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가상모형 교두 면적과 부피를 이용한 치아마모 정량 계측법 개발

Development of quantitative measurement methods for tooth wear using area and volume of virtual model cusps

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치의과학과 구강해부학 전공

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지도교수 이 승 표

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<Abstract>

Development of quantitative measurement methods for tooth wear using area and volume of virtual model cusps

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Objectives: Tooth wear represents the decrease of tooth enamel structure which is the result of the combined effects of many mechanisms. Clinicians must examine the level of tooth wear with specific criteria for the proper diagnosis of the oral health of the patient. Until now, there have been many ways to measure tooth wear. The advantages of qualitative methods are that they are intuitive, rapid, and do not require specific space or equipment. The disadvantages are that the methods are more subjective and require guidelines for training and calibration to ensure the reliability of the data. We have already developed new quantitative methods using virtual models with limitations. Therefore, the purpose of this study was to develop and evaluate easier and more intuitive quantitative parameters using cusp area and volume.

Methods: The subjects in this study are the identical virtual models used in the former study. Ninety maxillary and mandibular dental casts were prepared and rendered as virtual 3D models and stored in the computer hard disc as CAD image files. The same age group classification and NTWI scoring system were also reused. The reference highest point of each cusp was marked on the first molar of the virtual models and a virtual occlusal plane was generated with these reference points. The plane was then lowered vertically from 0.2, 0.4, 0.6, and 0.8 mm to create offset planes. The area and volume of each cusp was then measured and added together at the level of 0.2, 0.4, 0.6, and 0.8 mm, respectively. In addition to the former analysis, the differential characters of each cusp were analyzed.

Results: The scores of the new parameters were better than the former study for the differentiation of the age and new tooth wear index (NTWI) groups. Spearman's ρ coefficients between the total area and each cusp area also showed higher scores in area of 0.6 mm (0.6A) and 0.8A. The mesiolingual cusp (MLC) differed statistically ($P < 0.01$) with other cusps in the paired t-test. Also, the MLC exhibited the highest percentage of change of 0.6A within the age and NTWI groups. In the case of age groups, the MLC showed the highest score in groups 1 and 2. In the case of the NTWI groups, the MLC was not significantly different in groups 3 and 4. Those results coincided with the opinion that the lingual cusp exhibits rapid wear because it works as a functional cusp.

Conclusions: Although this study has limitations because it is a cross-sectional study, it suggests better quantitative parameters and analysis tools for each cusp wear characteristic. Therefore, these results are helpful to clinicians and researchers who are conducting studies on tooth wear.

Keywords: virtual model, parameters, quantitative analysis, differential wear, cusp
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Development of quantitative measurement methods for tooth wear using area and volume of virtual model cusps

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Contents

Ⅰ. Introduction

Generally, the cause of tooth wear is divided among attrition, abrasion, erosion, and cusp fracture. Regardless of etiology, tooth wear represents the decrease of tooth enamel structure which is due to the combined effects of these mechanisms. Clinicians should examine the level of tooth wear with specific criteria for the proper diagnosis of the oral health of the patient.

Until now, there are many ways to measure tooth wear. Many researchers and clinicians have developed qualitative or quantitative methods for their own studies. Typically, qualitative methods are conducted by trained clinicians through intraoral or dental cast examinations. The advantages of these methods are that they are intuitive, rapid, and do not require specific space or equipment. Eccles (1979) introduced the erosion index, which allows for broad interpretation. Smith and Knight (1984) proposed a more comprehensive tooth wear index concept that included attrition, abrasion, and erosion. Based on this concept, other indices were introduced. Hooper (2004) proposed a new tooth wear index (NTWI) for incisal/occlusal wear. Since then, many qualitative methods have been suggested for erosion (Larsen et al., 2000) and restorative materials status (Dahl et al., 1989, Oilo et al., 1987).

The disadvantages of qualitative methods are that they are more subjective and require guidelines for training and calibration to ensure the reliability of the data (Hooper et al., 2004, Smith and Knight, 1984). Moreover, various indices lead to a lack of standardization and problems in direct comparison of the results between studies. On the other hand, quantitative methods combined with 3D reconstructed virtual dental models have many advantage. When researchers measure the status of wear quantitatively, they require less training and no calibration. The results are expressed as ratio scale numbers and are not on the ordinal scale. Therefore, sophisticated statistical analyses are possible. Also, 3D scanner technology and specified software have been further developed and are easy to use.

Generally, clinicians consider that the lingual cusps of the maxilla and the buccal cusps of the mandible wear more rapidly because they are functional cusps (Hillson, 1996). Faster worn cusps could increase the accuracy of measurement. Therefore, if main functioning cusp wear is measured separately, more reliable results can be obtained even though measuring all cusps can give more comprehensive results (Mays, 2002).

We have already developed new quantitative methods using virtual models for the measurement of tooth wear with limitations. For example, too many points were imprinted, the definitions of the parameters were not easy to understand, and checking on the wear condition of each separated cusp was impossible. Therefore, the purpose of this study was to develop and evaluate easier and more intuitive quantitative parameters using the cusp area and volume.

Ⅱ. Material and Methods

The subjects in this study are the identical virtual models used in the former study (Lee et al., 2012b). Briefly, ninety maxillary and mandibular dental casts were prepared and rendered as virtual 3D models and stored in the computer hard disc as CAD image files. The same age group classification and data from the new tooth wear index (NTWI) scoring were also reused. Intra- and inter-observer reproducibility of the NTWI scoring was already obtained by kappa and PASs in the former study.

The dental casts were scanned repeatedly ten to twenty times with an Opto TOP-HE 3D scanner (Breuckmann GMBH, Meersburg, Germany). After scanning, information about the full-mouth dental casts including undercuts was obtained. Digital dental casts were combined and rendered as three-dimensional models using Rapidform XO software (INUS Technology, Seoul, South Korea). The three-dimensional models were then measured and analyzed with Rapidform 2004 software (INUS Technology, Seoul, South Korea).

The highest point of each cusp was marked as a reference on the first molar of the virtual models using the automatic recognition function of the software. A virtual occlusal plane (VOP) was generated with these reference points (Table 1). In the case of the maxilla, only MBCP, MLCP, and DBCP were used for the plane because the level of the DLCP was quite low and small in size. This is the same concept with the BOP of the former study (Fig. 1). In the case of the mandible, the MBCP, MLCP, DBCP, and DLCP were involved using the function of the least square method of the software. The plane was then lowered vertically from 0.2, 0.4, 0.6, and 0.8 mm, respectively, to create the offset planes. The area and volume of each cusp were then measured and added together at the level of 0.2, 0.4, 0.6, and 0.8 mm for the respective cusps (Fig. 2). The area and volume at the level of 0.2 abbreviated as 0.2A and 0.2V, for example.

Intra- and inter-observer reproducibility for NTWI scoring were already determined in the former study. Intra-class correlation (ICC) and the standard deviation of measurement error (SDME) for area and volume data were calculated in ten samples using the methods in a former study.

All the data were sub-grouped according to age and NTWI score groups. The mean ± the standard deviation of each subgroup was calculated and a one-way analysis of variance (ANOVA) test was performed followed by Duncan's test as a post-hoc analysis for testing the subgroup difference. Non-parametric Spearman's ρ coefficients were calculated between all parameters and age and NTWI groups

To compare the differential characters of each cusp, 0.6A of maxilla was selected. The wear rate of 0.6A of each cusp between the age and NTWI groups was expressed as a percentage. In addition, non-parametric Spearman's ρ coefficients were calculated between 0.6A of each cusp of the maxilla and age and NTWI groups. Statistical analysis was performed using statistical software (SPSS 11.5, SPSS Inc., Chicago, Ill).

Ⅲ. Results

Since the subjects of this study are the identical virtual models used in the former study, the same age group classification and NTWI scoring system were also reused. Intra- and inter-observer reproducibility of NTWI scoring was already checked by kappa and PASs in the former study.

The reproducibility of the quantitative measurements with new parameters were determined by ICC and SDME. ICC was very high (over 0.99) and SDME was low (0.32 - 0.62 in area and 0.07 - 0.33 in volume), which demonstrated that the inter-observer difference was negligible. These parameters exhibited good reproducibility even though the 0.2 mm level area and volume showed the worst value.

The means and standard deviations of each of the parameters are presented following the age and NTWI groups (Tables 2 and 3) with the significance results of the one-way ANOVA. In the age groups, all the parameters of the maxilla and mandible were significantly different between the groups and with post-hoc Duncan's test except of 0.2A of the mandible and 0.2V of the maxilla and mandible. In the NTWI groups, the 0.6A and 0.8A of the maxilla was different in every group and 0.6A and 0.8A of the mandible was different in four groups with the post-hoc Duncan's test. The findings from this study were better than the results found in the former study. Spearman's ρ coefficients for correlations between the wear parameters, age, or NTWI groups are shown in Table 4. All the parameters were statistically significant ($P < 0.01$). The scores of 0.6A and 0.8A of both the maxilla and mandible were higher compared to the former study parameters like buccal cusp angle (BCA).

MBC and DBC did not exhibit a difference in 0.6A of the maxilla while the MLC differed statistically ($P < 0.01$) with MBC and DBC in the paired t-test. In the mandible, every cusp showed a statistical difference ($P < 0.01$) in 0.6A (Tables 5 and 6).

In the maxilla, the MLC exhibited the highest percentage change in 0.6A within the age and NTWI groups compared to the other cusps (Table 7), while changes in all the cusps were similar in the mandible (Table 8).

Table 9 displays the Spearman's ρ coefficients between the total area and each cusp area of 0.6A. In the case of the age groups, the MLC showed highest score in groups 1 and 2, while the DBC exhibited the highest score in group 3. In the case of the NTWI groups, the DBC showed a constant high score, while the MLC was not significantly different in groups 3 and 4.

Ⅳ. Discussion

In this study, quantitative analysis parameters were newly developed and evaluated. Although the authors had already developed and evaluated the distance and angle parameters, they were not simple or intuitive and made isolated cusp analysis impossible.

As the tooth undergoes wear, the tip of cusp is gradually changed to a blunt form making the cusp height lower than before. As a result, the total tooth crown height is lowered and the horizontally sectioned area and volume of the tooth are enlarged. There have already been studies measuring crown height from the cemento-enamel junction (CEJ) to the cusp tip (Mehta and Evans, 1966); Walker et al., 1991. Errors can be introduced through this method by the measuring direction and subjective judgment (Mays 1995). Other sophisticated quantitative measuring methods used depth gauge and moiré fringe patterns even though equipment-dependent limitations still remained (Ozaki et al., 1987, Tomenchuk and Mayhall, 1979). The concept of depth gauge method was applied to the former study to the deepest point distance, while the moiré fringe pattern method was similar to this study. The main difference between the moiré fringe pattern method and this study method was that not only the cusp height was measured, but the area according to the cusp height was also determined, which was impossible with the traditional analogue technique. Butler (Butler, 1972) demonstrated a similar technique by using the occlusal plane and a protractor to measure the angle of the helicoidal plane even though a slight variation in alignment resulted in angle differences. Other quantitative methods use in vitro devices that have been developed to test the physical characteristics and clinical usefulness of dental materials (Kaidonis et al., 1998) and attempted to simulate the oral cavity environment and produce reliable and repeatable results. However, if different devices are applied, the results could vary with the same materials (Heintze et al., 2005). Because internationally accepted in vitro methods do not exist, there are many limitations in examining tooth wear conditions (Lee et al., 2012a).

Therefore, we developed and evaluated new parameters (Lee et al., 2012b). They assessed distances and angles involving at least two cusps simultaneously. However, they were somewhat conceptual and difficult to understand without figures making the interpretation of each cusp wear tendency impossible. New parameters in this study use the nature of cusp wear itself along with the sectioned area and volume. Wear facets have been measured through the morphometric analysis of molar crowns (Brothwell, 1981) or by using the Occlusal Fingerprint Analysis method (Fiorenza et al., 2009) which took into account the projected cusp area to reference the cervical plane. This method required the area of the occlusal plane floor and was not suitable for detecting longitudinal wear change. Regarding the volume analysis, we had attempted to measure the amount of cusp wear using a surface matching algorithm which required data sets and a long study period (Pintado et al., 1997). Even the wear amount difference in the matching models was very small which resulted in significant errors. To overcome these problems, new parameters were developed using the occlusal plane.

For evaluation, the measured data were subdivided into age and NTWI following the former study. Comparing the results with the former study, this study showed a more distinct difference between the groups in the ANOVA test especially for the maxilla parameters in the NTWI groups. There were no former parameters that could differentiate every group. Although the cusp plane height from the central pit had the most powerful discrimination capacity, it was increased in the more worn group (NTWI score 1) compared to the score 0 group. 0.6A and 0.8A of this study clearly exhibited a clear difference between NTWI scores 0 and 1. While 0.6A and 0.8A were differentiated in only four groups in the mandible, they did not discriminate between NTWI scores 0 and 1. This may due to the small number of cases of NTWI score 0 (three cases) and differential wear pattern of the lingual cusp of the mandible (Lee et al., 2012b). Spearman's ρ coefficients between the wear parameters, age group, and NTWI group also exhibited a similar tendency. 0.6A and 0.8A showed stronger coefficients than the former study. Therefore, this study demonstrated an improved method for tooth wear research.

Another advantage of this method was the ability to present the differential wear status of each cusp. First, each cusp area was statistically compared using the paired t-test. The MBC and DBC of the maxilla did not differ from each other through all the slice heights. This demonstrated that the cusp sizes were similar and that the MLC size was larger than other cusps as expected. The MBC was the largest in the mandible followed by the DBC, MLC, and DLC listed in the order of decreasing area size. However, this result is not directly connected with 'real cusp size' especially in older subjects because of tooth wear tendencies. Typically, the buccal cusps of the mandible exhibit wear and rounded tips with relatively unworn lingual incline surfaces while the lingual cusps showed relatively sharp tips and worn buccal inclines. Therefore, the parameters of this study are reflected by tooth wear tendencies.

Generally, the maxilla exhibited clearer results than the mandible and 0.6A and 0.8A showed clearer results than the other parameters. However, 0.8A could not be measured in some cases while 0.6A of the maxilla was selected for focused analysis. 0.6A_MLC showed a high coefficient score with the whole NTWI group, although it was low in groups 3 and 4. This may be related to the wear rate between groups 3 and 4. The gap was

51.51% while 0.6A_MBC and 0.6A_DBC were 8.95% and 14.41%, respectively. The area difference between age groups 1 and 3 and NTWI groups 0 and 4 were 90.37% and 194.49%, respectively. Moreover, 0.6A_MLC exhibited a statistical difference ($P < 0.01$) with MBC and DBC in the paired t-test. These results indicate that the amount of wear of the MLC is bigger than the MBC and DBC which is connected with differential wear patterns between the buccal and lingual cusps. This finding was previously suggested by the former study and the current study presented further evidence about functional and non-functional cusp wear difference which coincide with another study that the functional wear more rapidly than others (Hillson, 1996, Woda et al., 1987).

The average life expectancy of humans is increasing with the development of medical technology and improvement in living conditions. The geriatric population is growing rapidly in many countries. In North America, people over 65 years experienced pathological wear three times more than young people (Smith and Robb, 1996). Also, as more people are becoming interested in living a healthier and happier life, there is a sudden increase in demand for medical care.

Although this study has limitations because of it being a cross-sectional study, it has suggested better quantitative parameters and analysis tools for each cusp wear characteristic. Therefore, these results would be helpful to clinicians and researchers who are working on tooth wear studies.

References

BROTHWELL, D. R. 1981. Digging up bones : *the excavation, treatment, and study of human skeletal remains*, Ithaca, N.Y. London, Cornell University Press.

BUTLER, R. J. 1972. Age-related variability in occlusal wear planes. *Am J Phys Anthropol,* 36, 381-90.

DAHL, B. L., KROGSTAD, B. S., OGAARD, B. & ECKERSBERG, T. 1989. Differences in functional variables, fillings, and tooth wear in two groups of 19-year-old individuals. *Acta Odontol Scand,* 47, 35-40.

ECCLES, J. D. 1979. Dental erosion of nonindustrial origin. A clinical survey and classification. *J Prosthet Dent,* 42, 649-53.

FIORENZA, L., BENAZZI, S. & KULLMER, O. 2009. Morphology, wear and 3D digital surface models: materials and techniques to create high-resolution replicas of teeth. *J Anthropol Sci,* 87, 211-8.

HEINTZE, S. D., ZAPPINI, G. & ROUSSON, V. 2005. Wear of ten dental restorative materials in five wear simulators--results of a round robin test. *Dent Mater,* 21, 304-17.

HILLSON, S. 1996. Dental anthropology, Cambridge England ; New York, Cambridge University Press.

HOOPER, S. M., MEREDITH, N. H. & JAGGER, D. C. 2004. The development of a new index for measurement of incisal/occlusal tooth wear. *J Oral Rehabil*, 31, 206-212.

KAIDONIS, J. A., RICHARDS, L. C., TOWNSEND, G. C. & TANSLEY, G. D. 1998. Wear of human enamel: a quantitative in vitro assessment. *J Dent Res,* 77, 1983-90.

LARSEN, I. B., WESTERGAARD, J., STOLTZE, K., LARSEN, A. I., GYNTELBERG, F. & HOLMSTRUP, P. 2000. A clinical index for evaluating and monitoring dental erosion. *Community Dent Oral Epidemiol,* 28, 211-7.

LEE, A., HE, L. H., LYONS, K. & SWAIN, M. V. 2012a. Tooth wear and wear investigations in dentistry. *J Oral Rehabil,* 39, 217-25.

LEE, S. P., NAM, S. E., LEE, Y. M., PARK, Y. S., HAYASHI, K. & LEE, J. B. 2012b. The development of quantitative methods using virtual models for the measurement of tooth wear. *Clin Anat,* 25, 347-58.

MAYS, S. 2002. The Relationship Between Molar Wear and Age in an Early 19th Century AD Archaeological Human Skeletal Series of Documented Age at Death. *J Archaeol Sci,* 29, 861-871.

MEHTA, J. D. & EVANS, C. C. 1966. A study of attrition of teeth in the Arkansas Indian skulls. *Angle Orthod,* 36, 248-57.

OILO, G., DAHL, B. L., HATLE, G. & GAD, A. L. 1987. An index for evaluating wear of teeth. *Acta Odontol Scand,* 45, 361-5.

OZAKI, T., KANAZAWA, E., SEKIKAWA, M. & AKAI, J. 1987. 3-Dimensional Measurements of the Occlusal Surfaces of the Upper Molars in Australian Aboriginals. *Aust Dent J,* 32, 263-269.

PINTADO, M. R., ANDERSON, G. C., DELONG, R. & DOUGLAS, W. H. 1997. Variation in tooth wear in young adults over a two-year period. *J Prosthet Dent,* 77, 313-320.

SMITH, B. G. & KNIGHT, J. K. 1984. An index for measuring the wear of teeth. *Br Dent J,* 156, 435-8.

SMITH, B. G. & ROBB, N. D. 1996. The prevalence of toothwear in 1007 dental patients. *J Oral Rehabil,* 23, 232-9.

TOMENCHUK, J. & MAYHALL, J. T. 1979. A correlation of tooth wear and age among modern Igloolik eskimos. *Am J Phys Anthropol,* 51, 67-77.

WODA, A., GOURDON, A. M. & FARAJ, M. 1987. Occlusal contacts and tooth wear. *J Prosthet Dent,* 57, 85-93.

Table 1. Reference point and virtual occlusal planes in maxillary and mandibular first molar

Reference	Description
MBCP (mesiobuccal cusp point)	The highest point of the mesiobuccal cusp
MLCP (mesiolingual cusp point)	The highest point of the mesiolingual cusp
DBCP (distobuccal cusp point)	The highest point of the distobuccal cusp
DLCP (distolingual cusp point)	The highest point of the distolingual cusp

Table 2. Means and Standard Deviations for the Parameters in the Age Groups[a]

Age Group (No. subjects)	Parameters (Maxilla)	Mean ± STDEV (mm² or mm³)	Duncan's test	Parameters (Mandible)	Mean ± STDEV[b] (mm² or mm³)	Duncan's test
1 (30)	0.2A*	5.21 ± 1.80	A	0.2A*	7.95 ± 2.20	A
2 (30)		7.88 ± 1.79	B		10.47 ± 3.94	B
3 (30)		10.77 ± 4.10	C		11.88 ± 4.15	B
1 (30)	0.4A*	11.14 ± 2.57	A	0.4A*	15.89 ± 3.57	A
2 (30)		16.23 ± 2.87	B		20.67 ± 5.85	B
3 (30)		21.53 ± 5.93	C		24.54 ± 6.41	C
1 (30)	0.6A*	18.66 ± 3.75	A	0.6A*	25.45 ± 5.26	A
2 (30)		25.63 ± 4.02	B		32.93 ± 7.51	B
3 (30)		33.48 ± 7.41	C		37.89 ± 8.10	C
1 (30)	0.8A*	27.48 ± 4.83	A	0.8A*	36.70 ± 6.49	A
2 (30)		36.44 ± 5.34	B		46.26 ± 8.45	B
3 (30)		46.47 ± 8.96	C		51.98 ± 9.27	C
1 (30)	0.2V*	0.58 ± 0.33	A	0.2V	1.04 ± 0.37	A
2 (30)		0.84 ± 0.27	A		1.35 ± 0.90	AB
3 (30)		1.29 ± 0.86	B		1.61 ± 0.84	B
1 (30)	0.4V*	2.18 ± 0.75	A	0.4V*	3.40 ± 0.91	A
2 (30)		3.23 ± 0.70	B		4.40 ± 1.89	B
3 (30)		4.49 ± 1.76	C		5.36 ± 1.91	C
1 (30)	0.6V*	5.15 ± 1.38	A	0.6V*	7.48 ± 1.76	A

2 (30)		7.40 ± 1.34	B		9.84 ± 3.12	B
3 (30)		9.94 ± 3.00	C		11.46 ± 3.20	C
1 (30)	0.8V*	9.75 ± 2.21	A	0.8V*	13.57 ± 2.91	A
2 (30)		13.58 ± 2.23	B		17.60 ± 4.61	B
3 (30)		17.84 ± 4.46	C		20.13 ± 4.83	C

[a]The same letters indicate a non-significant difference between the groups based on the post hoc Duncan's test. Statistical significances were tested by one-way ANOVA among the groups (*P < 0.01, **P < 0.05).

[b]STDEV, standard deviation.

Table 3. Means and Standard Deviations for the Parameters in NTWI Groups[a]

NTWI group (No. subjects of Maxilla and Mandible)	Parameters (Maxilla)	Mean ± STDEV (mm² or mm³)	Duncan's test	Parameters (Mandible)	Mean ± STDEV[b] (mm² or mm³)	Duncan's test
0 (8, 3)	0.2A*	4.49 ± 1.06	A	0.2A*	6.22 ± 1.05	A
1 (22, 24)		5.79 ± 2.04	A		7.90 ± 1.93	AB
2 (25, 29)		7.51 ± 1.70	B		9.17 ± 2.40	BC
3 (18, 18)		9.05 ± 2.67	B		11.69 ± 4.63	C
4 (17, 16)		13.23 ± 4.01	C		14.52 ± 3.31	D
0 (8, 3)	0.4A*	9.85 ± 2.08	A	0.4A*	13.19 ± 1.95	A
1 (22, 24)		12.18 ± 2.79	A		15.79 ± 3.06	AB
2 (25, 29)		15.75 ± 2.85	B		19.14 ± 3.82	B
3 (18, 18)		18.92 ± 4.00	C		22.83 ± 6.88	C
4 (17, 16)		25.05 ± 5.55	D		29.22 ± 3.17	D
0 (8, 3)	0.6A*	16.76 ± 3.18	A	0.6A*	21.44 ± 1.94	A
1 (22, 24)		20.09 ± 3.87	B		25.28 ± 4.38	A
2 (25, 29)		25.15 ± 4.04	C		30.53 ± 5.71	B
3 (18, 18)		29.81 ± 5.36	D		36.89 ± 7.83	C
4 (17, 16)		38.09 ± 6.28	E		43.36 ± 3.94	D
0 (8, 3)	0.8A*	25.18 ± 4.06	A	0.8A*	32.16 ± 2.12	A
1 (22, 24)		29.16 ± 4.96	B		36.53 ± 5.49	A
2 (25, 29)		35.65 ± 5.16	C		43.41 ± 6.87	B
3 (18, 18)		42.10 ± 6.63	D		51.12 ± 8.51	C
4 (17, 16)		52.40 ± 6.75	E		57.98 ± 4.47	D
0 (8, 3)	0.2V*	0.47 ± 0.14	A	0.2V*	0.75 ± 0.09	A
1 (22, 24)		0.65 ± 0.38	A		1.04 ± 0.37	AB
2 (25, 29)		0.78 ± 0.22	AB		1.10 ± 0.44	AB
3 (18, 18)		1.05 ± 0.70	B		1.59 ± 1.06	BC
4 (17, 16)		1.65 ± 0.87	C		2.08 ± 0.83	C

0 (8, 3)	0.4V*	1.87 ± 0.44	A	0.4V*	2.66 ± 0.37	A
1 (22, 24)		2.42 ± 0.84	AB		3.39 ± 0.83	AB
2 (25, 29)		3.08 ± 0.66	B		3.91 ± 1.02	BC
3 (18, 18)		3.82 ± 1.27	C		4.94 ± 2.24	C
4 (17, 16)		5.46 ± 1.70	D		6.72 ± 1.34	D
0 (8, 3)	0.6V*	4.52 ± 0.97	A	0.6V*	6.09 ± 0.76	A
1 (22, 24)		5.63 ± 1.50	A		7.44 ± 1.54	AB
2 (25, 29)		7.15 ± 1.31	B		8.83 ± 1.96	B
3 (18, 18)		8.63 ± 2.10	C		11.02 ± 3.52	C
4 (17, 16)		11.73 ± 2.74	D		13.78 ± 1.72	D
0 (8, 3)	0.8V*	8.68 ± 1.65	A	0.8V*	11.07 ± 1.04	A
1 (22, 24)		10.55 ± 2.35	A		13.53 ± 2.45	AB
2 (25, 29)		13.20 ± 2.19	B		16.04 ± 3.15	B
3 (18, 18)		15.81 ± 3.18	C		19.61 ± 5.13	C
4 (17, 16)		20.60 ± 3.82	D		23.55 ± 2.26	D

[a]The same letters indicate a non-significant difference between the groups based on the post hoc Duncan's test. Statistical significances were tested by one-way ANOVA among the groups ([*]P < 0.01, [**]P < 0.05).

[b]STDEV, standard deviation.

Table 4. Spearman's ρ Coefficients Between Wear Parameters and the Age or NTWI Groups

Parameters (Maxilla)	Age group	NTWI groups	Parameters (Mandible)	Age group	NTWI groups
0.2A	0.68	0.72	0.2A	0.47	0.62
0.4A	0.76	0.79	0.4A	0.61	0.74
0.6A	0.79	0.82	0.6A	0.64	0.79
0.8A	0.81	0.83	0.8A	0.66	0.80
0.2V	0.51	0.55	0.2V	0.36	0.49
0.4V	0.67	0.71	0.4V	0.50	0.65
0.6V	0.73	0.77	0.6V	0.57	0.73
0.8V	0.77	0.82	0.8V	0.60	0.76

Table 5. Comparison Between the MBC, MLC, and DBC Areas of the Maxilla Using Paired T-test

	Parameters (Mandible)	N	Mean ± STDEV (mm²)	ρ-value	Correlation
Pair 1	0.2A_MBC	87	3.07 ± 1.76	0.00	0.05
	0.2A_MLC	90	3.01 ± 1.74		
Pair 2	0.2A_MLC	90	3.01 ± 1.74	0.00	0.25
	0.2A_DBC	90	2.31 ± 1.38		
Pair 3	0.2A_MBC	90	2.37 ± 1.03	0.62	0.58
	0.2A_DBC	90	2.31 ± 1.38		
Pair 4	0.4A_MBC	90	4.84 ± 1.53	0.00	0.44
	0.4A_MLC	90	5.95 ± 2.69		
Pair 5	0.4A_MLC	90	5.95 ± 2.69	0.00	0.42
	0.4A_DBC	90	4.57 ± 1.96		
Pair 6	0.4A_MBC	90	4.84 ± 1.53	0.11	0.62
	0.4A_DBC	90	4.57 ± 1.96		
Pair 7	0.6A_MBC	90	7.40 ± 1.90	0.00	0.43
	0.6A_MLC	90	9.13 ± 3.84		
Pair 8	0.6A_MLC	90	9.13 ± 3.84	0.00	0.47
	0.6A_DBC	90	7.07 ± 2.39		
Pair 9	0.6A_MBC	90	7.40 ± 1.90	0.11	0.63
	0.6A_DBC	90	7.07 ± 2.39		

Pair 10	0.8A_MBC	90	10.19 ± 2.47	0.00	0.47
	0.8A_MLC	90	12.43 ± 4.44		
Pair 11	0.8A_MLC	90	12.43 ± 4.44	0.00	0.47
	0.8A_DBC	90	9.83 ± 2.83		
Pair 12	0.8A_MBC	90	10.19 ± 2.47	0.16	0.60
	0.8A_DBC	90	9.83± 2.83		

Table 6. Comparison Between the MBC, MLC, DBC, and DLC Areas of the Mandible Using Paired T-test

	Parameters (Mandible)	N	Mean ± STDEV (mm^2)	ρ-value	Correlation
Pair 1	0.2A_MBC	87	3.07 ± 1.76	0.00	0.05
	0.2A_MLC	87	2.13 ± 1.16		
Pair 2	0.2A_MLC	90	2.15 ± 1.17	0.00	0.59
	0.2A_DBC	90	3.81 ± 2.13		
Pair 3	0.2A_DBC	84	3.57 ± 1.83	0.00	-0.19
	0.2A_DLC	84	1.04 ± 0.72		
Pair 4	0.2A_MBC	87	3.07 ± 1.76	0.03	0.05
	0.2A_DBC	87	3.71 ± 2.07		
Pair 5	0.2A_MBC	82	3.00 ± 1.76	0.00	0.50
	0.2A_DLC	82	1.06 ± 0.72		
Pair 6	0.2A_MLC	84	2.06 ± 1.04	0.00	-0.15
	0.2A_DLC	84	1.04 ± 0.72		
Pair 7	0.4A_MBC	90	6.57 ± 2.38	0.00	0.42
	0.4A_MLC	90	3.97 ± 1.58		
Pair 8	0.4A_MLC	90	3.97 ± 1.58	0.00	0.64
	0.4A_DBC	90	6.37 ± 2.63		
Pair 9	0.4A_DBC	90	6.37 ± 2.63	0.00	0.21
	0.4A_DLC	90	2.57 ± 1.13		

Pair 10	0.4A_MBC	90	6.57 ± 2.38	0.50	0.36
	0.4A_DBC	90	6.37 ± 2.63		
Pair 11	0.4A_MBC	90	6.57 ± 2.38	0.00	0.34
	0.4A_DLC	90	2.57 ± 1.13		
Pair 12	0.4A_MLC	90	3.97 ± 1.58	0.00	0.28
	0.4A_DLC	90	2.57 ± 1.13		
Pair 13	0.6A_MBC	90	10.08 ± 2.93	0.00	0.66
	0.6A_MLC	90	6.28 ± 2.18		
Pair 14	0.6A_MLC	90	6.28 ± 2.18	0.00	0.60
	0.6A_DBC	90	8.67 ± 2.71		
Pair 15	0.6A_DBC	90	8.67 ± 2.71	0.00	0.41
	0.6A_DLC	90	4.56 ± 1.74		
Pair 16	0.6A_MBC	90	10.08 ± 2.93	0.00	0.55
	0.6A_DBC	90	8.67 ± 2.71		
Pair 17	0.6A_MBC	90	10.08 ± 2.93	0.00	0.40
	0.6A_DLC	90	4.56 ± 1.74		
Pair 18	0.6A_MLC	90	6.28 ± 2.18	0.00	0.47
	0.6A_DLC	90	4.56 ± 1.74		

Pair 19	0.8A_MBC	90	13.52 ± 3.46	0.00	0.73
	0.8A_MLC	90	9.01 ± 2.57		
Pair 20	0.8A_MLC	90	9.01 ± 2.57	0.00	0.62
	0.8A_DBC	90	10.84 ± 2.98		
Pair 21	0.8A_DBC	90	10.84 ± 2.98	0.00	0.42
	0.8A_DLC	90	7.01 ± 2.29		
Pair 22	0.8A_MBC	90	13.52 ± 3.46	0.00	0.61
	0.8A_DBC	90	10.84 ± 2.98		
Pair 23	0.8A_MBC	90	13.52 ± 3.46	0.00	0.46
	0.8A_DLC	90	7.01 ± 2.29		
Pair 24	0.8A_MLC	90	9.01 ± 2.57	0.00	0.49
	0.8A_DLC	90	7.01 ± 2.29		

Table 7. Rate of Increase of 0.6A of the Three Different Cusps of the Maxilla within the Age or NTWI Groups

□	□	0.6A_MBC (%)	0.6A_MLC (%)	0.6A_DBC (%)
Age	1_2	19.53	45.42	42.41
	2_3	17.36	30.91	21.41
	1_3	18.45	38.17	31.91
	Ave.	40.28	90.37	72.91
NTWI	0_1	12.59	34.52	5.18
	1_2	13.22	23.51	35.52
	2_3	13.98	16.98	13.86
	3_4	8.95	51.51	14.41
	0_4	58.30	194.49	85.69
□	Ave.	12.19	31.63	17.24

Table 8. Rate of Increase of 0.6A of the Four Different Cusps of the Mandible within the Age or NTWI Groups

□	□	0.6A_MBC (%)	0.6A_MLC (%)	0.6A_DBC (%)	0.6A_DLC (%)
Age	1_2	31.66	26.00	18.97	41.73
	2_3	12.06	21.99	23.21	6.46
	1_3	47.53	53.71	46.59	50.88
	Ave.	21.86	24.00	21.09	24.09
NTWI	0_1	36.87	17.38	8.01	21.75
	1_2	18.95	19.47	12.52	39.57
	2_3	22.31	28.84	18.85	3.60
	3_4	13.98	8.59	36.00	17.47
	0_4	126.97	96.20	96.43	106.79
□	Ave.	23.03	18.57	18.84	20.60

Table 9. Spearman's ρ Coefficients between the Total Area and Each Cusp Area of the Maxilla within the Age and NTWI Groups

0.6A	□	0.6A_MBC (%)	0.6A_MLC (%)	0.6A_DBC (%)
Age	1	0.59**	0.84**	0.68**
	2	0.41*	0.71**	0.63**
□	3	0.42*	0.62**	0.71**
NTWI	0	0.74*	0.69*	0.83**
	1	0.48*	0.83**	0.70**
	2	0.41*	0.69**	0.71**
	3	0.50*	0.34	0.62**
	4	0.36	0.14	0.68**
	Age	0.56**	0.69**	0.68**
	NTWI	0.57**	0.78**	0.67**
□	0.6A	0.67**	0.88**	0.82**

(*P < 0.01, **P < 0.05).

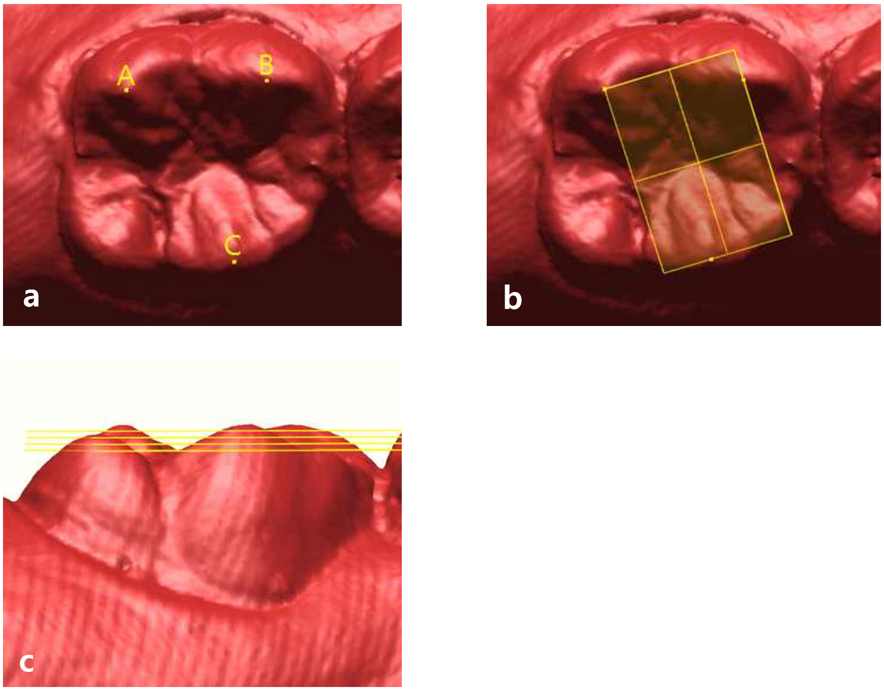

Figure 1. Reference points and virtual occlusal plane. a: A: MBCP, B: DBCP, C: MLCP. b: VOP. c: offset planes at 0.2 mm intervals.

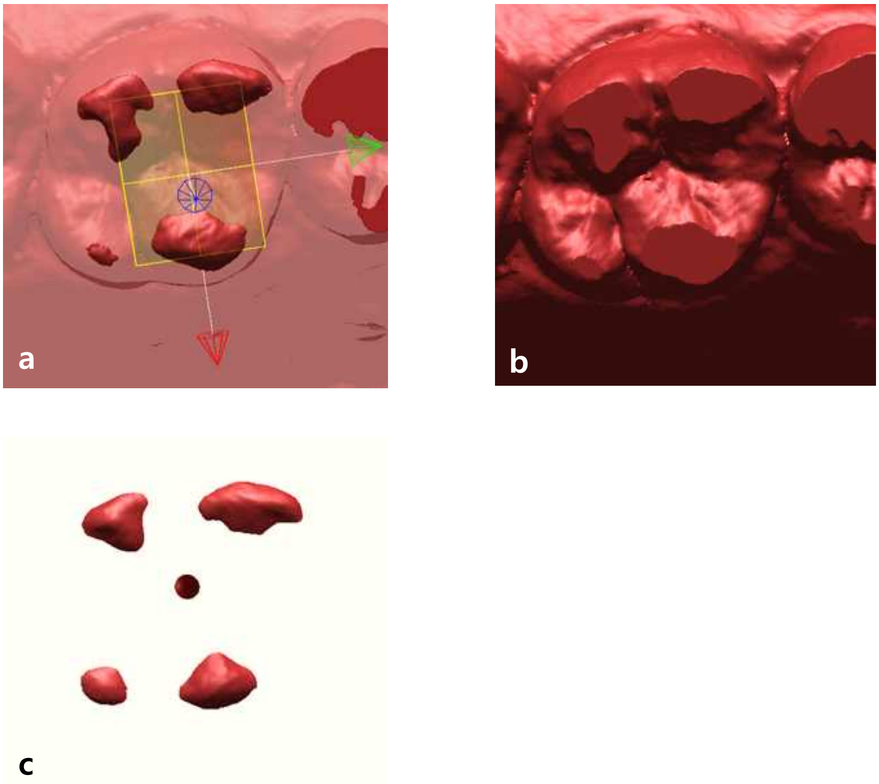

Figure 2. a: offset plane at 0. mm, b: sectioned area, 0.A. c: sectioned volume, 0.V

<국문요약>

개선된 치아마모 정량 분석 방법 연구

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서론: 치아마모는 다양한 원인에 의해 일어나며 임상가는 마모 상태를 정확히 파악하고 병적 상태인 경우 마모 진행이 더 일어나지 않도록 조치하는 것이 필요하다. 지금까지 치아마모를 판단하는 여러 가지 방법이 존재해왔으며, 임상에서는 일반적으로 몇 가지 기준을 적용하여 정성적으로 분석해왔다. 특별한 도구나 장비가 필요하지 않다는 장점이 있으나 측정자에 따른 오류나 반복 재현성 등의 문제가 일어나 이를 극복하기 위하여 정량적 분석법이 필요하게 되었다. 이미 본 교실에서는 정량 분석 지표를 개발한 바 있으나, 보다 직관적이고 교두별 분석이 가능한 새로운 지표를 추가로 개발하게 되었다.

방법:본 연구에서 사용된 가상모형은 이전 연구에서 만들어진 모형을 그대로 사용하여 효율성을 높이고 비교 분석이 가능하도록 하였다. 각 90예의 상악 및 하악 가상 모형을 사용하였고 연령군과 정성분석군 구분도 동일하였다. 이번 연구에서는 이전 연구와 달리 새로운 지표를 적용하였는 데, 우선 각 교두의 끝점을 연결하여 평

면을 형성하고 이를 치경부 방향으로 0.2 mm 간격으로 수평이동하여 단면을 형성하였다. 각 단면의 면적 및 단면 상부의 부피를 측정하여 마모도 지표로 사용하였다. 통계학적 분석을 위하여 이전 연구에 해당하는 일원분산분석법을 연령군과정성분석군에 사용하였고 상관분석을 시행하였다. 또한 각 교두별 면적 증가율 및 연령군과정성분석군에 대한 상관분석을 시행하여 마모속도를 비교하였다.

결과: 새롭게 만들어진 지표로 보다 명확한 군별 구분이 가능하였으며 연령군과정성분석군에 대한 상관계수도 높아졌음을 확인하였다. 특히 상악에서 더욱 분명하게 나타났다. 교두별 분석에서는 상악의근심설측교두가 다른 교두에 비해 더욱 빠른 마모속도를 보였으며 다른 두 교두와 유의한 차이를 보였다. 이는 상악의 경우 설측교두가 기능교두로 작용하여 더 빠르게 마모될 것이라는 예측과 일치하였다.

결론: 이상과 같은 결과를 통하여 나이가 들며 일어나는 마모의 교두별 경향을 확인할 수 있었다. 새로 개발된 정량 마모 지표는 치아 마모 연구자나 임상가들을 위하여 유용한 디지털 도구로 쓰일 수 있을 것이다.

주요어: 치아마모, 정량 분석, 한국인, 교두
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