a higher prevalence of criteria number 8. Inclusion of all morphological criteria (number 1–10) in a multiple binary logistic regression model using stepwise variable selection techniques only indicated criteria number 8 to be significant (Table 2).

3.4. Average number of teeth per patient with defined morphological criteria

In Table 3, the clusters are compared with respect to the average number of teeth affected by each morphological criteria in each patient. Individuals in cluster A had the highest number of teeth fulfilling criterion number 2, while those in cluster B had highest number of teeth fulfilling criteria number 6 and 9.

3.5. Reliability of morphological criteria

Fig. 2a shows the results computed for the intra- and inter-observer agreement regarding the scores of the presence or absence of the 10 defined morphological features. The intra-examiner kappa values for the first observer were very good (0.84–1.00) and for the second observer were good to very good (0.64 - 0.94) except for criterion number 6 which was only fair (0.38). Consequently, the inter-examiner kappa values were good to very good (0.75- 0.94) except for criterion number 6 which was fair (0.46). No measure of association could be computed for criterion 3 since this criterion was a constant variable in the randomly selected 41 participants and no variations could be detected by the SPSS.

The intra-class correlation coefficient (ICC) statistics associated with intra- and inter- examiner reproducibility for scores of the average number of teeth per patient with the defined morphological criteria are shown in Fig. 2b. The intra-examiner ICC values for the first observer were excellent (0.99 -0.93) and for second observer were good to excellent (0.68 - 0.93). Accordingly, the inter-examiner ICC values were good to excellent (0.72 - 0.93).

Table 1
Gender, age, total number of the maxillary and mandibular teeth, number of maxillary and mandibular teeth with TW > grade 2 in the study participants.

	Total	Cluster A	Cluster B	*P*
Number of patients	103	61	42	
Gender				
Number of women	23 (22.3%)	14 (23.0%)	9 (21.4%)	0.855
Number of men	80 (77.7%)	47 (77.0%)	33 (78.6%)	
Age (years)	43.1 (10.2) 17-65	41.1 (10.2) 17-63	46.0 (9.7) 27-65	0.015
Number of teeth	27.1 (1.3) 22-28	27.4 (1.0) 24-28	26.6 (1.6) 22-28	0.002
Maxillary	13.6 (0.8) 10-14	13.8 (0.5) 12-14	13.2 (1.0) 10-14	< 0.001
Mandibular	13.5 (0.9) 10-14	13.6 (0.7) 12-14	13.4 (1.1) 10-14	0.130
Number of teeth with TW > grade 2	16.0 (6.0) 4-28	16.4 (6.3) 4-28	15.5 (5.7) 6-28	0.442
Maxillary	9.0 (3.2) 2-14	9.2 (3.3) 2-14	8.7 (3.0) 4-14	0.431
Mandibular	7.0 (3.7) 0-14	7.2 (3.8) 0-14	6.7 (3.7) 1-14	0.572

Values represent mean (SD) and rang.

4. Discussion

In the current study, the clinical presentation of wear lesions in two phenotypes of TW patients was assessed on the bases of distribution and morphological features of the worn dentition.The findings suggested that the 2 clusters, indeed, differed with respect to the distribution and morphological characteristics of wear lesions that may develop as a consequence of underlying background factors. This implies that certain clinical features may be useful to distinguish individuals who belong to a specific TW cluster. The criterion of having similar degree of occlusal/incisal wear in both arches might be most beneficial for this purpose.

Studies reported that erosive lesions involve mostly the palatal surface of the maxillary incisors and the occlusal surfaces of the mandibular first molars [27]. It was also suggested that dental tissue softened by erosion can be removed from the palatal surface of upper anterior teeth by the abrasive effect of the tongue [28,29]. Moreover, the submandibular and sublingual saliva affords relatively good protection for mandibular anterior teeth against erosion, but these teeth commonly show incisal attrition [25,30]. Individuals in cluster A showed a higher percentage of extensive TW in the maxilary anterior teeth and the mandibular molars tooth groups compared with the same opposing tooth groups. On the other hand, participants in cluster B were characterized by the lack of significant differences between all three maxillary and mandibular tooth groups. These results may indicate that patients in cluster A have a relativly dominat chemical background whereas patients in cluster B appear to have a relativly dominant mechanical background.

While the first 7 morphological criteria in Tables 2 and 3 were supposed to represent presumed morphological criteria for chemical TW, the last 3 criteria may represent presumed criteria for mechanical TW [26,31–33]. The fact that individuals in cluster A had a higher prevalence of criteria number 1, 2, 4, 5, and higher number of teeth fulfilling criterion 2 may further substantiate the notion of the dominant chemical background for the TW in this cluster. Likewise, individuals who belonged to cluster B had a higher prevalence of criterion number 8 and higher number of teeth fulfilling criterion number 9 could support the proposal of the dominant mechanical background for the TW in this cluster. Results obtained from inclusion of all morphological criteria in a multiple binary logistic regression model indicated that criterion number 8 was the most significant criterion that may be used to differentiate between individuals in the 2 clusters (Table 2). On the other hand, the 2 groups overlapped and shared the presence of criteria number 3, 6, 7 and 9 whereas only few participants had criterion number 10. Typical cases representing the clinical presentation of wear lesions in cluster A and B are shown in Fig. 3a and b.

A quite large number of variables were used to cluster 125 patients in the previous study [22]. The conservative Bonferroni correction was used to adjust the significance level, among other things, to avoid exaggeration of the obtained results. Consequently, age was not considered amongst the important predictors which ruled the clustering process although the *P* value was 0.015. From a statistical perspective, every additional variable requires an over-proportional increase in observations to ensure valid results. Fewer variables or larger sample size might result in a more considerable difference in age between individuals assigned to the two clusters. Other studies showed that the older the individual, the greater the degree of tooth attrition [34]. Incisal and occlusal TW is therefore used for age determination in historical skull materials [35]. Moreover, there are also indications that erosive TW is more prevalent in younger age groups [36,37]. It has been suggested that the more advanced the TW, the more reliably it could be graded when qualitative assessment of severity of wear is performed [38]. A simplified variant for TWI was used in our previous study and the level for extensive TW were considered > grade 2. Accordingly, teeth with > grade 2 TW on any scorable surface were registered and given only one score regardless of the number of worn surfaces. Extensive wear lesions were registered and presented to show that the included study participants had an extensive degree of TW and high number of pathological wear lesions (Table 1).

Clinical photos and study casts have been used in several studies to score TW lesions and evaluation of TW indices since they allow several observers to perform examination under standardized conditions and without any time restrictions [39]. The reliability and validity of the registrations of erosive wear lesions on clinical photographs and study models was assessed by a group of examiners who found that both seems to be suitable for this purpose [39]. Photos were preferable over study casts when differentiation between enamel lesions and lesions with dentin exposure was required. Ganss et al. suggested, in a cross sectional and longitudinal study, that the advantage of the use of study casts was that the evaluation could be performed repeatedly by viewing them from all sides under optimal illumination and without any pressure of time [40].

Since the study cohort was collected from a consecutive series of patients that were referred to a specialist department in order to receive prosthetic rehabilitation, the included individuals had extensive wear lesions. It is known that patients often seek treatment when TW is well advanced, at which time the esthetic is notably affected and/or teeth are hypersensitive [41]. Different lists and diagnostic trees over defined morphological criteria have been recommended in the literature [3,16,24,31,32]. Those recommendations are collected from clinical observations and are not tested with the use of a special approach. To our knowledge, the current paper represents the first clinical trial which tested such criteria in adult patients where a study manual was developed and followed, and study casts and standardized clinical photographs were used for registration. Only criteria that could be detected by the use of study casts and clinical photos were used. The reproducibility of the applied method were verified by examining the intra- and inter-examiner reliability by Cohen's kappa and intra-class correlation coefficient. Involving patients with early or less extensive wear lesions may require a further intra oral examination for the registration of TW

Table 2
Distribution of patients with different morphological criteria in the 2 clusters and the odds of patients belonging to cluster A and B.

Morphological criteria	Cluster A (n = 61)	Cluster B (n = 42)	OR (95% CI)	P	Nagelkerke R^2
1.Thin and irregular incisal enamel resulting in increased translucency (Only 13-23 are included)	38 (62%)	17 (40%)	0.412 (0.184; 0.920)	0.031*	6.1%
2. More extensive wear in the upper anterior teeth than the lower anterior teeth (Only13-23 and 33-43 are included)	45 (74%)	21 (50%)	0.356 (0.155; 0.817)	0.015*	7.7%
3. Concavities and cupping on the occlusal surfaces (Only Premolars and molars are included)	59 (97%)	40 (95%)	0.678 (0.092; 5.013)	0.703	0.2%
4. Loss of convexities on the palatal side of maxillary teeth (Only 17-27 are included)	46 (75%)	19 (45%)	0.269 (0.116; 0.625)	0.002*	12.2%
5. Intact palatal border of enamel along the gingival margin of maxillary teeth (Only 17-27 are included)	44 (72%)	19 (45%)	0.319 (0.140; 0.729)	0.007*	9.6%
6. Margins of existing restorations may stand higher than surrounding tooth structure (Only premolars and molars are included)	44 (72%)	30 (71%)	0.966 (0.404; 2.312)	0.938	0.0%
7. Cervical/buccal lesions that are more broad than deep (All teeth)	38 (62%)	27 (64%)	1.089 (0.482; 2.465)	0.837	0.1%
8. Similar degrees of occlusal/incisal wear in both arches (All teeth)	27 (44%)	34 (81%)	5.352 (2.130;13.444)	< 0.001*	17.8%
9. Wear between 2 or more moving/functional surfaces and with matching facets (All teeth)	48 (79%)	39 (93%)	3.521 (0.936; 13.240)	0.063	5.3%
10. Localised wear of buccal and lingual surfaces with certain malposition or interferences (All teeth)	16 (26%)	8 (19%)	0.662 (0.254; 1.726)	0.399	1.0%

n = number of participants. Values represent number (%) of participants. Odds ratios with 95% confidence interval (CI) in parentheses.

criteria and even the use of other recommended morphological criteria. Not to forget, the registrations of these criteria in the current study were performed by 2 experienced specialists, such task might be more difficult for general dental practitioners.

Although there is no general accepted rule of thumb regarding minimum sample size when applying cluster analysis, the quality of the final cluster solution use to be based on the silhouette measure, the ratio of sizes (largest cluster to smallest cluster), practical grounds as well as solution's interpretability [42]. An important issue that should be considered with this mathematical approach is the decision regarding the number of clusters that can be derived from the available data [43]. According to previous knowledge about TW, a manageable number of clusters was deemed to be in the range of two to three, otherwise the model would not be interpretable. The unsupervised modelling was used in the previous study and the final cluster model consisted of 2 interpretable clusters [22]. Both chemical and mechanical background factors were included in the final cluster model in order to be able to describe the final cluster members and to avoid misapplication or abuse of clustering technique. Results collected from the current study indicated that there is a relationship between the presumed etiological factors for TW and the clinical presentation of the worn dentition. This may strengthen the choice of the final cluster model.

Whether or not specific etiological factors can be determined from case history, a protocol for prevention of progression of pathological TW can be initiated if the chemical or/and mechanical impacts on teeth surfaces are distinguished. Clinically, it is known that there is clear inter-subject variation in the involvement of attrition, erosion and abrasion and some of these processes or risk factors may be more relevant than others at certain time [44]. For those reasons, it is not always easy to identify the background factor(s) by the collection of case history or performance of other investigations. Furthermore, case history does not always justify a specific chemical or mechanical etiology, especially when the appearance of tooth damage suggests a different diagnosis [45]. That might be ascribed to individual-related factors such as differences in saliva, composition- and degree of hardness of teeth and genetic factors [6,46]. Results obtained from this study showed that adult TW individuals with presumed chemical background can be characterized by having thin and irregular incisal enamel that results in increased translucency, more extensive wear in the upper anterior teeth than the lower anterior teeth, loss of convexities on the palatal side of the maxillary teeth and an intact palatal border of enamel along the gingival margin of the maxillary teeth. It has been mentioned that the preserved band of enamel or pseudo-chamfers which present along the gingival margins of teeth affected by erosion, are perhaps due to the protection offered by some plaque remnants or gingival crevicular fluid [18,25]. Conversely, individuals with presumed mechanical background can be characterized by having similar degree of occlusal/incisal wear in both arches and matching facets between 2 or more moving /functional surfaces. The use of characteristic clinical features, as those tested in the current study, may facilitate the identification of patient-related risk factors and promote the providence of the appropriate preventive and therapeutic measures.

One of the difficulties in the design of this study, was the lack of a gold standard in terms of the evaluation of clinical features of different wear lesions with the use of photos and study casts. As far as we know, evaluation of the clinical morphological features of TW had not been reported in previous studies. Yet, there are many studies that examined the reliability of different TW indices [47–50]. Evaluation of TW indices was presented in a review which pointed out the lack of standardization of terminology and vague definition of criteria as limitations that allows for a wide interpretation of severity scores [2]. The World Health Organization advised that the reliability of clinical measures should be a part of oral health reports, since the results of measurement error are serious in research settings [51]. In an attempt to avoid diagnostic uncertainties in observing TW morphologies in the current study,

Table 3
Average number of teeth per patient with the defined morphological TW criteria in the 2 clusters.

Morphological criteria	Cluster A mean, range, SD (n)	Cluster B mean, range, SD (n)	*P*
1.Thin and irregular incisal enamel resulting in increased translucency (Only 13-23 are included)	3.0, 1-6, 1.4 (114)	2.5, 1-4, 1.0 (43)	0.253
2. More extensive wear in the upper anterior teeth than the lower anterior teeth (Only 13-23 and 33-43 are included)	5.4, 2-6, 1.0 (244)	4.8, 1-6, 1.5 (100)	0.031*
3. Concavities and cupping on the occlusal surfaces (Only premolars and molars are included)	9.1, 1-16, 4.8 (539)	8.3, 1-16, 4.4 (332)	0.710
4. Loss of convexities on the palatal side of maxillary teeth (Only 17-27 are included)	5.9, 2-14, 2.8 (272)	5.4, 1-12, 2.4 (102)	0.659
5. Intact palatal border of enamel along the gingival margin of maxillary teeth (Only 17-27 are included)	5.8, 2-14, 2.7 (256)	4.9, 1-12, 2.8 (93)	0.321
6. Margins of existing restorations may stand higher than surrounding tooth structure (Only premolars and molars are included)	4.6, 1-12, 3.3 (201)	5.6, 1-13, 3.1(167)	0.045*
7. Cervical/buccal lesions that are more broad than deep (All teeth are included)	7.5, 1-21, 5.6 (284)	8.1, 1-16, 6.0 (219)	0.444
8. Similar degrees of occlusal/incisal wear in both arches (All teeth are included)	11.9, 2-28, 7.6 (318)	12.4, 2-24, 6.0 (421)	0.186
9. Wear between 2 or more moving/functional surfaces and with matching facets (All teeth are included)	12.8, 2-28, 7.3 (616)	15.1, 5-24, 4.8 (587)	0.014*
10. Localised wear of buccal/lingual surfaces with certain malposition or interferences (All teeth are included)	7.5, 2-14, 3.9 (120)	7.3, 1-18, 5.6 (58)	0.806

n = total number of teeth with TW criteria in parentheses.

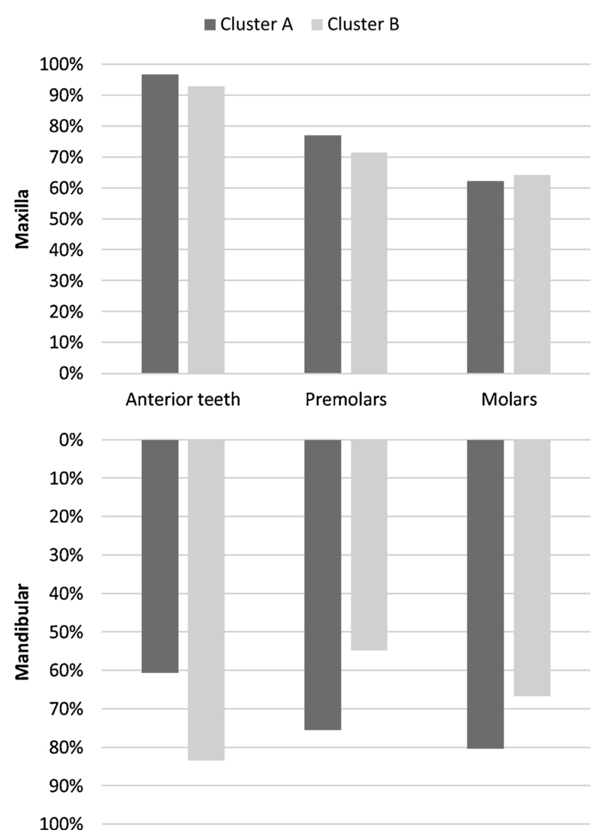

Fig. 1. Distribution of extensive tooth wear. Percentage of individuals in cluster A and cluster B with TW > grade 2. Anterior teeth = central incisors, lateral incisors and canines. Premolars = 1st premolars and 2nd second premolars. Molars = 1st molars and 2nd molars.

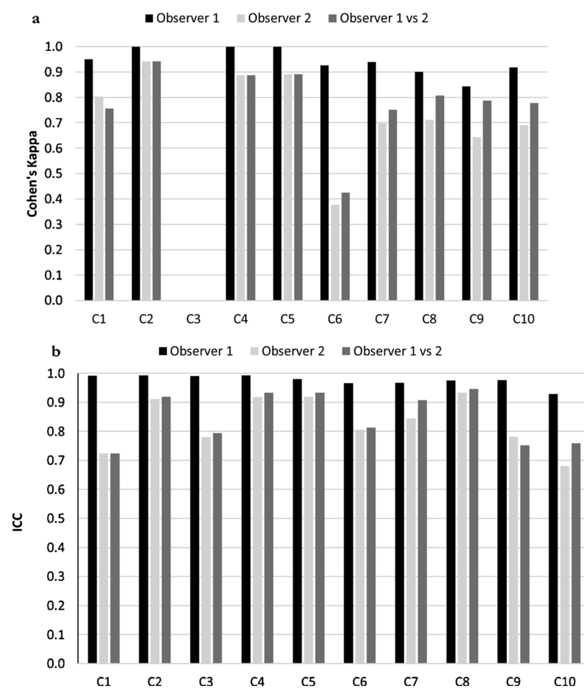

Fig. 2. (a) Results for intra- and inter-observer agreement concerning the presence or absence of the defined morphological TW criteria, measured by linear weighted Cohen's kappa. No measure of association were computed for C3 since the variable was constant in all participants. (b) Results for the intra- and inter-observer reproducibility of scoring the average number of teeth per patient with the defined morphological criteria (C1-C10), measured by intra-class correlation coefficients (ICC).

evaluation and registration was performed by 2 experienced examiners who together went through photos and study casts and thereby considered their first registration as a reference. To ensure the reproducibility of the applied method, the inter- and intra-examiner agreement results for the 2 observers were calculated. As recalibration turned out to improve the reliability for assessing clinical variables and diagnosis, both examiners were recalibrated before the second registration [52]. Overall, the results demonstrated good or excellent levels of agreement except for criterion number 6. The difficulty to identify this particular criterion by the second observer might be attributed to a less stringent definition or to the fact that most of these patients had modern composite restorations instead of amalgam that may be easier to identify in connection with this criterion.

The other issue is that the current study cohort consisted of adult patients with a mean age of 43.1 years. The majority of the previous epidemiological studies were performed on children and young adults since it is easier to recruit school children [40,53]. Unlike wear lesions in children and adolescents, the identification of wear lesions in adult patients may be complicated by the fact that many wear lesions are already restored with direct or indirect restorations. This was balanced by the use of strict dental inclusion criteria and by the fact that only criteria that were considered obvious dental wear defects were recorded and scored.

There are several important implications that stem from this work and the previous work [22]. In contrast to previous studies on TW, the present approach has several distinct features. A much larger set of risk factors for TW were used while previous studies used to include individuals with a limited number of background factors [10,54,55]. The achievement of data simplification by the use of clustering methods was shown; instead of analyzing all observations as unique, they could be

Fig. 3. (a) Typical example of a female patient in cluster A, age 52 years, with a history of gastric reflux and acidic diet consumption fulfilling criteria 1, 2, 3, 4, 5, 6 and 7. (b) Typical example of a male patient in cluster B, age 55 years, with a self-report of sleep- and awake bruxism, heavy labour, heavy sport exercises (body builder) and snuff-use fulfilling criteria 3, 7, 8 and 9.

viewed as a member of a cluster and profiled by its characteristics. The clinical applications of such methodology was demonstrated which enabled to study the clinical characteristics of the generated clusters. Other characteristics like occlusion and occlusal loads in relation to varying intensity, muscle activates, facial biotypes, and biting/chewing behavior are possible issues to study in such clusters. Moreover, the application effect of preventive measures on TW progression in a specific cohort of patients (e.g. individuals with different intrinsic and/or extrinsic erosion) is also possible to study by the use of such mathematical approach. Since cluster membership can be identified quickly and accurately, the methodology can be used in a clinical setting. For example, one could assign future individuals to clusters by the use of a small set of variables, e.g. a set of short questionnaire, putative etiological variables or even morphological features.

The performed multidimensional TW research suggests that generalizability is likely but needs to be replicated in future studies. Separate cluster analysis can even be performed on a control group if comparison is desired in future studies. Yet, it is worth to remember, especially when longitudinal studies are carried out, that one's cluster assignment might be temporary stable since new future factors (positive or negative) can permit an individual to move from one cluster to another. We believe that statistical clustering or categorization techniques based on TW characteristics and morphology may be a useful screening tool in the development of TW classifications that ultimately should guide therapeutic options or have prognostic significance. Just like other diseases/conditions, the application of this mathematical technique to disease processes can be useful in helping us understand human pathology, particularly in large datasets such as population registries [14].

5. Conclusion

With respect to the distribution and morphological characteristics of wear lesions that may develop as a consequence of underlying background factors, two phenotypes of TW patients defined by cluster analysis differed from each other but with a certain degree of overlap. The findings showed that the clinician may use certain clinical features to distinguish between individuals who belong to a specific TW cluster with presumed chemical or mechanical etiology. The null hypothesis that the clinical presentation of the worn dentition in two phenotypes of TW patients did not differ in terms of distribution and morphology of wear lesions, was rejected.

Conflict of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jdent.2019.05.028.

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