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Mapping, profiling and clustering of pressure pain threshold (PPT) in edentulous oral mucosa

T. Ogawa[a,*], M. Tanaka[b], T. Ogimoto[b], N. Okushi[b], K. Koyano[b], K. Takeuchi[a]

[a]*Division of Advanced Prosthodontics, Biomaterials and Hospital Dentistry, Weintraub Center for Reconstructive Biotechnology, UCLA School of Dentistry, P.O. Box 951668, 10833 Le Conte Avenue, B3-088 CHS, Los Angeles, CA 90095-1668, USA*
[b]*Department of Removable Prosthodontics, University of Kyushu, Kyushu, Japan*

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Summary *Objectives*. Edentulous oral mucosa involves different tissue types, various innervation and wound healing process. We hypothesized that pressure pain threshold (PPT) of edentulous oral mucosa varies significantly among different regions. The objective of this study is to examine regional differences and correlations of PPT in edentulous oral mucosa.

Methods. Pain threshold (PPT) was measured at 112 sites in 15 edentulous patients using an electric-controlled pressure algometer. PPT mapping was created by the level of PPT, and PPT clustering was undertaken based on the inter-site correlation of PPT.

Results. PPT increased from the anterior to posterior alveolus in both maxilla and mandible, but decreased from the anterior palate to the posterior palate. PPT decreased from the ridge crest to the buccal vestibule. The inter-site difference was four fold within the maxilla and 2.4 fold within the mandible. Principal component analysis applied on PPT inter-site correlation matrix revealed that the maxilla and mandible could be differentiated statistically. The maxilla and mandible were divided into three and four clusters, respectively.

Conclusion. These results demonstrate that different areas of edentulous oral mucosa have different PPT and that the PPT varies proportionally in selected areas, providing useful diagnostic and therapeutic information in removable prosthodontics and a new opportunity for understanding pain underneath the denture.

Introduction

When subjected to denture wearing, oral mucosa becomes a significant source of mechanoreceptive functions normally undertaken by periodontal or other receptors.[1,2] Given the potential movement and loading on dentures oral mucosa must resist the various pressures developed during functional and parafunctional behaviors. It is not surprising therefore, that pain in the supporting mucosa is the most common complaint among those experiencing problems with their dentures.[3]

Edentulous oral mucosa exhibits anatomical and physiological variations in different regions of

*Corresponding author. Tel.: +1-310-825-0727; fax: +1-310-825-6345.
E-mail address: tack@dent.ucla.edu

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the mouth. When teeth are extracted, formation of keratinized, scarless tissue occurs through a unique biological process.[4-6] Thickness of the healed mucosa is not related to the original gingival thickness.[5,7,8] Epithelial and connective tissues exhibit different mechanical properties, such as elasticity, because of their own histological structure.[9-11] Various branches originated from the trigeminal nerve innervate oral mucosa.

Pressure pain threshold (PPT) is defined as the minimum pressure that induces pain. Measurement of PPT using a pressure algometer provides reliable data for quantifying various pain sensations in muscles and at trigger points in orofacial and other areas.[12-15] Studies investigating PPT in the oral mucosa have been limited.[16,17] Since the primary function of edentulous oral mucosa is load bearing when subjected to denture wearing, assessing PPT is necessary for understanding the basis of its somatosensory characteristics. We hypothesized that PPT of edentulous oral mucosa varies significantly among different regions. If there would be a variation of PPT among different areas of edentulous oral mucosa, it should be useful information in determining and validating potential stress-bearing sites for dentures. The objective of this study is to examine regional differences and correlations of PPT in edentulous oral mucosa.

Materials and methods

Subjects

To examine the location of natural teeth relative to anatomical landmarks, 20 dentate adults, 10 males and 10 females (ages 20–29 years; mean age = 25.2 years), were recruited from the faculty and staff of the School of Dentistry, Kyushu University. To measure PPT of edentulous oral mucosa, 15 edentulous patients, eight males and seven females (age range from 62 to 85, mean age of 74.9 years old) were recruited from complete denture patients pooled in the prosthodontics clinic in Kyushu University Dental Center. All subjects had worn complete dentures on both jaws for three years or more.

Pressure pain threshold measuring device

The electric-controlled pressure algometer designed for use in oral mucosa was used.[18] The algometer consists of a pressure-sensitive strain gauge (LM3KA, Kyowa Dengyo, Tokyo, Japan) and a signal-recognizing hold switch (Fig. 1A and B). Pressure exerted on the tip was detected by the strain gauge, and the signal was amplified and transmitted to a personal computer (Fig. 1C). The use of a personal computer allowed a visualization of magnitude and duration of applied force and their control (Fig. 1D).

PPT measurement

On the day of the recruitment, maxillary and mandibular impressions were taken. All designated measuring sites were marked on the casts based on the data from the dentate subjects and a custom stent was fabricated on the cast (Fig. 1E). The day before the measurement, the subjects were instructed to remove dentures overnight and visit the clinic without wearing the dentures, eating or drinking. All measuring sites determined on the cast were transferred to the mucosal surface by marking with a waterproof pen through the holes made on the stent (Fig. 1E). The marking was undertaken gently so as not to stimulate the sensory nerve. The rater touched the tip of the algometer perpendicularly to the surface of the target mucosa and increased the load at a controlled load-rate of 50 g/s (Fig. 1F). The subject was instructed to fix his/her attention on the test stimulus and to press the hold switch button when the pressure changed from a feeling of 'being pressed' to 'initial pain recognition'. Pressure at this point was defined as PPT (Fig. 1D). The process was delivered twice with a 3 min interval between measurements and the mean values were used for statistical analyses.

Measuring sites

The PPT was measured at 112 sites (60 sites on the maxilla, 52 on the mandible). The measuring points were consistently applied for each subject. The standardization of the measurement site is described in Fig. 1G. First, virtual locations of natural teeth were determined relative to the anatomical landmarks based on the data from the 20 dentate subjects. Using these tooth positions as reference levels, the measuring sites were evenly distributed to cover the entire edentulous oral mucosa. Each site was labeled using linguo-buccal (A–H) and antero-posterior (0–9) levels (Fig. 1H). Five variations regarding the order of measurements were prepared without separating the maxilla and mandible, and randomly applied. All measurements were made by the same rater. For selected ridge sites (3E, 5E and 7E in the maxilla and 3C, 5C and 7C in the mandible), the PPT was measured at both right and left side, and the inter-side difference and correlation were examined.

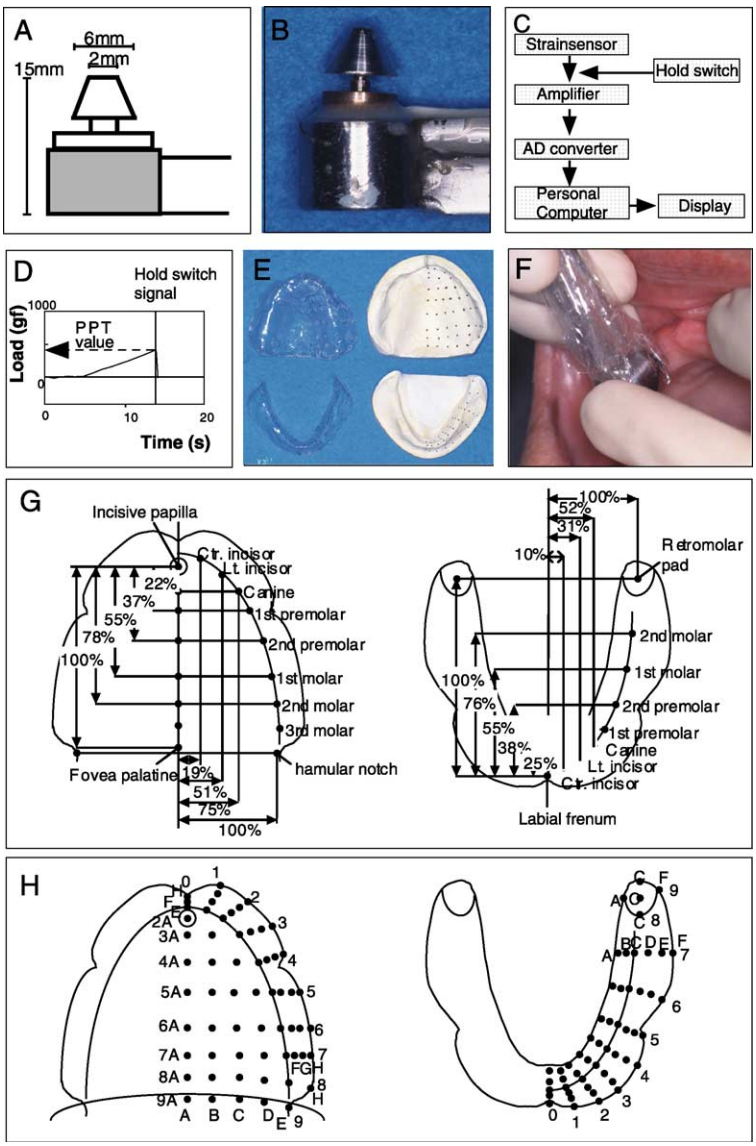

Figure 1 Diagram (A) and photograph (B) of the tip of electronic-controlled pressure algometer. (C) Block diagram of the pressure-pain threshold (PPT) measurement system. (D) Schematic description of computer monitoring during PPT measurements. The PPT is defined as the load where a hold switch mark appears on the plot. (E) PPT measuring sites marked on casts and resinous stents for transferring the measuring sites intraorally. (F) PPT measurement. (G) Location data of individual teeth derived from 20 dentate subjects. (H) 112 (60 on the maxilla, 52 on the mandible) PPT measuring sites based on the tooth location data (panel G). Linguo-buccal levels are labeled level A–H, while antero-posterior levels are labeled as level 0–9.

Based on the results, PPT measurement for the rest of the measuring site was made only unilaterally on the randomly chosen side; seven subjects had the measurement on the left side, and eight subjects had on the right side.

Statistical methods

Analysis of variance (ANOVA) at a significance level of 5% was used for data analysis, using the Bonferroni method for multiple comparisons. The *t*-test was used to compare PPT between the maxilla and mandible at matching sites and to test the PPT stability between sides. Pearson's correlation coefficient was also used to evaluate the PPT stability between sides. Principal component analyses (PCA) with promax rotations were performed on correlation coefficient matrixes of PPT values to explore clusters that were characterized by inter-site PPT relationship. The number of PCA components was determined in order to explain over 80% of the total variance. These analyses were preformed using SPSS (Version 11.0) statistical software.

Results

PPT inter-side stability and inter-jaw difference

There was no inter-side PPT difference between the three sites measured (3E, 5E and 7E in both maxilla and mandible) ($p > 0.05$, t-test). There was a strong inter-side PPT correlation ranging from 0.785 to 0.987 for these sites. Therefore, the following PPT measurement was performed only on the randomly chosen side as mentioned in Section 2.

Inter-jaw comparison at matching sites along the ridge crests (upper level E vs lower level D) indicated that the PPT is higher the maxilla compared with the mandible from the canine to the second molar site (t-test, $p < 0.05$) (Fig. 2A, right). The difference was nearly two-fold in molar sites, although, in the areas toward the buccal vestibule, such differences were not found (Fig. 2A, right and middle).

PPT profile

Representative maxillary (Fig. 2B and C) and mandibular (Fig. 2D and E) PPT profiles are presented based on the data from 15 edentulous subjects. The profiles are created in the coronal (Fig. 2B and D) and sagittal (Fig. 2C and E) planes. There was a significant effect of palato-buccal level on maxillary coronal PPT along selected levels (level 3–8). In the level 5 profile (Fig. 2B), PPT was greater on the palate than on the buccal region peaking before reaching the ridge crest (ANOVA, $p < 0.0001$). The PPT decreased while approaching the buccal vestibule. The maxillary sagittal profiles were significantly related to the antero-poterior level at all but the level H (Fig. 2C). Level A profile (palatal mid line) showed a PPT change decreasing toward the posterior end ($p < 0.0001$). Conversely, PPT increased toward the posterior along the ridge crest (level E) and along the buccal alveolus (level F) ($p < 0.0001$). The PPT dropped at the hamular notch as seen at site 9E.

As shown in the mandibular frontal profile at levels 7 and 9 (Fig. 2D), the PPT was the greatest on the ridge crest (sits 7C and 9C). The mandibular sagittal profile was characterized by increasing PPT toward the posterior as seen in the levels C, D and F ($p < 0.0005$) (Fig. 2E). The profile along the lingual floor (level A) did not show antero-poterior level-dependent PPT fluctuation ($p = 0.3200$).

PPT mapping

Maxillary PPT mapping indicated that PPT was high in the mid palatal area up to the ridge crest (Fig. 3A). In the buccal region, the PPT decreased as it approached the vestibule. In the ridge crest and buccal alveolar regions, the PPT increased as measurement moved posteriorly. The PPT consistently showed low values in the posterior boundary of the palate from the fovea palatine to hamular notch. The smallest PPT, 149.4 gf, was found at site 9E, while the greatest PPT, 599.9 gf, was found at site 7E (arrow heads, Fig. 3A); the difference between them was four-fold.

The anterior mandible generally showed low PPT (Fig. 3A). The PPT on the ridge crest increased posteriorly up to the inferior half of the retromolar pad. The buccal shelf area showed higher PPT than other regions, while PPT along the most lingual level consistently showed low PPT. Site 0D showed the smallest PPT (127.9 gf); sites 7C and 8C showed the greatest PPT (310.9 gf) (arrow heads, Fig. 3A). Thus, the PPT fluctuation was a 2.4 fold within the mandible.

Each maxilla and mandible was divided into nine regions (Fig. 3B). First, the area was divided into the buccal alveolar, ridge and lingual/palatal zones. Secondly, each zone was divided into anterior, mid and posterior parts. Anatomical factors was also taken into consideration to reflect clinical significance; for instance, hamular notch (9E) was included in the region nine to form 'posterior end of the maxilla' instead of including in the region six. This revealed a common trend for PPT to increase toward the posterior in the buccal and ridge regions both in both jaws. PPT decreased toward the posterior in the palate and did not show fluctuation in the mandibular lingual region. PPT was elevated in segments 5–7.

Clustering

To validate use of PCA in clustering oral mucosal PPT, PCA was applied to collective PPT data incorporating the maxilla and mandible. The results revealed that the maxilla and mandible were distinctively designated by components 1 and 2, respectively, with an explanatory percentage of 76.5% (Fig. 4A). This indicated a proportional PPT variation within each jaw, but not between the jaws. The maxilla was divided into three clusters by its PPT variation with a high explanatory percentage of 85.2% (Fig. 4B). Component 1 signified a wide area that included ridge, alveolus and anterior, lateral palate. Components 2 and 3 were

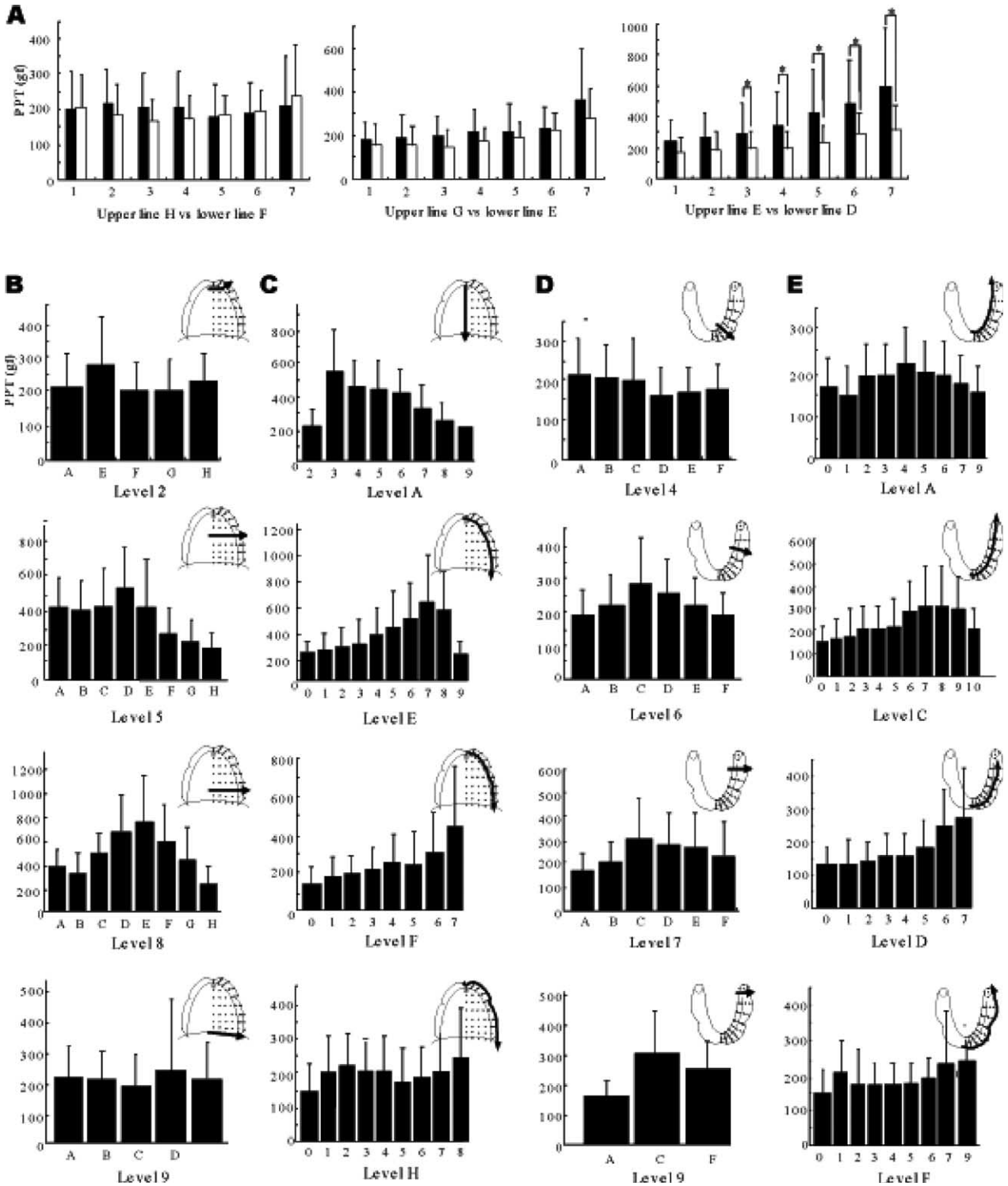

Figure 2 (A) Pressure-pain threshold (PPT) comparisons between the maxilla and mandible made at matching sites. *Statistically significant ($p < 0.05$) by t-test. ($n = 15$) (B)–(E) Representative PPT profiling showing level-dependent PPT changes in selected levels. B and D show the frontal profiles for the maxilla and mandible, respectively. (C) and (E) show sagittal profiles. The level where the histogram is made is highlighted in jaw illustrations.

located at the posterior third of the palate and around the mid line of the palate, respectively. Mandibular PCA identified four components: (1) ridge crest area, (2) buccal and lingual vestibular margin, (3) buccal alveolus and mylohyoid area and (4) anterior mandible in the order of the components, yielding an explanatory percentage of 86.0.

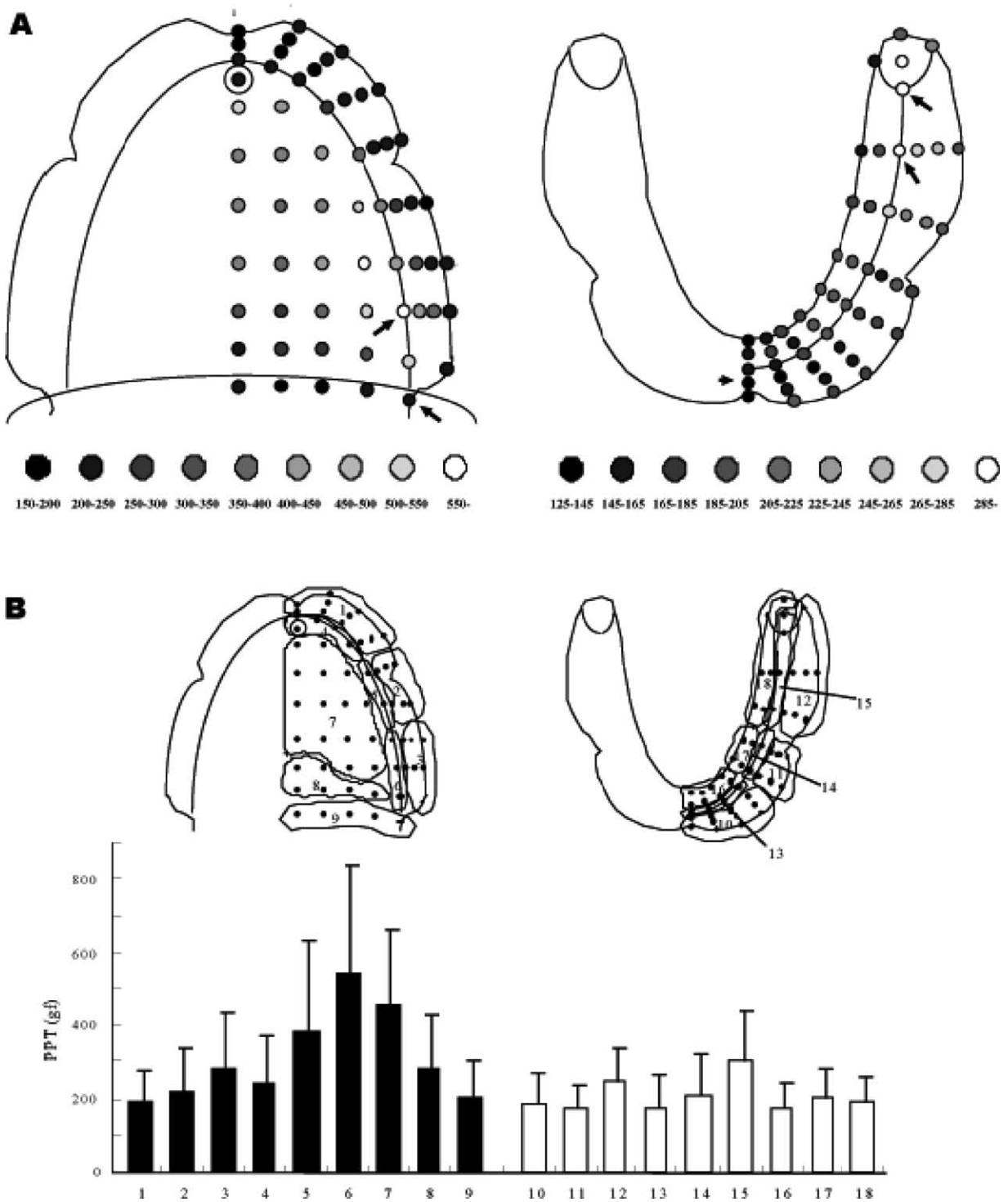

Figure 3 (A) Pressure-pain threshold (PPT) mapping in the maxilla (left) and mandible (right). An arrayal plot of averaged PPT value from 15 edentulous subjects is displayed as a color gradient (gf). In the maxilla, minimum PPT was found at the hamular notch (150.2 gf), and the maximum PPT is found at the posterior ridge crest (599.9 gf) (arrows), while in the mandible, minimum PPT is found at the anterior vestibule (127.9 gf), and maximum PPT is found in the posterior ridge crest and anterior end of the retromolar pad (310.9 gf) (arrows). (B) Geography-based PPT mapping. Black bars, maxillary PPT; white bars, mandibular PPT.

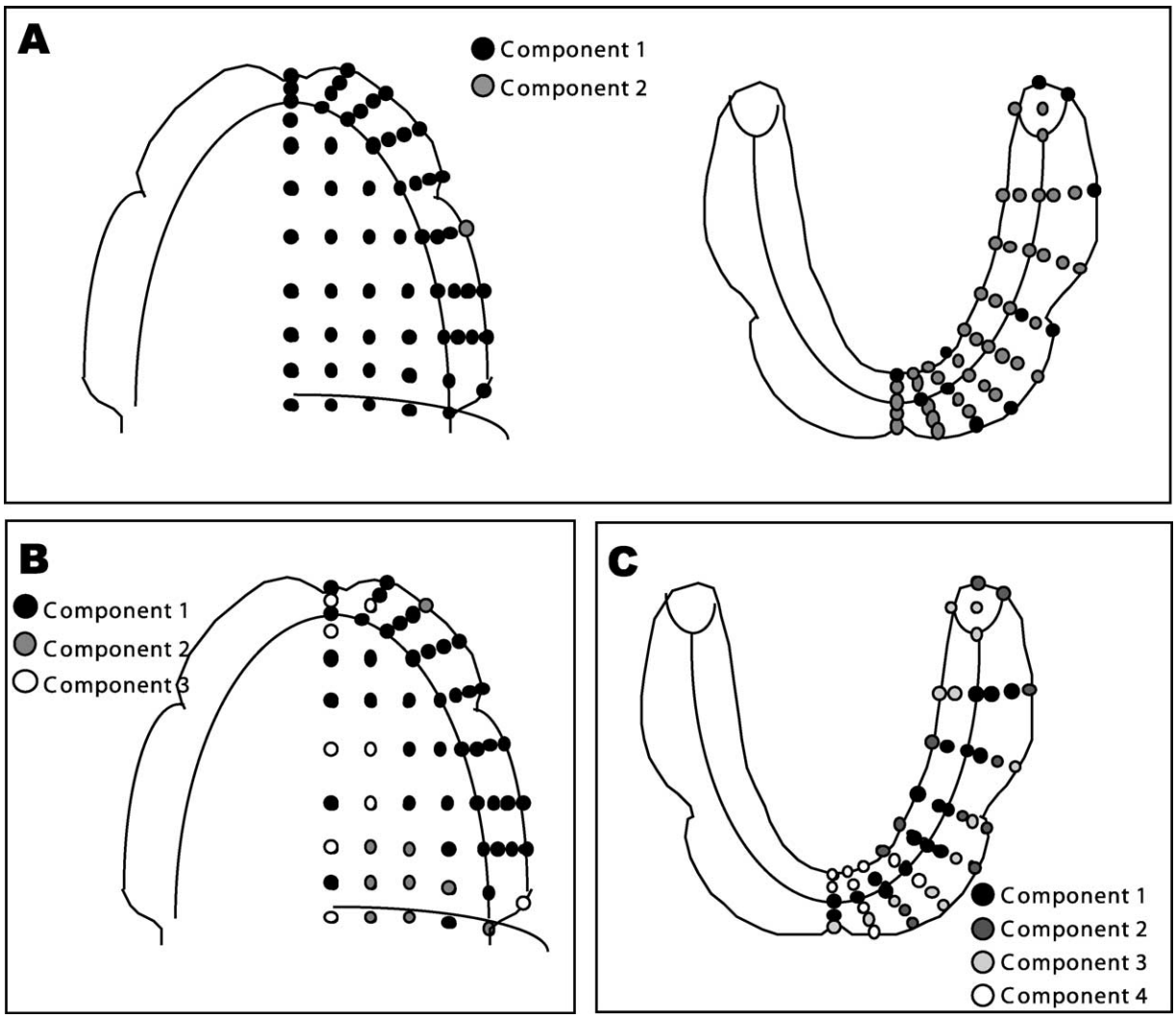

Figure 4 Pressure-pain threshold (PPT) clustering using the principle component analysis (PCA) applied to the matrix of inter-site correlation coefficient of PPT. (A) A set of the maxilla and mandible captured by two components (B) The maxillary PPT was clustered into three factors. (C) Four factors that covered the mandible.

Discussion

The present results revealed that the maxilla showed higher PPT than the mandible at matching recording sites on the ridge crest. The higher PPT of the mandible than the maxilla was also reported in a previous study that measured PPT in dentate subjects.[17] The type and mechanical property of mucosa may play a role in regulating local PPT. In edentulous patients, the thickness of the maxillary mucosa ranges 1.95–2.34 mm, and that of the mandibular mucosa ranges from 1.49 to 1.54 mm.[8] Mucosal thickness seems greater in the maxilla compared with the mandible. Although, the difference in mucosal thickness does not fully explain the two-fold inter-jaw PPT differences, disproportional changes of mucosal thickness between the maxilla and mandible after tooth extraction may induce inter-jaw PPT variation. In addition, the degree of keratinization and collagen organization of mucosa is subject to regional differences,[19] which may alter the compressibility and elasticity of oral mucosa by these histological modifications may exist between the maxilla and mandible. A greater mucosal elasticity of the maxilla may have resulted in its higher PPT than the mandible.

In both maxilla and mandible, PPT increased from the anterior alveolus to the posterior alveolus and decreased from the ridge crest to the buccal vestibule. PPT may be partially determined by the innervation patterns and receptor density. Although, details are unknown, sensory receptors are more commonly situated in the anterior part of the mouth than in the posterior part.[20] In addition, our results showed that the PPT was higher in the ridge crest compared with the vestibular areas,

suggesting that receptor density is reduced in the ridge crest compared with the vestibule. It is possible that superior and inferior alveolar nerves amputated during the tooth extraction may not re-innervate as densely toward the superficial mucosa as is the case with the innervation of the buccal and lingual vestibules.

The palate generally exhibited high PPT compared with other areas. Palatal mucosa is covered by branches from the maxillary nerve. These branches are extended through the maxillary bone and may not produce dense superficial free endings. Additionally, the lateral palate has thicker glandular tissue with a thickness ranging from 4.0 to 5.5 mm. Low receptor density, as well as thick mucosa, may be responsible for the high value for PPT determined in this region.

PCA-based clustering identifies inter-relationships among large numbers of variables and reveals any common underlying factors.[21] The PCA revealed that the maxilla and mandible are discriminated statistically (Fig. 4A), suggesting an existence of factors potentially discriminating maxillary and mandibular pain sensation. Different innervation by the maxillary and mandibular nerves, distribution of free endings, types of nociceptors and nature of mucosal tissue could be the candidate factors. The maxillary nerve innervates the majority of the maxilla, while the facial nerve innervates the posterior palate up to the hamular notch.[22] This peripheral innervation was coincident with components 1 (premaxilla, ridge and vestibular areas) and 2 (posterior third of the palate), respectively (Fig. 4B). Additionally, component 2 represents a low PPT area, despite great flexibility of the mucosa. This suggests a high, superficial nociceptor density in this area as opposed to a deep innervation pattern in the rest of the palate. Component 3 (mid line area of the palate) can be interpreted as a poor nociceptor area located at a conjunction of bilateral branching of the maxillary nerve.

Component 1 for the mandible is situated along the ridge crest, provably related to consistency in regenerated tissue type and re-innervation after tooth extraction. Component 2 consisted of the buccal and lingual vestibular margins. An elastic property of non-attached tissue is a common attribute in this clustering. Although component 3 is split into anterior buccal and posterior lingual areas, both areas are superficially innervated by the mental nerve and lingual nerves, respectively. Component 4 was located at the anterior mandible having the lowest PPT, where the superficial nerves from the labial and lingual floors meet.

Thermal stimulus[23] and laser light stimulus[24] have been successfully used for characterizing sensory and pain thresholds of the oral mucosa. However, application of PPT in the oral mucosa have been limited,[16,17] due to the physiologic and geographical aspects of oral mucosa that distinguish it from the skin or muscle tissue.[25,26] The pressure algometers designed for other parts of human body, which are equipped with a large contact point, a straight and thick access rod, and a high range of pressure-sensing, are not suitable for the oral mucosa. We previously developed a hand-held pressure algometer with a thin, bent access rod at the tip to reach any site within the oral mucosa and to apply the pressure perpendicularly on the target tissue.[18]

In determining the measurement site, this study utilized the location data of natural teeth obtained from young adults, e.g. central incisor and second molar sites. However, the drastic dimensional change of alveolar ridge and dentition occurs with increasing age and with tooth extraction. Therefore, the data from the natural dentition did not represent the location where the individual tooth was located in the edentulous subjects and were only used to regulate the measurement site as designated by various levels and lines. The age of edentulous subjects recuited in the present study ranged from 62 to 85-years-old. The effect of age on PPT of oral mucosa has never been addressed in the literature. The ridge resorption associated with age or history of denture wearing might affect endosseous sensory system. Technically, the age of subjects might have effects on the reaction time to press the switch button during PPT testing. The effect of age on PPT in edentulous oral mucosa needs to be examined.

These results provide useful diagnostic and therapeutic information for prosthodontics. There was over four-fold inter-site variation of PPT in edentulous oral mucosa, adding a new basis for understanding sensory characteristics of denture-supporting tissue. Knowledge of high-pressure sensitivity areas from the created PPT mapping may be advantageous in identifying and interpreting pain spots. Pressure areas may have a multifactorial aetiology, however, clinical and technical factors and faults for example would appear to account for many of the problems experienced. Therefore, the PPT mapping might have a role in patients who experience chronic discomfort with dentures. For instance, the mandible inherently possesses lower PPT than the maxilla along the ridge. Coverage of the retromolar pad by a denture is empirically advised as being essential to obtain stability for the mandibular denture.[27] The present

study found that PPT was high at an anterior half of the retromolar pad, but low at the posterior half, probably due to a thin, nonkeratinized epithelium.[27] High PPT found in the maxillary tuberosity and mandibular buccal shelf suggests that these advantageous stress-bearing sites may be used for load bearing with reduced potential for pain compared with other regions of the edentulous mouth.[28] The relationship between denture pain and mucosal PPT has never been addressed previously. Association of the areas having low PPT with the areas representing high prevalence of pain would be beneficial clinically. Surprisingly, the posterior end of the palate, including postdam area and hamular notch, showed the lower PPT than the rest of the maxillary mucosa, and the PPT levels were nearly identical to the ones of the mandible. The low PPT in such areas might have a role in controlling masticatory function. It will be specifically interesting to examine the relationship between the individual PPT level and maximum bite force.

Conclusions

The objective of this study was to examine regional differences and correlations of PPT in edentulous oral mucosa. Oral mucosal PPT varies greatly in edentulous mouths owing to a variety of factors, such as thickness and type of mucosal tissue, receptor density and innervation pattern. Further, the PPT varies proportionally among selected sites, resulting in the formation of several clusters. The results provide useful diagnostic information in denture dentistry and a new opportunity for understanding pain underneath the denture.

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