障害高齢者の口腔機能と低栄養

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障害高齢者とはどういうものか

「われわれはどのようにして老いていくのであろう」．この問いにあなたは答えられるだろうか．

人間は加齢とともにさまざまな心身の機能が低下していく．高齢であるほど個人差は大きく，この個人差は「同年齢の平均」との差でイメージされている．緩やかな老化という機能低下のカーブから下方に逸脱してしまったとき，障害高齢者と呼ばれるのだろうか（図1）．

「障害高齢者の日常生活自立度（1991年11月18日老健102-2号　厚生省大臣官房老人保健福祉部長通知）」[1]においては，障害を有していても日常生活が自立し外出可能であるのが「ランクJ（生活自立）」と判断される．「ランクA（準寝たきり）」では屋内での日常生活は自立しているが介助なしに外出できないもの，となる．どうやらこの境界線は，現在老年学分野で注目されている「frailty」に類似しているようである．（※ frailtyは暫定的に虚弱と訳されているが，日本老年医学会において日本語訳が検討されている最中である．）

高齢期のfrailty

高齢期におけるfrailtyとは，健康と要介護の間の中間的な段階で，「高齢期に生理的予備能が低下することでストレスに対する脆弱性が亢進し，生活機能障害，要介護状態，死亡などの転帰に陥りやすい状態で，筋力の低下により動作の俊敏性が失われて転倒しやすくなるような身体的問題のみならず，認知機能障害やうつなどの精神・心理的問題，独居や経済的困窮などの社会的問題を含む概念」[2]とされている．Frailtyの主要因としてsarcopenia（サルコペニア：筋肉減弱症）があげられる．骨格筋の減少は主に脂肪組織に置き換わるといわれ，とくに下肢筋量低下・筋力低下はふらつき，転倒，frailtyへのかかわりが強い．Sarcopeniaは複数の要因によって起こり，加齢変化や不適切な食習慣，家族関係・住居の変化や活動の低下，慢性疾患，糖尿病や腎臓病などの代謝性疾患，慢性の呼吸器疾患，消化器疾患，消耗性疾患，嚥下障害とあげれば枚挙に暇がない．高齢者医療において，これらが単独で存在することは多くはない．つまり彼らはつねに複数の慢性疾患と加齢変化，社会的変化を抱えているのであって，疾患モデルとはまったく別の視点からのサポートが必要となる．

Friedの基準は表1[3]にあげるが，ほかにもfrailtyの臨床的スクリーニングがあり[4,5]，これらの臨床的スクリーニングは，それぞれに

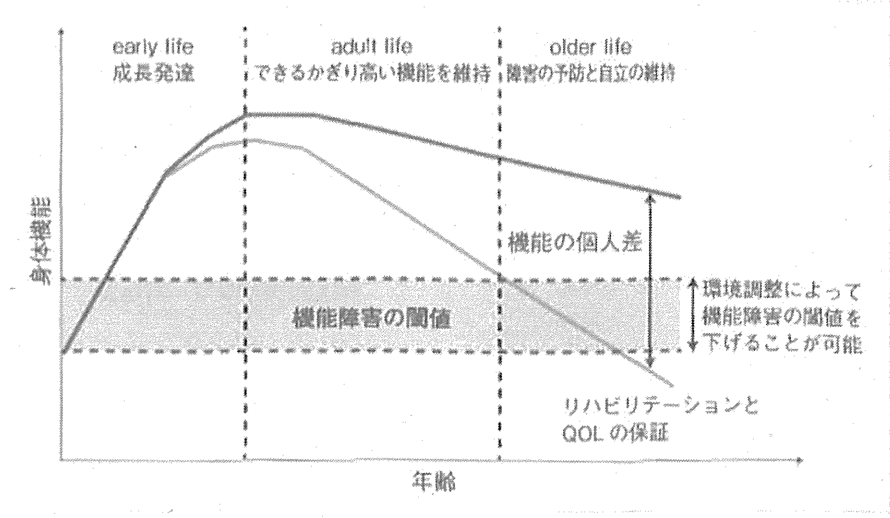

図1　高齢期における機能の個人差の例
〔WHO/HPS, Geneva : 2000（http://www.who.int/ageing/publications/lifecourse/alc_lifecourse_training_en.pdf）より筆者作成〕

表1　Cardiovascular Health Study Frailty Screening Scale

1～2 項目の該当：prefrail 3 項目以上の該当：frail
①体重減少：1 年間で 10 ポンド（約 4.5 kg）の意図しない体重の減少，あるいは 60 歳のときから 10%体重減少 ②疲労：疲労の自覚，異常な疲労感，あるいはこの 1 カ月で弱った ③活動量減少：身体活動の頻度や時間の減少（歩行，家事，家庭外の活動，ダンス，ボーリング，エクササイズ） ④歩行速度の低下：159 cm 以下の者は 4 m 歩行するのに 7 秒以上要する，あるいは 159 cm 以上の者は 6 秒以上要する，歩行速度の低下 ⑤虚弱：BMI（kg/m²）に対する握力（kg）

（Fried LP, et al. J Gerontol A Biol Sci Med Sci 2001；56：M146-56[3], Tinetti ME, et al. JAMA 2012；307：2493-4 より筆者作成）

「(3カ月ないし6カ月の，または予期せぬ)体重減少」が項目としてあげられている（日本の「基本チェックリスト」もたいへん有効なスクリーニングツールとして，海外でも評価されていることも併記しておく）．医療介入の適否判断のため，あるいは全般的日常生活機能の改善のために70歳以上にはfrailtyのスクリーニングを実施すべきで，身体的なfrailtyの改善には，(負荷や有酸素）運動や栄養・たんぱく質およびビタミンDの摂取，薬剤の多剤併用を避けることとされている[6]．栄養低下が高齢者を障害高齢者にさせるリスクを高め，そしてまた栄養のサポートがそれを改善させるのである．

さらに低栄養についても，地域高齢者における低栄養有病率は2～10%と報告されているが，地域在住の要介護高齢者では20～60%，介護施設入所高齢者では30～60%と高率に存在する[7]．低栄養は生命予後，健康障害に密接にかかわっていることから，低栄養スクリーニングによって早期の低栄養リスクをとらえる必要性があるのはいうまでもない．

加齢による食欲低下と口腔機能の変化

いかにして高齢者は低栄養状態になるのであろうか（表2）．エネルギー摂取量の低下に焦点を当てるならば，エネルギー摂取量の低

表2 高齢者の低栄養要因

社会的要因	精神・心理的要因
独居 貧困 不適切介護 社会的孤立	うつ 認知機能障害 誤嚥・窒息の恐怖 融通が利かない
疾病要因	**加齢の影響**
臓器不全 炎症性疾患 悪性腫瘍 口腔・歯科の問題 疼痛 身体機能障害（嚥下障害を含む） 薬剤（多剤投与を含む）	食欲低下 不適切食習慣

（葛谷雅文. 高齢者の栄養スクリーニングツール MNA ガイドブック CD-ROM 付：医歯薬出版；2011. p14-7[7]より）

下の原因が“食形態は不変だが食事摂取量（体積）が減少した”であるとすると，なんらかの原因による食欲低下が代表だろう．ストレスをともなうライフイベント，パートナーとの別離，独居，うつ，糖尿病，視覚・聴覚の機能低下，心臓病，認知機能低下は食欲低下を起こす要因である[6,8]．歯の喪失，義歯の不具合，咀嚼筋の筋力低下など器質的・機能的な咀嚼能力の低下や，味蕾機能低下による味覚低下，口腔衛生の低下による歯肉を含む口腔内の炎症，また粘膜疾患など口腔内のなんらかのトラブルでも食欲低下を起こす原因になる．また高齢者において頻繁にみられる薬剤の多剤併用は，思わぬ副作用が出現し食欲不振を引き起こす．

食欲低下は消化吸収能の低下によっても引き起こされるが，食事摂取量は40歳時に比較して70歳時で25%低下しているという報告がある[8]．さらに単調なメニューになれば不適当な栄養摂取状態になることが容易に推測される．食欲に関しての指標は多くはないが，地域在住高齢者における6カ月間10%の体重減少に関するカットオフラインは，CNAQ（council on nutrition appetite questionnaire：total 8-40）で28.5，その簡易版のSNAQ（the simplified nutritional appetite questionnaire：total 4-20）で13.5といわれ，早期に低栄養リスクをとらえるためにはこうした食欲スクリーニング検査も有用であると報告されている[9]．

低栄養の理由が“食形態を変化させたことでエネルギー密度が減少し，摂取総エネルギー量が低下した”エネルギー摂取量低下であるならば，その原因の代表例は摂食嚥下機能低下を含む口腔咽頭機能の障害であろう．加齢による身体機能，精神的変化および社会的背景の変化は，全身の筋力低下と同時に口腔咽頭筋，嚥下運動にかかわる筋群の筋力低下を起こし，摂食嚥下障害を含む口腔咽頭機能低下を引き起こす[7]．消化管における消化吸収率の低下は食欲不振の原因になるばかりか，摂取した栄養が身体に取り込まれない結果となってしまう．結果として栄養摂取量の低下はprotein-energy malnutrition：PEMを惹起する．栄養障害は除脂肪体重（lean body mass：LBM）の減少を引き起こし，ひいては

筋肉組織の細小化，筋力低下，骨塩量低下等が引き起こされる．まさに栄養障害の負のスパイラルである[10]．

加齢現象にかかわる摂食嚥下障害の要素

摂食嚥下障害を引き起こす原因疾患は器質的障害・機能的障害・神経心理的障害に大別される[11]．前述のように，高齢者においては摂食嚥下障害の原因が単独の疾患であると断定できないケースが大半であるので，本稿では加齢にしぼって摂食嚥下障害に関係のある口腔咽頭機能について検討していく．

■舌

食べ物の咀嚼や移送に多大な寄与をしている舌は，横紋筋が中心のいわば筋肉の塊である．内舌筋は上下左右前後に走行する筋線維が入りまじり，協調して収縮することで，舌を自由に変形させることができる．一般的に筋肉の代謝は蛋白合成と蛋白分解によって成り立っているが，加齢によって蛋白合成（成長ホルモン，インスリン様成長因子，テストステロン等内分泌系，アミノ酸，ビタミンDなどが関与）は減少し，蛋白分解（炎症性サイトカイン，ステロイドホルモン，グルカゴン）は増加する[12]．加齢によって蛋白分解量が蛋白合成能を上回ると筋量は減少するため，全身的な筋量低下とともに舌の筋量も低下するといえる．さらに舌を含む口腔粘膜は加齢により萎縮し弾性が低下することで，舌においては内部の筋線維の体積の減少，結合組織内の脂肪組織の増加が相まって可動性の低下が起こる[13]．舌運動の協調性の低下，最大舌圧と舌圧持続時間の減少によって嚥下動作が障害され，咽頭圧の低下にともなう嚥下障害が出現する[14]．

■舌骨上筋群

嚥下運動の際に舌圧を支え，喉頭を引き上げるのが舌骨上筋群である．舌骨上筋群は顎二腹筋，茎突舌骨筋，顎舌骨筋，オトガイ舌骨筋で構成され，嚥下時にはこれらの収縮によって喉頭が挙上し喉頭閉鎖（気道の入り口が閉鎖される）し，また食道入口部開大（食道の入り口が開く）にも関与している．全身的な筋量低下とともに，舌骨上筋群の筋量低下が起こることは前述のように想像に難くなく，高齢者が若年者に比較して喉頭・舌骨がより下方に位置していることも説明がつく．そのような状態での嚥下運動では，若年時よりも下方に位置している舌骨や喉頭を引き上げるため，舌骨と喉頭の挙上量や前方移動量の低下，挙上にかかる時間の延長が起こり[13]，結果的に食物の咽頭残留や喉頭内侵入のリスクが上がることが示唆される．

■咀嚼筋

咀嚼運動は上下の顎をつなぐ咀嚼筋（咬筋，側頭筋，外側翼突筋，内側翼突筋）のほかに，舌や頬，唇（舌筋や頬筋，口輪筋など表情筋の動き），唾液量，歯なども関与する複雑な運動であるため，一義的な定義は困難である．咀嚼筋に焦点を当ててみると，触診によって触知可能である咀嚼筋の活動時収縮量は超音波検査によって得られる咬筋厚と有意に関連し，また年齢や機能歯数（残存歯に義歯やブリッジなどの補綴歯を加えた機能的に活用可能な歯の本数），咬合力とも有意な関連があると報告されている[15]．特殊な機械を使わずに簡易的に咀嚼筋活動をとらえられる咬筋触診

法は，高齢者栄養管理の臨床において有用である．咀嚼能力を判定するために開発された方法はいくつかあるが，“ガム咀嚼”によって咀嚼機能を簡易的に定義した場合，地域高齢者において身体のsarcopeniaが起こるリスクは，年齢，そして咀嚼機能低下が高いといわれている[16]．一方，口腔機能にsarcopeniaの概念を当てはめて，ガム咀嚼，咬筋筋肉量，咬合力によって定義した便宜的な口腔機能虚弱モデルには，全身のsarcopeniaと栄養状態が有意に関連しているとも報告されている[17]．

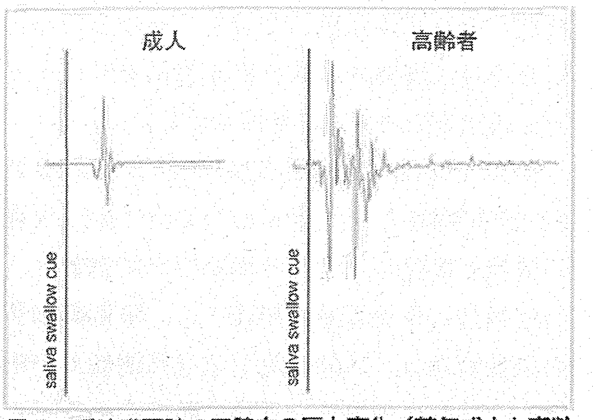

図2　唾液嚥下時の口腔内の圧力変化（若年成人と高齢者の比較）

（Humbert IA, et al. Neuroimage2009；44（3）：982-91[21]より）
高齢者のほうがより唾液嚥下に努力が必要であることを示す．

■口腔咽頭感覚

口腔咽頭感覚や神経活動についても加齢変化が報告されている．飲食物の体積や粘度，温度の情報は口腔咽頭感覚受容器による検出によって嚥下反射を誘発させるが，前期高齢者に比較し後期高齢者では口腔感覚が「muted（消音）」されたと報告されている[18]．これは嚥下反射惹起時間の遅延に関連している[19]．すなわち加齢によって口腔感覚は鈍化することが知られており，味覚刺激や温度刺激，触覚刺激の少ない飲食物では検知能が低下し，さらにそれが嚥下反射惹起時間の遅延を起こす．また神経病理学的には，より微細な変化が報告されている．A penetration-aspiration scale[20]などの評価で検出困難な神経病理学的な加齢変化が生じることで，とくに味覚刺激や温度刺激の少ない唾液の嚥下では高齢者のほうがより若年成人に比較して大脳皮質の広域の活動が認められ，同時に口腔内での活動もより努力性であったと報告されている（図2）[21]．とくに甘味刺激のある液体より唾液のほうが右脳の活動が多い結果であった．このことは同程度の負荷のかかる同一の運動を起こす際に，高齢者ではより多くの大脳皮質機能の動員が必要であるということで，裏を返せば高齢者においていったん大脳皮質の機能低下が生じはじめると，これまで行っていた嚥下運動を同じように起こすことが困難になるものと考えられる．口腔咽頭機能についても同様のことが考えられる．

以上の要因による全般的な加齢による嚥下機能低下は，presbyphagia（老嚥）と呼ばれることがあるが[22]，脳血管障害と異なり嚥下機能の本質が損なわれることはないといわれている[23]．すなわち“反応するが鈍い”や，“動くが疲れる，動くが弱い”といった嚥下機能低下である．特徴を把握することで栄養管理，食事支援の手法にも特徴を踏まえた工夫が可能である．

支援の視点

障害高齢者の食事，栄養管理を考えるうえで，食事はただたんに生命維持としての栄養管理のみではなく，生活のなかでの楽しみや季節を感じる文化でもある．したがって障害

高齢者それぞれに適した栄養，その方になじむ食事は，周囲の環境を整え生活をサポートする視点があってこそ達成される．

本稿では加齢現象や口腔機能と低栄養をfrailtyに関連させ記載した．栄養状態は全身の機能と関連し，全身の機能は口腔機能と，口腔機能は栄養状態と関連する．障害高齢者の栄養管理は，口腔機能や全身機能低下を把握しなければ効果的な支援に結びつかないものである．

高齢化の波のなかで，frailtyとの闘いは，もう待ったなしの段階にきている[6]．臨床的なfrailty支援を広く進める必要がある．

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Gerodontology

Original article

Does wearing dentures change sensory nerve responses under the denture base?

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Does wearing dentures change sensory nerve responses under the denture base?

Background: The standard textbook on complete dentures suggests the necessity of relief for the incisive and posterior palatine foramina of denture wearers to prevent the impingement of the nerves and vessels passing through these foramina. However, concrete evidence of the effect of dentures on the sensory function of the nerves underlying dentures is lacking.
Objective: The study aim was to investigate the influence of denture-induced compression on sensory nerve responses to stimulations.
Materials and methods: Only partially edentulous patients of maxillary Kennedy class II who wear dentures (WD) or who never wear dentures (ND) were recruited as participants. The WD and ND groups had 15 participants with a mean age of 66.9 years and 22 participants with a mean age of 60.2 years, respectively. Current perception thresholds (CPTs) at 2000, 250 and 5 Hz, corresponding to A-beta, A-delta and C fibres, respectively, were measured by the Neurometer® NS3000 device and compared between groups. The data were analysed by the *t*-test, the paired *t*-test and analysis of covariance adjusted for age, sex and thickness of the mucosa.
Results: The CPTs showed large differences at 2000 Hz but no differences at the other frequencies when the WD and ND groups were compared. Only the CPT of the edentulous side at 2000 Hz was significantly different between groups.
Conclusion: Wearing removable partial dentures contributes to changes of responses to stimulations in the large fibre of the sensory nerve underlying the maxillary alveolar ridge.

Keywords: current perception threshold, denture wearing, greater palatine nerve, sensory nerve.

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Introduction

The standard textbook on complete dentures suggest the necessity of relief for the incisive and posterior palatine foramina of long-term denture wearers to prevent the impingement of the nerves and vessels passing through these foramina[1]. Although this suggestion was based on concerns that compression by dentures may induce functional changes to nerves and vessels located underneath the dentures, no concrete evidence of a relationship between functional changes in the nerves and compression from dentures has been reported.

We previously investigated the influence of denture-induced compression on sensory nerve responses to stimulations by measuring the current perception threshold (CPT);[2]. This previous study compared the CPTs of dentulous subjects with those of complete denture wearers and showed that complete denture wearers experience asymptomatic hypoesthesia that primarily affects the nasopalatine and greater palatine nerves[3].

Two possibilities could explain why complete denture wearers experience asymptomatic hypoesthesia: (i) the effects result directly or indirectly from wearing complete dentures and (ii) damage to the nerves from oral surgery, such as tooth extractions[4]. The previous study showed that edentulous patients have increased CPTs relative to dentulous patients. However, because the study did not compare edentulous patients who wear complete dentures with those who do not wear them, it could not address whether wearing dentures affects the nerve underlying the edentulous alveolar ridge (i.e. the study could not account for the possible effects of oral surgery). For clearly investigating the effects of dentures on the sensory nerve, a study would ideally compare the nerve functions of edentulous patients with complete dentures to those without complete dentures as a control group. Unfortunately, such a study is difficult because of the challenges in obtaining a sufficient control group. That is, complete denture wearers have little alternative but to use their dentures for masticating food, and edentulous participants who did not wear their complete denture are not frequently encountered in a clinical setting.

Thus, to accurately assess the effects of wearing dentures on this sensory nerve, we targeted maxillary Kennedy class II patients, with or without subdivisions, who have a unilateral free-ended, partially edentulous state[5]. We chose this type of patient because they tend not to wear dentures due to the reason that they possess a large dentulous area where mastication is performed well without a denture.

The purpose of this study was to investigate whether wearing dentures causes functional changes in the sensory nerve underlying the greater palatine foramen of the maxillary alveolar ridge by measuring the CPT. We hypothesised that CPTs of partially edentulous patients who wear dentures would differ from those who do not wear them.

Materials and Methods

Study population

This study was approved by the Human Ethics Committee of Nihon University School of Dentistry at Matsudo. The volunteers were enrolled after obtaining written informed consent.

Only partially edentulous patients of maxillary Kennedy class II, with or without subdivisions, mostly missing the first and second molars, were recruited as participants. All dentures had extracoronal retainers and a major connector to traverse the palate from the edentulous side to the dentulous side. The edentulous side of denture wearers was covered by denture, whereas the dentulous side was partially covered by major connector to connect the side opposite the edentulous side to stabilize the denture.

Patients with the following conditions were excluded: (i) general health problems (e.g. diabetic mellitus, trigeminal neuralgia and postherpetic neuralgia) that could affect the measurements of nerve activity; (ii) neuropathic complaints involving the maxillary alveolar ridge; (iii) pacemakers; (iv) obvious cognitive impairment and (v) a lack of understanding of written or spoken Japanese.

Participants in the group who wore dentures (WD) were compared with those who had never worn dentures (ND). The WD had 15 participants with a mean age of 66.9 years; the ND group had 22 participants with a mean age of 60.2 years.

Measurements of participant characteristics

After recording the gender and age of the participants, the mucosal thickness over the great palatine foramen of the edentulous and dentulous sides was measured by a single operator using an ultrasonic measuring device (Krupp SDM®; Austenal Medizintechnik, Cologne, Germany). The probe of this device was placed perpendicular to and in contact with each target point by the application of slight pressure; each measurement was performed three times (Fig. 1). The mean value of the measurements was used as a representative value for the analyses.

Current perception threshold measurements

The participants were seated comfortably on dental chairs in a quiet room. A single operator obtained mucosal CPT measurements around the greater palatine foramen of the edentulous and dentulous sides using a Neurometer® NS3000 device (Neurotron Inc., Baltimore, MD, USA) to deliver electrical stimulations at frequencies of 5, 250 and 2000 Hz (Fig. 2a,b). The area around the greater palatine foramen was selected as a targeted site because the denture covered it in the WD group, and because this site was available for comparing nerve function between the WD and ND groups. The greater palatine nerve is a branch of the pterygopalatine ganglion and emerges upon the hard palate through the greater palatine foramen and supplies the mucous membrane nearly to the incisor teeth.

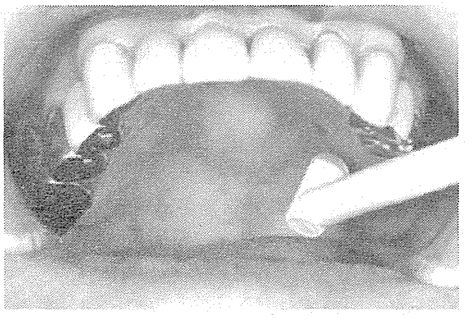

Figure 1 Measurement of mucosal thickness.

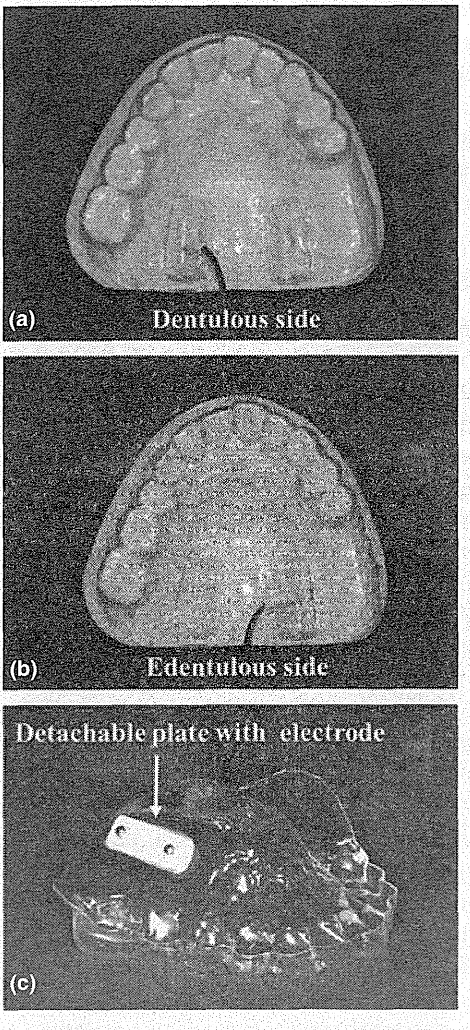

Figure 2 Measurement of the current perception threshold (CPT). (a) Point for measuring the CPT on the dentulous side. (b) Point for measuring the CPT on the edentulous side. (c) Intraoral removable device with stimulating electrodes for measuring CPT.

Thus, the Neurometer® NS3000 device can stimulate fibres generally covered by the maxillary denture. Three subpopulations of sensory nerve fibres, A-beta, A-delta and C fibres, were tested by using three types of frequencies (2000, 250 and 5 Hz). The 2000, 250 and 5 Hz stimulate A-beta, A-delta and C fibres, respectively. Thus, CPT evaluation provides selective activation of fibre type (6).

For ensuring contact between the mucosa and stimulation electrodes, a measurement apparatus with Ø 1-mm thermoforming disks (Erkodur®; Erkodent, Baden-Württemberg, Germany) was developed for each subject. Plates (18 × 6 × 3 mm) with stimulation electrodes (Ø 2 mm) mounted on an intraoral removable appliance (Fig. 2c). The plate was detachable by means of retentive grooves (rectangular-shaped depressions) so that the measurement sites could be changed easily, as required.

The electric current was increased slowly from 0.01 mA until participants reported a sensation at a particular frequency of electrical stimulation as recommended by the manufacturer of the measurement apparatus to determine an approximate CPT level. Subsequently, a microprocessor-controlled forced-choice technique, which delivered 6–20 cycles of randomly selected real and false stimuli above and below the approximate CPT level, was used in a double-blinded manner until the exact CPT levels were determined.

Statistical analysis

All statistical analyses were performed using the statistical package SPSS II for Windows (SPSS, Chicago, IL, USA). A p value of <0.05 was considered to be statistically significant.

After verifying the normality of the data using the Kolmogorov–Smirnov test, we applied a parametric statistical analysis to the data. The differences in the age and mucosal thickness between the ND and WD groups were analysed using the t-test. The gender ratio in the ND and WD groups was compared using the chi-square test. The effects of wearing dentures on the CPTs were analysed by analysis of covariance (ANCOVA), taking into account potential confounders such as gender, age and mucosal thickness. The t-test was used to assess mean differences of CPTs between the WD and ND groups. A paired t-test was used to compare the CPT at the dentulous side to that at the edentulous side within the WD group and the ND group.

Results

Participant characteristics

The mean age of the WD group was significantly higher than that of the ND group (t-test, $p = 0.039$), but the mucosal thickness did not significantly differ between the two groups (Table 1). The chi-square test showed that the gender ratio was similar in the ND and WD groups.

Current perception threshold measurements

At a stimulation of 2000 Hz, the CPTs of the WD and ND groups were 44.5 ± 20.0 and 35.7 ± 18.8 at the dentulous side, respectively, and 53.9 ± 19.4 and 40.0 ± 17.2 at the edentulous side, respectively (Fig. 3). When the stimulation occurred at 250 Hz, the CPTs of the WD and ND groups were found to

Table 1 Participant characteristics.

Variable	*WD (n = 15)* *Mean ± 1SD*	*ND (n = 22)* *Mean ± 1SD*
Age (years)[a]	66.9 ± 7.5	60.2 ± 10.3
Edentulous site mucosal thickness (mm)	1.5 ± 0.8	1.4 ± 0.6
Dentate site mucosal thickness (mm)	1.1 ± 0.8	1.3 ± 0.6
Gender (male/female)	6/9	8/14
Duration of wearing denture (years)	3.7 ± 4.8	–

[a]Significantly difference between WD and WD groups ($p < 0.05$).
WD, participants in the group who wore denture; ND, participants in the group who never wore denture.

be 18.3 ± 11.7 and 17.7 ± 11.4 at the dentulous side, respectively, and 18.7 ± 11.2 and 18.3 ± 8.9 at the edentulous side, respectively. At a stimulation of 5 Hz, the CPTs of the WD and ND groups were 13.8 ± 8.7 and 11.3 ± 6.1 at the dentulous side, respectively, and 13.9 ± 9.7 and 14.1 ± 8.8 at the edentulous side, respectively. The CPT values were proportional to the stimulation frequency, but only the 2000-Hz frequency resulted in large differences in the CPTs between the groups.

The *t*-test showed that only the CPT for the edentulous side at 2000 Hz was significantly different ($p = 0.028$) between the groups. The difference in the CPTs between the dentulous and edentulous sides of the WD group at 2000 Hz was large but not significantly different.

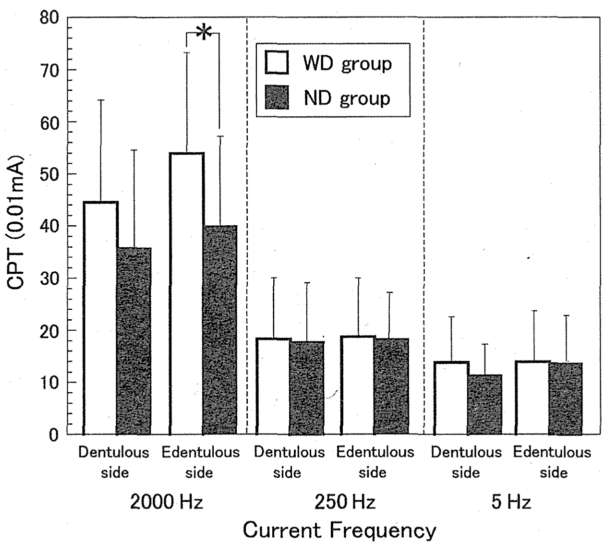

Figure 3 Differences in the current perception thresholds (CPTs) at each frequency between the group that had never worn dentures (ND) and the group that wore dentures (WD). *t-test, $p < 0.05$.

The ANCOVA revealed that (i) the thickness of the mucosa significantly affected CPTs at all frequencies at both the edentulous and dentulous sides; (ii) wearing dentures only affected the CPT of the edentulous side at the 2000-Hz stimulation and (iii) gender and age did not affect the CPTs at any of the frequencies on either side.

Discussion

We found that denture wearers had changes of sensory nerve responses to stimulations in the greater palatine nerve due to the compression caused by the dentures.

The CPTs of the WD group at 2000 Hz were higher than those of the ND group. This suggested that wearing dentures contributes to changes in the sensory nerve underlying the maxillary alveolar ridge and that the sensory nerves have few functional changes caused by the oral surgery for teeth extraction. The effect of denture wearing on sensory nerves can be further clarified by comparison with entrapment neuropathy caused by dynamic mechanical compression of a short segment of a single nerve at a specific site, as it passes through a fibro-osseous tunnel or an opening in fibrous or muscular tissue[7–10]. The similarities between entrapment neuropathy and denture wearing can be summarised as the alveolar mucosa of denture wearers is subjected to dynamic mechanical compression caused by masticatory forces transmitted through the dentures, and the greater palatine nerve passes through the greater palatine foramen to the alveolar mucosa under the denture. Furthermore, one of the clinical symptoms of entrapment neuropathies is hypoesthesia, which is paralleled by increased CPT values experienced by partial denture wearers. The greater palatine nerve is entrapped and compressed in the area overlying the greater palatine foramen by occlusal forces transmitted through the dentures, which is similar to the alterations in nerve fibres associated with entrapment neuropathies.

The question remains as to why only the CPT values at 2000 Hz were affected by denture wearing. A 2000-Hz frequency stimulates the A-beta fibre, which is the largest myelinated fibre among the sensory nerves[11]. A study of the CPT indicated that dysfunctional sensory nerve fibres, caused by compression, apparently initiates in larger fibres before extending stepwise to smaller fibres as the clinical grade of dysfunction progresses (12). Thus, large fibres, stimulated by a frequency of 2000 Hz, were more easily affected by the compression than the small A-delta and C fibres stimulated by lower frequencies. This may suggest that the mechanical compression induced by the occlusal forces obtained from Kennedy class II denture wearers may be enough to affect the A-beta fibre but not the small fibres.

We recruited participants without neuropathic complaints; therefore, changes in the sensory nerve of the denture wearers can be considered asymptomatic hypoesthesia. As asymptomatic hypoesthesia was observed only in the large A-beta fibres, the grade of severity of the functional changes in the nerve appears moderate—the sensory nerve fibre dysfunction caused by compression had not yet progressed to the smaller fibres[12]. Although the mean duration of denture wearing by the participants was only 3.7 years, the CPTs were clearly disturbed. Presumably, long-term denture wearing could potentially induce some functional changes in small nerve fibres. This asymptomatic progressive change in sensory nerves might well increase in patients who wear denture at night when sleeping. Nocturnal denture wearing has been discussed from different viewpoints such as the quality of sleep[13], denture hygiene[14–16] and bone resorption[17] and psychological aspects. This study added a new aspect to the debate on nocturnal denture wearing and indicates that nocturnal denture wearing should be avoided due to the risk of inducing changes in the sensory nerve.

Conclusion

We conclude that wearing removable partial dentures contributes to changes of sensory nerve responses to stimulations in the sensory nerve underlying the maxillary alveolar ridge.

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Original article

Basic investigation of the laminated alginate impression technique: Setting time, permanent deformation, elastic deformation, consistency, and tensile bond strength tests

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ABSTRACT

Purpose: Laminated alginate impression for edentulous is simple and time efficient compared to border molding technique. The purpose of this study was to examine clinical applicability of the laminated alginate impression, by measuring the effects of different Water/Powder (W/P) and mixing methods, and different bonding methods in the secondary impression of alginate impression.

Methods: Three W/P: manufacturer-designated mixing water amount (standard), 1.5-fold (1.5×) and 1.75-fold (1.75×) water amount were mixed by manual and automatic mixing methods. Initial and complete setting time, permanent and elastic deformation, and consistency of the secondary impression were investigated (n=10). Additionally, tensile bond strength between the primary and secondary impression were measured in the following surface treatment; air blow only (A), surface baking (B), and alginate impression material bonding agent (ALGI-BOND: AB) (n=12).

Results: Initial setting times significantly shortened with automatic mixing for all W/P ($p < 0.05$). The permanent deformation decreased and elastic deformation increased as high W/P, regardless of the mixing method. Elastic deformation significantly reduced in 1.5× and 1.75× with automatic mixing ($p < 0.05$). All of these properties resulted within JIS standards. For all W/P, AB showed a significantly high bonding strength as compared to A and B ($p < 0.01$).

Conclusions: The increase of mixing water, 1.5× and 1.75×, resulted within JIS standards in setting time, suggesting its applicability in clinical setting. The use of automatic mixing device decreased elastic strain and shortening of the curing time. For the secondary impression application of adhesives on the primary impression gives secure adhesion.

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1. Introduction

According to a 2011 Japanese national dental disease survey [1], the prevalence of edentulousness decreased from 7.9% in 1975 to 5.2% in 2011. However, the prevalence of edentulousness among people aged 75 years or older has greatly increased from 21% in 1975 to 64% in 2011. The increasing age of edentulous patients may indicate a rise in the number of patients for whom conventional treatments are both mentally and physically insufficient. Further, the present circumstances may require diversity among the treatments for individual patients.

The appropriate insertion of complete dentures is considered to a major factor in the oral and general health of edentulous patients. In order to construct complete dentures with appropriate support and stability, it is necessary to generate a record of the appropriate denture base surface area, flange contour, and mucosal surface and to generate a record of the lining mucosa by making an impression. Therefore, the objectives of making a complete denture impression are as follows: to generate a record of all anatomical landmarks in the oral cavity; to obtain strong adhesion or retention with the mucosal surface; and to obtain an appropriate border shape to maintain the adhesion [2]. The conventional precise impression method records movement of the muscular tissue of the circumference of the mouth in a *modeling compound, and identifies the range of a denture* base. Then, the final impression is made using a precision impression material. This method has an advantage that determines the range of a denture base strictly and can manufacture a minute master cast. However, the treatment period is extensive [3], is greatly affected by the skill of the operator, and is burdensome for the patient. This treatment is particularly difficult to recommend as a first choice for elderly patients, patients with systemic diseases, and patients receiving treatment at home.

Alginate impression material, which is inexpensive and easy to handle, is frequently used to make complete denture impressions in general clinical settings [4]. However, because alginate impression material involves the use of a stock tray to make a preliminary impression, it is sometimes difficult to generate an impression that adheres strongly to the mucosal surface or the appropriate border shape. Therefore, a laminated alginate impression technique, in which the alginate impression material is double-layered before making an impression, has been devised in order to compensate for this flaw, and many clinicians have used this technique and noted its advantages [5,6]. The laminated alginate impression technique for edentulous patients is comprised of several steps. First, a preliminary impression is made with a standard Water/Powder (W/P) by using a stock tray. Next, the impression surface is treated baked or application of an alginate-bonding agent, and W/P is subsequently increased and a secondary impression is made with alginate impression material that is sufficiently fluid. This process is expected to achieve results similar to those of conventional precise impressions. The effects of the laminated alginate impression technique devised by Nakazawa et al. [7,8] on model shapes have been reported. However, the physical properties of alginate impression material with an increased W/P and the effect of different preliminary impression surface treatments on bonding strength in the preliminary and secondary impressions are unclear. Adequate scientific evidence is lacking regarding whether this technique can be sufficiently adapted to a clinical setting.

Therefore, the objective of the present study was to examine the clinical applicability of the laminated alginate impression technique, by measuring the effects of different alginate impression material W/P and mixing methods in the secondary impression on the properties of the material (setting time, permanent deformation, elastic deformation, and consistency) and the effects of different preliminary impression surface treatments on bonding strength in preliminary and secondary impressions.

Null hypothesis of the study was: 1. There is no difference in the physical properties of the alginate impression material that has been mixed with three different W/P of alginate impression material as a secondary impression by two different mixing method. 2. There is no difference in tensile bond strength between the primary and secondary impression due to different method of surface treatment of primary impression.

2. Materials and methods

2.1. *Physical properties of the secondary impression*

2.1.1. *Study samples and measuring items*

Seven and half grams of alginate impression material (Algiace Z, Dentsply Sankin, Ibaraki, Japan) was mixed with distilled water (17.0 ± 0.5 °C) with 3 W/P; 17 ml (manufacturer-designated mixing water amount; hereafter "standard"), 25.5 ml distilled water (1.5-fold of the manufacturer-designated mixing water amount; hereafter "1.5×"), and 29.8 ml of distilled water (1.75-fold of the manufacturer-designated mixing water amount; hereafter "1.75×") [9]. The mixing methods were manual mixing for 40 s and automatic mixing for 12 s by using an automatic mixer (Mikrona Mixer, Mikrona, Switzerland). Thus, six different mixed impressions (three W/P, mixed by two mixing methods, n=10 respectively) were used for the measurement. The measuring items were setting time, permanent deformation, elastic deformation and consistency. All measurement were followed to Japanese Industrial Standard (JIS) T-6505 [10] at constant room temperature (23.5 ± 1 °C).

2.1.2. *Setting time*

The mixed impression materials were poured into metal rings (a diameter of 30 mm) placed on a glass board. The materials were brought into contact with the impression surface at 10-s intervals by using a polymethyl methacrylate (PMMA) stick polished at one end. The initial setting time was defined as the amount of time that elapsed until the material no longer adhered to the stick surface, and the complete setting time was defined as the amount of time that elapsed until the PMMA stick marks disappeared.

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2.1.3. *Permanent deformation*

The mixed impression materials were poured into a metal split mold and were covered with a glass board. After 2 min (the oral cavity-retention time, as indicated by the manufacturer), the mixtures were removed from the split mold and made into cylindrical samples with a diameter of 12.5 mm and a height of 20 mm. Dial gauge heads (0.5 ± 0.1 N) were brought into contact with the tops of the sample bodies (A). Immediately after measuring the dial gauge graduation, 20% deformation was applied for 30 s. Following load removal, the dial gauge head was brought into contact with the sample body again (B). The permanent deformation (D) was calculated from these two values.

$$D = \frac{A - B}{20} \times 100$$

2.1.4. *Elastic deformation*

Cylindrical sample bodies were made according to the protocol described for permanent deformation. A load of 1.25 ± 0.05 N was applied to the sample bodies and the dial gauge graduation was measured (C). An overall load of 12.5 ± 0.1 N was subsequently applied, and the dial gauge graduation was measured (D). The elastic deformation (S) was calculated from these two values.

$$S = \frac{C - D}{20} \times 100$$

2.1.5. *Consistency*

Two ml of the mixed alginate impression material was placed in the center of a 100 × 100 mm glass board. A 100 × 100 mm glass board (1.20 ± 0.02 N) was gently placed on the material 90 s after mixing was initiated. The spread of the alginate impression material was quantified by measuring the diameter in 2 arbitrary places at 6 min after mixing was initiated. The average of these 2 measurements was used to calculate the area, as the consistency.

2.2. *Effects of different bonding methods on the tensile bond strength*

Tensile bond tests measurements were conducted at room temperature (23 ± 2 °C). A pair of cylindrical metal molds was prepared and impression material mixed with a standard W/P filled in one metal mold. After the material had set completely, the surplus material was removed with a knife. The following three treatments were subsequently performed on the surface of the impression: air blow for 10 s (hereafter "A"), surface baking until the impression surface turns white and dry (hereafter "B"), and an alginate impression material bonding agent (ALGI-BOND, Tokuyama Dental, Tokyo, Japan; hereafter "AB"). Next, the other metal mold was filled with the impression materials that would be used as the secondary impression (W/P: standard, 1.5×, and 1.75×). Then the mold was joint to primary impression mold and kept until complete setting of the impression.

After the material was set completely, the surplus material was removed and the sample was removed from the metal mold. We then conducted a tensile strength test at a crosshead speed of 2 mm/min by using an Instron Universal Testing Machine (TG-5kN, Minebea, Tokyo, Japan). All samples were prepared with automatic mixing ($n = 12$).

2.3. *Analysis*

The setting time, permanent deformation, elastic deformation, and consistency were compared by the two factors: mixing method and each water–powder ratio (two-way ANOVA repeated measures, and Bonferroni test for post hoc test). Tensile bond test results for each water–powder ratio were compared by surface treatment (Kruskal–Wallis test; the Bonferroni correction was used for multiple comparisons). All of these analysis was carried out by PASW® Statistics 18.0 (SPSS, IL, USA).

3. Results

3.1. *Physical properties of the secondary impression*

3.1.1. *Initial setting time*

A comparison of the initial setting times according to W/P showed that the setting times were significantly longer for higher W/P as compared to the standard for both manual and automatic mixing. Further, a comparison between the manual versus automatic mixing showed that the initial setting times were significantly shorter with automatic mixing for all W/P ($p < 0.05$) (Table 1).

3.1.2. *Complete setting time*

A comparison of the complete setting time according to W/P showed that the setting times were significantly longer for higher W/P as compared to the standard for both manual and automatic mixing. Moreover, a comparison between manual versus automatic mixing showed that the setting times were significantly shorter with the automatic mixing method for the standard and 1.75× ($p < 0.05$) (Table 1).

3.1.3. *Permanent deformation*

No significant differences in permanent deformation were observed according to the mixing method. However, the permanent deformation showed to decrease as W/P increased, regardless of the mixing method (Table 1).

3.1.4. *Elastic deformation*

The elastic deformation was significantly reduced in 1.5× and 1.75× with automatic mixing ($p < 0.05$). The elastic deformation significantly increased as compared to standard W/P, regardless of the mixing method (Table 1).

3.1.5. *Consistency*

The consistency significantly reduced with the standard and 1.75× with automatic mixing ($p < 0.05$). The consistency significantly increased as W/P increased, regardless of the mixing method (Table 1).

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Table 1 – Setting time, permanent deformation, elastic deformation, consistency.

		Powder-water ratio					
		Standard (n = 10)		1.5x (n = 10)		1.75x (n = 10)	
Initial setting time (s)	Manual mixing	170 (6.7)	*	236 (12.6)[a]	*	265 (5.3)[bc]	*
	Automatic mixing	127 (4.8)		222 (14.0)[a]		253 (8.2)[bc]	
Complete setting time (s)	Manual mixing	230 (16.3)	*	318 (12.3)[a]		390 (20.0)[bc]	*
	Automatic mixing	178 (4.2)		330 (13.3)[a]		376 (9.7)[bc]	
Permanent deformation (%)	Manual mixing	3.6 (0.7)		2.4 (0.8)[a]		1.7 (0.6)[b]	
	Automatic mixing	3.4 (0.8)		2.6 (0.9)[a]		2.0 (0.5)[b]	
Elastic deformation (%)	Manual mixing	12.9 (0.3)		17.6 (0.3)[a]		19.1 (0.2)[b]	*
	Automatic mixing	13.0 (0.4)		16.9 (0.6)[a]		16.3 (4.9)[b]	
Consistency (mm^2)	Manual mixing	889.8 (39.9)	*	2333.9 (105.6)[a]		3162.7 (98.7)[bc]	*
	Automatic mixing	720.9 (79.9)		2353.9 (193.6)[a]		2847.0 (89.5)[bc]	

(): SD.
[a]1.5× showed a significant difference compared to standard ($p < 0.05$).
[b]1.75× showed a significant difference compared to standard ($p < 0.05$).
[c]1.5× showed a significant difference compared to 1.75× ($p < 0.05$).
*$p < 0.05$.

3.2. *Effects of different bonding methods on the tensile bond strength*

For all W/P, AB showed significantly higher bonding strength as compared to A and B ($p < 0.01$). Further, no significant differences in bonding strength were observed between A and B for any water–powder ratio (Figs. 1–3).

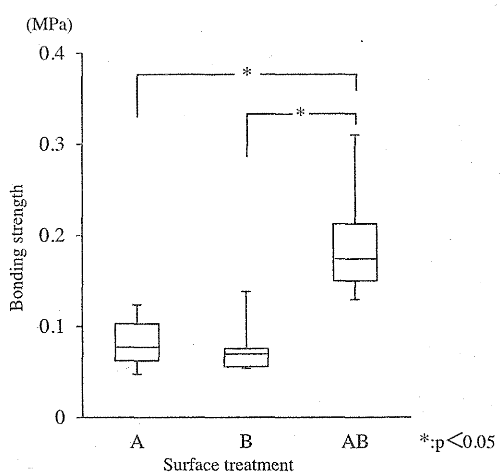

Fig. 1 – Tensile bond test (powder-water ratio: standard). (A) Air blow; (B) Surface baking; (AB) Alginate impression material bonding agent.

4. Discussion

This study tested two null hypothesis. One was: there is no difference in the physical properties of the alginate impression material that has been mixed with three different W/P of alginate impression material as a secondary impression by two different mixing method, which was rejected and use of a high W/P (1.5× to 1.75×) significantly increased initial setting times, complete setting time, elastic deformation and consistency has become evident. Another hypothesis was: there is no difference in tensile bond strength between the primary and secondary impression due to different method of surface treatment of primary impression, which was also rejected and found that ALGI-BOND showed a significantly higher bonding strength as compared to Air blow and surface baking for all water–powder ratios.

Measuring setting time, permanent deformation and elastic deformation was carried out according to JIS standard method. No standard method of testing consistency of alginate impression exist in JIS standards. So sample test of dental elastomeric impression consistency had been applied, which use 0.5 ml amount of the material by the standard syringe. However, in this study, 10 ml syringe by injecting 2 ml of alginate impression was applied. This was based on preliminary experiment that injecting 0.5 ml of alginate impression produce bubbles in the material which may produce systematic error.

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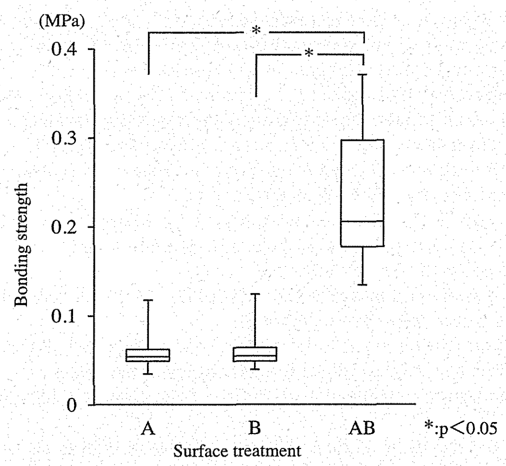

Fig. 2 – Tensile bond test (powder–water ratio: 1.5×). (A) Air blow. (B) Surface baking; (AB) Alginate impression material bonding agent.

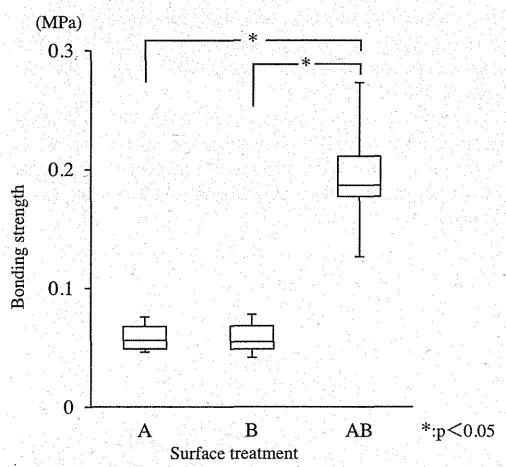

Fig. 3 – Tensile bond test (powder–water ratio: 1.75×). (A) Air blow; (B) Surface baking; (AB) Alginate impression material bonding agent.

The secondary impression for the double alginate impression technique requires the following 4 conditions: 1) higher consistency than standard water–powder ratio, 2) sufficient operating time, 3) appropriate elastic deformation, and 4) necessary dimensional accuracy for constructing dentures. The W/P of the alginate impression material must be increased in order to ensure higher consistency than standard W/P. However, this presents two problems: 1) a decline in physical properties and 2) a longer setting time. Regarding the decline in physical properties, the JIS-standard for elastic deformation and permanent deformation is 5–20% and less than 5%, respectively; in the present study, the elastic deformation and permanent deformation of 1.5× and 1.75× were within these respective ranges. Regarding the longer setting time, both 1.5× and 1.75× were within the JIS-standard initial setting time range of 1–5 min in the present study. Therefore, it was suggested that there are following with physical properties with regard to JIS standards.

However, even if these properties are within JIS-standard ranges, the overly long setting time and increased elastic deformation pose problems, such as operation time and mold deformation, respectively, in a clinical setting. In the present study, the use of an automatic mixer reduced the setting time and elastic deformation compared to manual mixing. According to Inoue et al. [11], when the material is mixed at high speed, the temperature of the paste increases slightly (2.3 °C within the 15 s mixing time) as a result of the mechanical friction between the material particles or between the material and the mixing vessel. It is assumed that a similar phenomenon also occurred in this study that the setting time toward the automatic mixing has been shortened as compared with the manual mixing. According to McDaniel et al. [12], the centrifuge and the vacuum mixer were superior to the other techniques regarding presence of surface porosity. According to Dreesen et al. [13], elastic recovery was small with manual mixing than automated mixing method, due to inclusion of air lumps in the samples. Therefore, this suggested that the use of a high W/P (1.5× to 1.75×) and an automatic mixer fulfills the first 3 of the above-mentioned 4 conditions necessary for the secondary impression in the double-alginate impression technique.

Regarding the alginate bonding strength in the double-alginate impression technique, Shigeto et al. [14] reported that the bonding is the strongest when 1 layer of the alginate impression material in the preliminary impression is removed and the surface is fired until white and that the use of a bonding agent resulted in greater bonding strength compared to no treatment. However, in the present study, no significant differences were observed among the different water–powder ratios between air blowing only and baking until the surface was dry. In addition, the use of a bonding agent (ALGI-BOND increased the bonding strength for all water–powder ratios compared to air blowing only or baking. According to Hashimoto et al. [15], roughly 0.03 MPa of force is applied to the impression material when removing the impression, and the impression accuracy is not thought to be affected if this level of bonding strength is obtained. In the present study, all surface treatments displayed values >0.03 MPa. However, the secondary impression in the double-alginate impression technique peels away easily from the preliminary impression because it is thin. According to communication with the product company, the materials that been used for the adhesives is polyamine. It is assumed that the amino groups of the polyamine may bind to the carboxy group of the hardened surface of alginate secondary impression material. Therefore, the application of a bonding agent as a surface treatment was deemed necessary in order to make the secondary impression bond more strongly to the preliminary impression. Since the present study only examined the secondary impression technique, future examinations are necessary in which preliminary and secondary impressions are combined.

5. Conclusions

Within the limitations of this study, the following conclusions can be drawn:

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1. The increase of mixing water, 1.5× and 1.75×, resulted within JIS standards in setting time, permanent and elastic deformation, suggesting its applicability in clinical setting.
2. The use of automatic mixing device decrease elastic strain and shortening of the curing time.
3. It was found that to use an adhesive to secondary impression is significantly effective in the adhesion of secondary and primary impression.

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Reliability of pain tolerance threshold testing by applying an electrical current stimulus to the alveolar ridge

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SUMMARY The purpose of this study was to assess the reliability of testing pain tolerance threshold (PTT) by applying an electrical current stimulus to the alveolar ridge. Twenty volunteers studying or working at the Nihon University School of Dentistry at Matsudo participated in this study. Participants were seated comfortably on a dental chair in a quiet room during testing. A single operator obtained mucosal PTT measurements around the right greater palatine foramen using a Neurometer CPT/C® device (Neurotron Inc., Baltimore, MD, USA) to deliver electrical stimulation at frequencies of 5, 250 and 2000 Hz. The participant released a button to automatically discontinue the stimulus when it could no longer be tolerated. Two types of factors were confirmed: the consistency of repeated measurements and a potential carry-over effect on PTTs. The consistency and carry-over effects of pain with regard to PTT measurements were analysed via Cronbach's coefficient α. The Cronbach's coefficient α of PTTs calculated more than 6 days of PTT testing at 5, 250 and 2000 Hz was 0·97, 0·95 and 0·97, respectively, suggesting that the consistency of the measurements was excellent. The Cronbach's coefficient α calculated when the three frequencies of 5, 250 and 2000 Hz were applied in different orders was 0·91, 0·87 and 0·90, respectively, suggesting no carry-over effect. In conclusion, the measurement of PTTs at the alveolar ridge as assessed by applying an electrical current stimulus with an electro-diagnostic device exhibited excellent reliability, and thus, it constitutes a widely available option for PTT measurement in the clinical setting.

KEYWORDS: current stimulus, oral mucosa, pain tolerance threshold, reliability

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Introduction

The number of people requiring complete dentures is predicted to increase more than the next 20 years due to the ageing population (1–3). Elder denture users with advanced atrophic alveolar ridge mucosa due to ageing cannot bear the stress caused by occlusal force, resulting in pain.

One of the major complaints reported by denture users is pain of the mucosa, which increases with age (4–6). Dentists listen carefully to denture wearers' complaints, in an effort to objectively understand the pain reported by each individual, and attempt to identify inflamed mucosa that may be contributing to the pain. They then decide how to treat the patient, and how to adjust their dentures, based on this collective information. However, some patients complaining of severe pain do not exhibit inflamed mucosa, while others reporting no pain or only slight pain exhibit severely inflamed mucosa. This diversity derived from the subjective nature of pain severity results in uncertainty with regard to dentists' decisions when making adjustment plans for dentures. Moreover, dentists could select alternative modalities such as implants or resilient denture liners before starting treatment, if they could accurately predict which patients would

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complain of severe pain when using conventional dentures. Thus, it is very important to know a patient's pain tolerance threshold (PTT) in the context of denture wearing, before starting treatment.

Because it is affected by numerous factors (3, 7), the pain complained of by denture wearers is very complex. However, we believe that objectively understanding certain aspects of patients' pain, particularly their PTTs, would assist in the prediction of the severity of pain that denture users would experience after the fitting of new dentures. Although we have previously studied denture wearers' electrical current perception thresholds (8–10), pain tolerance to an electrical current stimulus applied to the oral mucosa has not been studied. To our knowledge, this is the first study to report the potential quantification of PTTs in the context of the oral mucosa using an electrical current stimulus. As there were no previous reports, we first verified the reliability of the technique. The purpose of this study was to assess the reliability of PTT testing as performed by applying an electrical current stimulus to the alveolar ridge via an electro-diagnostic device.

Materials and methods

Participants

This study was approved by the Human Ethics Committee of Nihon University School of Dentistry at Matsudo. Twenty volunteers 10 male (average age, 24·3 years) and 10 female (average age, 24·4 years) participants studying or working at the Nihon University School of Dentistry at Matsudo took part in the study. The volunteers were enrolled after obtaining written informed consent. Individuals with the following conditions were excluded: (i) general health problems that could affect the measurement of nerve activity (e.g. diabetes mellitus, trigeminal neuralgia or postherpetic neuralgia); (ii) neuropathic complaints involving the maxillary alveolar ridge; (iii) pacemaker wearers; (iv) obvious cognitive impairment; and (v) a lack of understanding of written or spoken Japanese.

PTT test

Each participant was seated comfortably on a dental chair in a quiet room throughout the testing. The same operator obtained all mucosal PTT measurements from around the right greater palatine foramen using a Neurometer CPT/C® device* to deliver electrical stimulation at frequencies of 5, 250 and 2000 Hz (Fig. 1a). After taking each individual PTT measurement, and before taking the next, the targeted area was checked using a dental mirror, and the participant was asked whether they still felt any residual irritation from the stimulus they had just received.

The PTT value represents the maximum amount of electrical stimulus that can be tolerated. The stimulus was applied in an ascending 'staircase' fashion (11, 12). Pain tolerance threshold was evaluated by having the participant press and hold a 'Test Cycle' button on a remote box (pictured in Fig. 1b). The participant released the button to automatically discontinue the stimulus when it could no longer be tolerated. The stimulation would automatically stop if the maximum output intensity (9·99 mA) was reached. The PTT measurements were performed at frequencies of 5, 250 and 2000 Hz, once at the test site.

To ensure contact between the mucosa and stimulation electrodes, a measurement apparatus with Ø 1-mm thermoforming discs† was developed for each participant. Plates (18 × 9 × 6 mm) with stimulation electrodes (Ø 2 mm) mounted on an intraoral removable appliance were utilised (Fig 1c,d).

Reliability of PTT testing

Two types of factors were investigated in this study. One was whether repeated measurements of PTT would exhibit consistency. The other was whether there was a carry-over effect, whereby one PTT test would influence the next test administered immediately thereafter to that same individual.

Every possible order of administration of the different electrical stimuli was administered, to investigate the carry-over effect, as follows: (i) 2000, 250, then 5 Hz; (ii) 2000, 5, then 250 Hz; (iii) 250, 2000, then 5 Hz; (iv) 250, 5, then 2000 Hz; (v) 5, 2000, then 250 Hz; and (vi) 5, 250, then 2000 Hz. To allocate different patterns to different measurement days, a random number table was prepared. As there were 720 different permutations of the six orders tested ($6 \times 5 \times 4 \times 3 \times 2 \times 1 = 720$), the random number

*Neurotron Inc., Baltimore, MD, USA.
†Erkodur®; Erkodent, Baden-Württemberg, Germany.

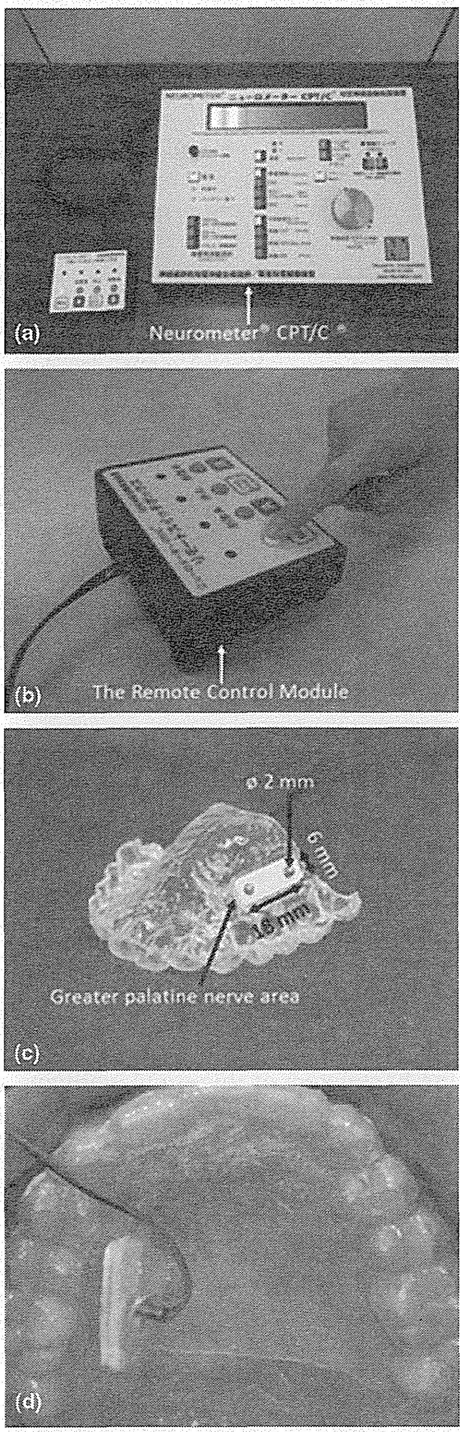

Fig. 1. Pain tolerance threshold (PTT) measuring system. The participants press, hold and release the button on the remote box when they can no longer tolerate the electrical stimuli. Participants wear the measurement apparatus with Ø 1-mm thermoforming discs to ensure contact between the mucosa and stimulation electrodes.

table consisted of 720 numbers, and one of these was randomly selected for each of the six measurement days. One number included six patterns of order, for example: 1st day order (2000, 250, then 5 Hz); 2nd day order (2000, 5, then 250 Hz); 3rd day order (250, 2000, then 5 Hz); 4th day order (250, 5, then 2000 Hz); 5th day order (5, 2000, then 250 Hz); and 6th day order (5, 250, then 2000 Hz). Thus, the measurement of PTT was performed six times in each subject; once per week for 6 weeks.

Statistical analyses

The effects of current frequency, gender and consistency on PTTs were analysed using the three-way repeated measures ANOVA incorporating the Tukey–Kramer *post hoc* test. The reproducibility of the data and a potential carry-over effect with regard to PTT measurement were analysed using Cronbach's coefficient α. All statistical analyses were performed using the statistical package IBM® SPSS® Statistics 21.[‡] A p-value of <0·05 was considered statistically significant.

Results

PTT measurements

Figure 2 shows repeated PTT measurements taken once a week for 6 weeks. The three-way repeated measures ANOVA incorporating the Tukey–Kramer *post hoc* test showed that the first measurement was the smallest among all PTTs at each frequency ($P < 0{\cdot}05$), and the PTTs gradually became constant thereafter. The Cronbach's coefficient α of PTTs calculated based on 6 days of PTT measurements of 5, 250 and 2000 Hz was 0·97, 0·95 and 0·97, respectively. The measurement consistency was very high.

Figure 3 shows PTTs observed for different frequency orders. The Cronbach's coefficient α calculated for the three different orders for each frequency (first measurement, second measurement and third measurement) of 5, 250 and 2000 Hz was 0·91, 0·87 and 0·90, respectively. Three PTTs obtained in different orders at each frequency were almost same. Therefore, it was shown that there was no carry-over effect

‡SPSS-IBM Inc., IL, USA.