A Study of the Surface Roughness of Tongue Cancer and Leukoplakia Using a Non-contact Three-dimensional Curved Shape Measuring System

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Nagaoka S, Hirata Y, Iwaki H, Sakamoto K, Takagi M and Amagasa T: A study of the surface roughness of tongue cancer and leukoplakia using a non-contact three-dimensional curved shape measuring system. *Oral Med Pathol* 2001; 6: 85-90, ISSN 1342-0984.

The surface roughness (SR) of the tongue intonguettdicates various aspects of abnormal epithelial hyperplasia, including leukoplakia and squamous cell carcinoma (SCC). Quantification of surface roughness value (SRV) would provide clinicians with more precise estimates of lesions than visual inspection alone. SRV was measured and calculated for 40 tongues with SCC, 20 tongues with leukoplakia and 14 normal tongues, using a non-contact, three-dimensional curved shape measuring and data analysis system. SCC and leukoplakia-affected tongues showed a higher SRV than normal tongues, and SCC showed the highest SRV ($p<0.05$). The mean SRVs of normal tongue, leukoplakia and SCC were 51.1 mm, 203.5 (m, and 300.9mm, respectively. Well differentiated SCC showed higher SRV than moderately or poorly differentiated SCC ($p<0.05$).

Our results demonstrate that SRV is an excellent indicator of SR and can be used by clinicians to support the correct diagnosis and proper treatment of abnormal epithelial hyperplasia.

Key words: tongue squamous cell carcinoma; leukoplakia; surface roughness; surface roughness value; non-contact 3-D shape measurement system

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Introduction

Visual inspection plays an important role in clinical oral medicine, providing important information necessary for correct diagnosis. Although the diagnostic value of ocular inspection is significant, the evaluation and description of its results rely on subjective observations by clinicians, which sometimes lead to misinterpretation and misunderstanding of lesions. This lack of objectivity contrasts with other clinical laboratory procedures, such as biochemistry or blood examination.

Quantitative standardization of visual inspection would help to compensate for these disadvantages. A rough and uneven surface frequently indicates abnormal epithelial hyperplasia or ulcer formation caused by malignancy. Amagasa *et al.* focused on the surface roughness (SR) of dysplastic lesions of the oral epithelium and tried to quantify the SR of oral mucosa. They calculated the Rmax value, which is the distance between the highest and the lowest point of the subject (1-2), using several sections cut from a replica in a fixed direction. However, their Rmax was a two-dimensional index from only lim-

ited data. Also, the error ascribed to the lower value was not negligible because Rmax was calculated from only two point values. As the oral mucosa consists of a three-dimensional (3-D) structure, clinicians require an improved index to provide a 3-D analysis representing most of the lesion. Such an index should be reproducible and be based on thorough data collection and evaluation. A non-contact 3-dimensional measurement system using semiconductor laser light has been developed recently (3-4-5). This system has enabled us to measure and analyze the 3-D structure of mucosal surfaces. In this study, we perform a 3-D evaluation of the SR of the tongue that is affected by oral cancer or leukoplakia, and demonstrate the effectiveness of SR quantification in clinical oral medicine.

Materials and Methods

Patients

We examined 40 patients with SCC of the tongue (26 men, 14 women; mean age 59.5 years), 20 patients with leukoplakia of the tongue (10 men, 10 women; mean

age 60.0 years; with or without epithelial dysplasia), and 14 volunteers with normal tongue (9 men, 5 women; mean age 54.1 years), at the First Department of Oral and Maxillofacial Surgery, Tokyo Medical and Dental University Hospital, between April 1999 and August 2000 (Table 1). None of the patients had previously received preoperative chemotherapy or radiotherapy. Tongue SCC were classified according to World Health Organization (WHO) criteria: T-category (size of tumor), clinical pattern (exophytic or endophytic) and histological characteristics.

Evaluation of SR of the tongue

Lesions which occurred on the lateral border of the tongue were examined in this study (6). The healthy lateral borders of the tongue facing the first molar served as a negative control. A precise negative replica of each lesion or healthy control was made by taking its impression using silicone rubber impression material (Exahiflex®, GC Corp., Japan). A positive replica was then made with cold-curing pour resin (Flowing®, Kanebo Corp., Japan). The SRV of the positive replica was mea-

Fig. 1: The principle of measurement by VOXELAN HEV-50S®. Measurement precision is 20.0mm in the field of vision range (9.800mm×9.185mm), using a 61,440 (256×240) pixel format. The size of a pixel is 38.4mm×38.4mm.

sured using the non-contact 3-D shape measurement system (Voxelan HEV-50S[®], Hamano Engineering Corp., Japan). The principle of measurement by Voxelan HEV-50S[®] is illustrated in Fig.1. The construction of the illumination and image pickup system involves rotational scanning of a slit beam over the object's entire surface from diagonally above, as well as picking up the image with a telecamera placed directly above. In the conventional visual cutting method, the position of a slit beam was extracted from each slit beam image, and the original shape was found by restructuring the position.

In contrast, the main feature of this method is that image synthesis is employed for original shape regeneration using the photographed slit beam image. This method provides realtime operation of an image synthesizing unit, the image encoder. A projection angle coded image $q(x, y)$ is synthesized at the moment it passes each point of an object in order to measure the value of the point. This is performed using the projection angle of a slit beam. Then, the shape is regenerated based on the coded image. The value for each pixel of $q(x, y)$ corresponds to the elevation angle from each point on the surface to the slit beam rotating axis. Given that the perspective of the telecamera is ignored, the object's height shape $f(x, y)$ can be found as: $f(x, y) = z_0 - (x_0 - x) \tan q(x, y)$ where x_0 and z_0 are

representative of x-coordinate and z-coordinate of the slit beam rotating axis, respectively.

An image encoder is a system used to produce coded images through real-time processing of a video signal input by a telecamera. Data were analyzed using the software package 3-D Rugle[®] (Medic Engineering Co., Japan). To express SR as a numerical value (the SRV), we applied ten-point average roughness based on Japanese Industrial Standards (JIS) criteria. The original ten-point average roughness is obtained from a flat object and calculated by measuring the deviation from a flat plane. In order to apply this index to uneven objects, we measured the distance from each point to a standard plane surface. The standard plane was calculated by computationally conducting a smoothing process on the original plane. The standard plane was produced by setting the 9×9 domain average of the original plane as the value of the central coordinate. This smoothing procedure was repeated 20 times. The number of repetitions was decided by the pilot test as follows: 5, 10, 20, 40, and 80 replicates of the smoothing process were performed and the SRV were compared. The SRV tend to converge as the number of replicates increases, and 20 repetitions were deemed to be sufficiently accurate for our purposes. The original SR plane was superimposed on the standard plane, and the

Fig. 2: Data analysis by 3-D Rugle. (A) Wire frame image. (B) The plane of tongue surface (a), the standard plane (b), and the normal vector (n) are shown. (C) Calculation of SRV (mm) in 3-D Rugle[®]. Normal vector lengths of the highest (p1, p2, p3, p4, p5) and the lowest (q1, q2, q3, q4, q5) points were measured, and SRV were calculated by the following equation.

$$SRV(mm) = ([p1+p2+p3+p4+p5] + [q1+q2+q3+q4+q5]) / 5$$

Fig. 3: Comparison of SRV of normal tongue, leukoplakia and SCC

normal vector length from the standard plane was measured as the height of the spot. We followed the modified evaluation method of ten-point average roughness.

Statistical analysis

The SRV were compared using one-way ANOVA and Sheffe's multiple comparison test. Data from two independent groups were compared using the Mann-Whitney U-test for non-parametric data. Differences at $p < 0.05$ were considered significant.

Results

Reproducibility of SR and reliability of SRV

The SR of the normal tongues can be reproduced well on a replica model (7). To check the reliability of SRV, triplicate replica models were prepared from a tongue and the SRV of each model was compared. Two independent normal tongues were measured in this pilot test and the SRV were 72.2, 73.4, and 72.8mm (maximum error 1.64%) and 52.0, 54.4, and 53.8mm (maximum error 4.49%) respectively. The error was sufficiently low in our measuring system to be considered suitable for evaluating SR with high reproducibility.

Comparison of SRV of normal tongue, leukoplakia and SCC

The mean SRV of normal tongue was 51.1mm, ranging from 13.5mm to 108.4mm ($n=14$). The mean SRV of leukoplakia was 182.3mm, ranging from 55.4mm to 308.0mm ($n=20$). The mean SRV of SCC was 300.9mm, ranging from 14.0mm to 686.0mm ($n=40$). The mean SRVs of leu-

koplakia and SCC were significantly higher than that of the control normal tongue ($p < 0.01$). The mean SRV of SCC was significantly higher than that of leukoplakia ($p < 0.05$) (Table 2). Fig 3 shows SRVs exceeding 350mm are SCC cases only. Values from 150mm to 349mm include SCC and leukoplakia; 50mm to 149mm include SCC, leukoplakia and normal epithelia and 0mm to 49mm include SCC and normal epithelia. For SCC cases, 92.5% (37/40) showed a SRV higher than the mean value of normal tongue (51.1 (m). All samples exceeding 308.0mm (maximum SRV of leukoplakia) were SCC. 45% (18/45 sample) of the SCC exceeded this value. Only 5% (1/20) of leukoplakia samples exceeded 300.9mm (the mean value of SCC). There was no significant correlation between the SRVs of leukoplakia (Table 3), the histopathological grades of dysplasia and the clinical patterns which were classified as either homogeneous (flat, corrugated, wrinkled, pumice-like) or non-homogeneous (verrucous, nodular, ulcerated, erythroleukoplakia). There was no significant difference between SRV of T1, T2, and T3 SCC. The mean SRV of the exophytic tumor was 350.2mm (range 77.8-686.0mm). For the endophytic tumor, the mean SRV was 218.9mm (range 14.0mm-613.6mm). The SRV of exophytic tumor was significantly higher than that of endophytic tumor ($p < 0.05$), and 76% (19/25) of the exophytic tumor was Grade I SCC. The mean SRV of Grade I SCC was 356.3mm (range 82.6-613.6mm), while the mean SRV of Grade II and III SCC was 226.0mm (range 14.0-686.0mm). SRV of Grade I was significantly higher than Grade II or III ($p < 0.05$) (Table 4).

Discussion

Visual examination is the basic way to collect information on the character of a lesion, yielding data about the size, color, stiffness, roughness and other features. However, the estimation of these features depends on the experience and objectivity of the clinician. This is very different from the majority of laboratory-based examinations in which information about the patient's condition is described as a numerical value. Precise estimation and description of the patient's physical condition are essential for correct diagnosis, treatment and follow-up, and clinical medicine requires a greater quantification of visual examination data.

In the diagnosis of tongue cancer, it is important to take into account the surface roughness, color and consistency of the lesions. For measuring consistency of the oral mucosa, Sato introduced an instrument capable of measuring consistency which a function of load needed to displace oral mucosa 2.0mm using a probe 2.0mm in diameter, and he reported that SCCs were ascertained to be statistically harder than the normal mucosa (8-9). Ogura *et al.* devised an instrument capable of measuring consistency, which a function of load needed to displace tongue by 1.0mm by a probe 1.0mm in diameter, and reported that differences in consistency among tongue carcinoma, leukoplakia, and normal tongue were significant (10-11). Miyakura *et al.* reported the detailed consistency values of healthy oral mucosa (12).

Quantification of palpation data alone is not enough for clinical diagnosis. Little is known about quantification of visual examination data. We focused on the tongue SR which suggests abnormal proliferation of the epithelium, and tried to quantify SR by developing a data collection and analysis system. SR is a mixture of various kinds of unevenness such as defects by ulcers, elevation by tumor growth, and normal epithelial waving. The most important information in this respect is about the small-scale waving of the epithelium that indicates abnormal proliferation. Therefore, we used fine-scale scanning (256 (240 pixel) devices and applied the ten-point average roughness with a standard plane specially designed for extracting small-scale roughness. It should be noted that SRV does not represent large-scale roughness, such as ulcer or swelling. Amagasa *et al.* tried to quantify the SR of oral mucosa, and reported that an instrument using the light sectioning method and a micron depth and height measuring scope was most suitable for measuring SR (1-2). However, suitability of their instrument for clinical SR determination was low due to the lack of a small-scale roughness measurement and a direct performance measurement.

In our study of measuring oral mucosa using a non-contact 3-D curved shape measuring system we measured small-scale roughness and, in addition, we developed the possibility of recording the tissue surface form by direct

laser scanning. We also demonstrated that the SRV of the tongue significantly increases in SCC and leukoplakia. Only 92.5% (37/40) of SCC cases showed a SRV higher than the mean value (51.1mm) of normal tongue. The SRV for leukoplakia was never less than this value. The mean SRV of SCC was significantly higher than that of leukoplakia. It should be noted that our measurement system detects fine-scale roughness, such as waving of the keratin layer, and not unevenness of the gross structure. Therefore, an increase in the SRV is mainly attributable to abnormal and uncoordinated epithelial proliferation, but not to defect formation due to ulceration or swelling due to tumor outgrowth. All samples with SRV exceeding 308.0mm (maximum SRV of leukoplakia) were SCC, and 45% (18/40 samples) of SCC exceeded maximum SRV of leukoplakia. Only 5% (1/20) of leukoplakia samples exceeded the SCC mean value (300.9mm). These results imply that SCC should be suspected when SRV exceeds 350.0mm. In SRVs from 0mm to 49mm SCC and normal epithelia should be suspected; from 50mm to 349mm SCC and leukoplakia should be suspected (Fig3).

Lumerman *et al.* reported that 16% of leukoplakia showed development of invasive SCC(13). Banoczy *et al.* pointed out that the frequency of carcinomatous change is greater in verrucous leukoplakia (4.6%) than in leukoplakia simplex (0%) but not as great as in erosive leukoplakia (28%) (14). Thus the histopathological marker of a premalignant disorder of the oral mucosa presents clinically as leukoplakia. However, quantitative clinical standardization of leukoplakia or SCC has not been reported. We demonstrated that SRV is an excellent indicator of SR and useful for clinicians to support the correct diagnosis and proper treatment of leukoplakia and SCC. It also will support other imaging techniques (15-16) such as computed tomography (CT), magnetic resonance imaging (MRI), and ultrasonography (US).

The epithelium of the oral cavity undergoes an abnormal squamous differentiation with keratinization during oral carcinogenesis. Prediction of keratinization and histopathological differentiation from SR provides very effective information for clinicians. Correlations between SRVs and WHO classification which reflect the anaplasticity of the lesions were discussed. SRV of Grade I was significantly higher than Grade II or III. The SRV of exophytic tumor was significantly higher than that of endophytic tumor. 76% (19/25) of the exophytic tumor was Grade I SCC. Thompson *et al.* reported patients with exophytic SCCs have a better prognosis than those with conventional SCCs (17). Our results indicate that high SRV of SCCs reflects exophytic growth, which tends to be well-differentiated and low in malignancy, and that SRV is a useful indicator for reflecting the anaplasticity of oral cancer. However, further development of our system will be required in order to perform direct measurement of tissues.

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(Accepted for publication November 17, 2001)