Gender Discrimination and Age Estimation through Overall Analysis of Korean Teeth

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Gender Discrimination and Age Estimation through Overall Analysis of Korean Teeth

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2018년부터 해부학교실에 들어온 지 벌써 4년이 되어가고 있습니다. 뒤늦게 해부학을 접하고 배워야 할 것도 많던 제가 어느새 학위논문을 작성하게 되었습니다. 늦은 시작에도 불구하고 부족함이 많은 제가 여기까지 도달할 수 있었던 것은 주변의 많은 분의 도움이 있었기 때문입니다.

가장 먼저 해부학을 연구하는 학자로서의 마음가짐을 가르쳐주고 나아가야 할 방향을 지도해주신 김희진 교수님과 허경석 교수님께 감사드립니다. 언제나 곁에서 지켜봐 주시고 연구부터 저 자신에 대한 조언까지 아끼지 않고 말씀해주시고 신경을 써주셔서 감사합니다.

너무도 부족함이 많은 논문을 끝까지 읽어주시고 논문 작성에 대한 조언을 아끼지 않으셨던 길영천 선생님과 제가 연구자로서 나아가야 할 길에 대해 조언해주신 정한성 교수님께도 감사의 말씀을 드립니다. 그리고 연구와 논문에 대한 조언뿐만 아니라 박사과정 중의 연구실 생활에 대해 언제나 도움을 주시고 조언해주신 최유진 교수님께 감사드립니다.

처음 해부학교실에 와서 지금까지 해부학 교실원들에게도 많은 조언과 도움을 받았습니다. 해부학을 접하고 처음 쓰는 논문부터 많은 조언을 해주시고 정신적으로 지지해주셨던 이형진 선생님, 연구적으로도 개인적으로도 항상 적극적으로 도와주시고 함께 해주신 이지현 선생님과 이강우 선생님, 업무적으로 부족한 부분을 항상 진심으로 도와주신 이규림 선생님, 항상 부족한 저를 적극적으로 도와주시고 관심을 가져주신 박현진 선생님과 배형규 선생님, 그리고 언제나 교실 업무에 많은 도움을 주셨던 허혜원 선생님, 박형수 선생님, 김수빈 선생님, 안혜련 선생님께도 감사의 말씀을 드립니다.

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Abstract

Gender Discrimination and Age Estimation through Overall Analysis of Korean Teeth

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(Supervised by Professor Hee-Jin Kim D.D.S., Ph.D.)

Teeth that are strong against external stimuli and have little diversity for each individual can be an important individual identification factor. The goal of this study is to present a method that anyone can use easily and accurately to identify individuals using their teeth, in particular, to discriminate gender and estimate age.

In this study, all teeth were extracted from 166 Korean cadavers that were donated to Yonsei University College of Medicine and College of Dentistry. From these teeth, the crown length, mesiodistal width, and buccolingual width were measured using a digital caliper. In addition, measurements were analyzed using SPSS and MATLAB software.

First, measurements of all teeth were regression-analyzed to determine the relationship between each dimension measured. As a result, the mesiodistal width and the buccolingual width showed a relatively high correlation. Next, tooth morphology was compared between males and females. When tooth crown measurements were compared and analyzed, there was a significant difference between males and females. On the other hand, when comparing proportions between three types of measurements, only the maxillary 2nd premolar and mandibular canine showed special differences. Also, when regression analysis was performed for each measurement separately for both males and females, it was found that the overall correlation between mesiodistal width and buccolingual width of the mandibular teeth of males tended to be higher than that of females. Finally, each linear discriminant was calculated from the measurements of all tooth crowns in order to confirm accuracy. The discriminant calculated between the mandibular 1st premolar crown length and mesiodistal width showed the highest accuracy of 80.2%. In addition, the maxillary 2nd molar, mandibular 2nd molar, 1st premolar, and canine showed high accuracy for all discriminants presented in the corresponding tooth. In addition, the correlation between tooth measurements and age was confirmed through regression analysis, and based on this analysis, age estimation equations could be obtained.

Since teeth began to be used for individual identification, most methods of these studies must required various types of teeth and measurements for the gender discriminant even if the high accuracy is presented. In the case of the existing age estimation method, although the accuracy is high, the subjectivity of the individual who performs the estimate is heavily involved because it must be determined using the attrition of teeth. Considering these limitations, gender discriminants and age estimations were derived from all teeth, which shows that there is an easy and objective way to discriminate and estimate even in a limited situation where all teeth can not be used.

Keywords: individual identification, tooth crown, gender discriminant, age estimation

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I . INTRODUCTION

Individual identification is one of the very important issues not only in our daily lives but also in academic fields such as physical anthropology. This identification is usually to specify the individual and uses all information that can be obtained from someone who could not be identified. Generally, in the field of physical anthropology, the information directly related to the body is primarily used. This information could be appearance, fingerprints, teeth or an iris, as well as DNA. There are wide variety of methods as well as different factors involved in individual identification, so consideration must be given to the individual's situation and the status of each factor when determining which method to employs.

Generally, the DNA-based identification method has the highest accuracy and is known as a method that can be applied for obtaining a variety of information. However, there is also a limitation that it is difficult to use easily due to the need for specialized equipment and knowledge. In addition, most identification factors as well as DNA are from soft tissues, so they are easily damaged by external stimuli. Therefore, in the case of severely damaged or aged corpses, hard tissues such as bones and teeth become important identification factors. Especially, teeth are the hardest part of the human body and are very resistant to natural decomposition (Ron et al., 2007). As a result, teeth are considered a body organ suitable to prove an individual's identity because they do not regenerate once they have been developed. Because of this, teeth are continuously studied as one of the important identification factors (Pretty et al., 2001).

However, it is difficult to use same identification methods with hard tissues globally. Previous studies have shown that morphological variations of skeletons, especially skulls, have significant differences according to race and culture (Katz et al., 2017; von Cramon-Taubadel et al., 2011; William, 2011). Similar to skulls, teeth also show differences according according to race and culture, so studies related to this were also of interest (Dou et al, 2017; Edgar, 2007; Yaacob et al, 1996; Brace et al, 1982).

For this reason, identification methods using teeth are considerably different depending on the country and race, and each country is continuously studying and improving their identification methods.

Individual characteristics must also be considered. Especially, both gender and age are the most representative characteristics with clearly defined criteria. Males and females show distinct differences in physical characteristics as well as differences in the molecular domain such as the presence or absence of a Y chromosome, and these differences have been studied for a long time. Similarly, a lot of studies have been conducted on the characteristics of aging as well as its estimation methods. However, there is a significant difference between gender determination and age estimation. An individual's age is as clear as gender, but unlike gender, which can be clearly divided into only two types, age follows continuity. Therefore, it is not possible to "discriminate" an individual's age as clearly as gender, and it should be considered that the goal is to "estimate" the age in the narrowest possible range.

Teeth have been used as one of the important factors for gender discrimination and age estimation. There are various methods for discriminating gender using teeth, such as molecular analysis of an extracted sex chromosome, chemical analysis, enamel spectral transmittance analysis, and measurements of the specific gravity of dentin. (Kim, 2005) Among them, the analysis of tooth morphology is one of the notable methods in that it can be easily measured by anyone and does not require special skills or equipment. Basically, teeth differ between males and females, and in most cases, male teeth are larger than female teeth (Martins Filho et al., 2016; De angelis et al., 2015). It is known that the degree of contribution to gender discrimination differs depending on the type of tooth, and canine, especially the maxillary canine, has been confirmed to be meaningful in discrimination (Acharya et al., 2007). However, it can not be said that different ethnic groups show the same tendency. This is because of tooth diversity caused by genetic and environmental influences (Brook et al., 2009). For this reason, the characteristics of the population should be considered when discriminating gender, and it is necessary to study a population with similar characteristics (Daniele et al., 2020). There has been a lack of research in this field in Korea. Although studies using teeth in various ways continue to be conducted, research to identify gender using only the size of teeth has not been conducted since 2002 (Mun et al., 2002). The discrimination method presented in that study had a high discrimination accuracy of up to 84.6%. However, the mesiodistal width and buccolingual width of all mandibular teeth were required for the corresponding discrimination, and other presented discriminants also required multiple teeth. For this reason, if these requirements are not satisfied, the accuracy of the discrimination decreases.

On the other hand, most methods of estimating age using teeth focus on the attrition of teeth. Drusini's method and Takei's method are the most famous methods for measuring attrition (Jeong et al., 2015). In almost cases, tooth attrition has been the mainstream of age estimation, and various techniques and methods are being developed to supplement this (Verma et al., 2019). All of these methods are highly systematized and are widely used, but most of the accuracy is dependent on the skill level of the researcher because subjective judgment is involved in estimation. For this reason, recent age estimation studies using attrition have been focused on the objectification of estimation methods (Faillace et al, 2017; Lu et al, 2017; Singh et al, 2014; Ball, 2002).

In this study, each axis of all permanent teeth from modern Korean adult cadavers, especially the morphologically well-preserved crown, was measured and the characteristics were analyzed according to gender and age. To discriminate gender, the size and morphology of male and female crowns were compared, and to estimate age, changes in size according to age were investigated. As a result, it was possible to present improved, objective identification methods suitable for identifying Korean adults through tooth crown measurement.

Ⅱ. MATERIALS & METHODS

This study consisted of 166 cadavers (127 male and 39 female cadavers). The age of death for these cadavers ranged from 20 to 93 years with the mean age at death of 53±17 years. The age of males ranged from 20 to 88 years with the mean age of 49±16 years, and for females, the range was from 35 to 93 years with the mean age of 63±14 years.

All teeth were extracted on the maxilla and mandible of cadavers, and all crowns of teeth that were preserved in a measurable state were selected and used for analysis.

This study was performed following the principles outlined in the Declaration of Helsinki. Appropriate consent and approval were obtained from the families of the cadavers before the teeth extraction was performed. The institutional ethics committee approved the study, and the cadaver donor and the donor's families provided written consent for research to be conducted after the cadaver donation.

Teeth labeling and crown measurement

In general, maxillary and mandibular teeth differ in size, while the left and right teeth are symmetrically similar. Therefore, in this study, the teeth of the maxilla and mandible were analyzed separately, and the teeth on the left and right sides were analyzed as a single group. These teeth were named based on Palmer notation. Teeth from the maxillary central incisor to the 2nd molar were designated as the upper 1 to 7, and teeth from the mandibular central incisor to the 2nd molar were designated as the lower 1 to 7, respectively.

Then, the crown length, mesiodistal width, and buccolingual width of all tooth crowns were measured. First, the crown length was obtained by measuring the furthest distance from the crest of curvature on the cervical line to the incisal edge or the facial cusp. Additionally, the mesiodistal width was measured as the furthest distance between the mesial crest of curvature, which is the inner contact area, and the distal crest of curvature, which is the distal contact area. Similarly, the buccolingual width was measured as the furthest distance from the facial crest of curvature to the lingual crest of curvature on the occlusal surface (Figure 1). All these measurements were conducted using a digital caliper (CD-20PSX, Mitutoyo, Kawasaki, Japan).

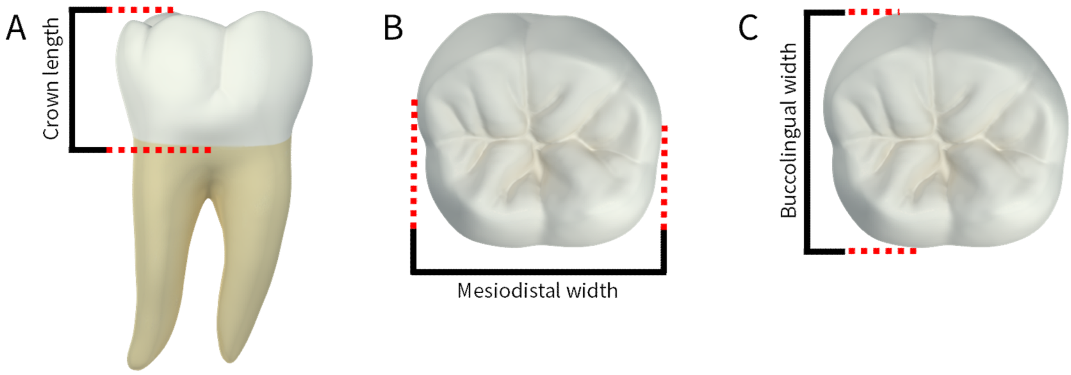

Figure 1. Measurement methods of tooth crown. (A) The crown length was measured as the furthest distance from the crest of curvature on the cervical line to the incisal edge. (B) The mesiodistal width was measured as the furthest distance from the mesial crest of curvature to the distal crest of curvature. (C) The buccolingual width was measured the furthest distance from the facial crest of curvature to the lingual crest of curvature on the occlusal surface.

Statistical analysis

All measurements were presented as mean and standard deviation values. The crown length, mesiodistal width, and buccolingual width of the tooth crowns were compared between males and females using the Mann-Whitney U test. After calculating the ratio between two of each of the three measurements, this ratio was also compared to the gender of the individuals using the Mann-Whitney U test. All statistical analyses were performed with the statistical package IBM SPSS Statistics v26 (IBM, Armonk, N.Y., USA).

Simple regression analysis and the Fisher's linear discriminant using all measurements were performed by MATLAB (Mathworks, Natick, Massachusetts, USA). All three measurements from each tooth were used in both analyses to show the correlation between tooth morphology or to show the gender discriminant, respectively. The correlation between age and each measurement was also shown by regression analysis.

Ⅲ. RESULTS

General morphological features

Regression analysis was performed between each measurement using the three measurements of all the collected tooth crowns. The three correlations, specifically the correlation between crown length and mesiodistal width, the correlation between crown length and buccolingual width, and the correlation between mesiodistal width and buccolingual width, were analyzed for a total of 14 types of teeth. Each analysis result was visualized as a scatter plot (Figure 2), and the coefficient of determination for these results was quantified as R^2 (Table 1). According to these scatter plots, when the mesiodistal width and the buccolingual width were used in the analysis, most types of teeth showed a densely distributed positive correlation. However, in cases related to crown length, either a very wide distribution or an uncorrelated distribution was shown (Figure 2). A similar trend is seen in Table 1. In most types of teeth, the coefficient of determination between mesiodistal width and buccolingual width was relatively higher than the coefficient of determination related to crown length in most cases (Table 1).

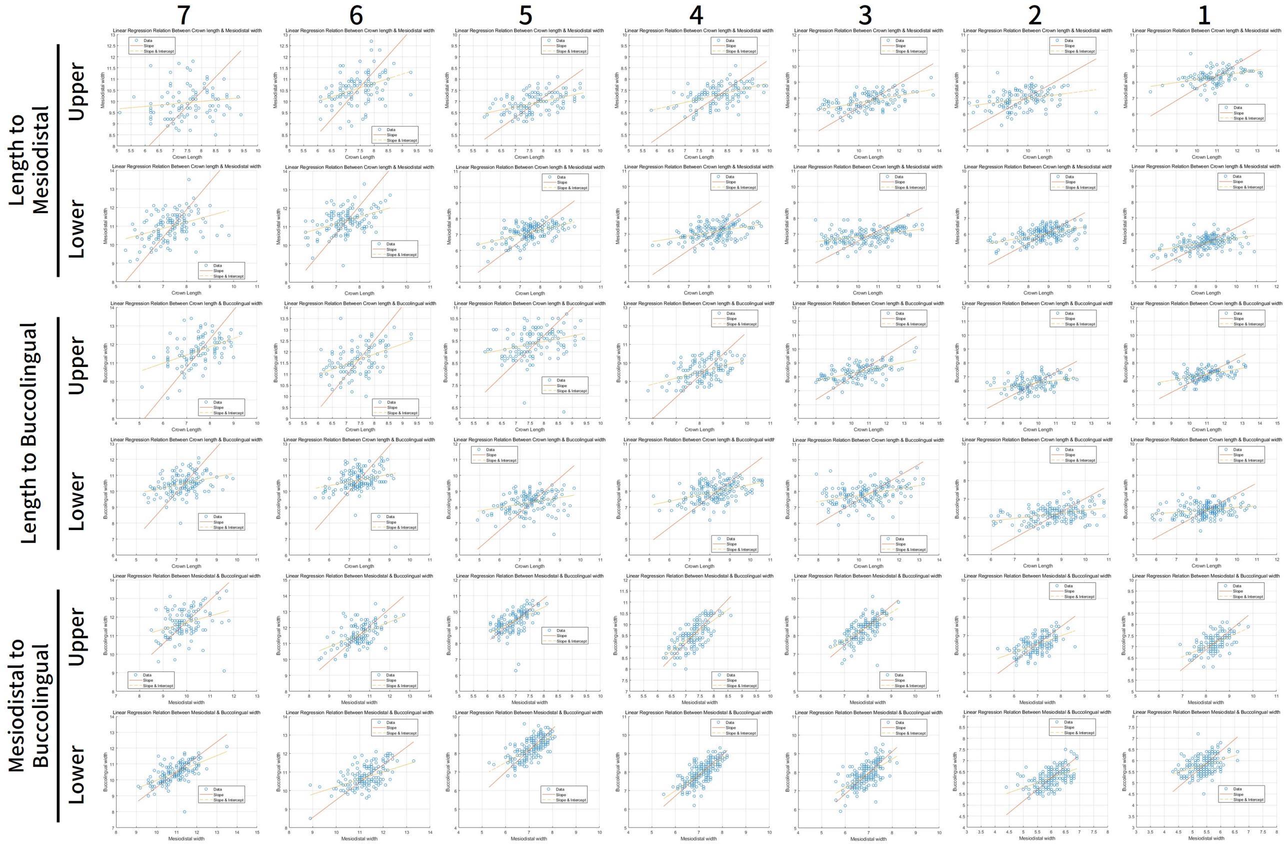

Figure 2. Regression analysis using measurements with all types of tooth crowns. Regression analysis of all tooth measurements from the central incisor (1) to the 2nd molar (7) in the maxilla (Upper) and mandible (Lower) was presented as a scatter plot. In the scatter plots labeled 'Length to Mesiodistal' on the left, crown length is the x-axis and mesiodistal width is the y-axis. In the scatter plots labeled 'Length to Buccolingual' on the left, crown length is the x-axis and buccolingual width is the y-axis. In the scatter plots labeled 'Mesiodistal to Buccolingual' on the left, mesiodistal width is the x-axis and buccolingual width is the y-axis. Each blue spot is one tooth corresponding to each measurement.

Table 1. Regression analysis using measurements with all types of tooth crowns.

Tooth No.	Crown length to Mesiodistal width		Crown length to Buccolingual width		Mesiodistal width to Buccolingual width	
	R^2	N	R^2	N	R^2	N
Upper 7	0.020	98	0.209	99	0.100	117
Upper 6	0.149	110	0.227	111	0.309	132
Upper 5	0.213	129	0.080	127	0.300	151
Upper 4	0.257	129	0.212	130	0.494	155
Upper 3	0.289	125	0.318	127	0.448	164
Upper 2	0.090	120	0.138	120	0.298	139
Upper 1	0.173	115	0.240	120	0.303	132
Lower 7	0.144	128	0.114	134	0.364	144
Lower 6	0.189	133	0.069	139	0.161	147
Lower 5	0.268	153	0.108	157	0.440	182
Lower 4	0.170	171	0.185	172	0.518	205
Lower 3	0.173	173	0.156	171	0.376	211
Lower 2	0.267	185	0.140	189	0.252	208
Lower 1	0.200	175	0.056	180	0.152	194

Linear regression analysis. R^2, coefficient of determination; N, number of samples

Gender analysis with tooth crown measurements

First, the size of male and female tooth crowns was compared (Table 2). When the measurements for all teeth were compared and analyzed, it was found that all measurements were significantly greater for males than for females overall. Most of the previous studies in other countries had similar results, and the tooth size of modern Korean males and females follows that trend.

Table 2. Mean values of tooth crown length, mesiodistal width and buccolingual width measurements from males and females

Tooth No.	Crown length (mm)					Mesiodistal width (mm)					Buccolingual width (mm)				
	Male	**N**	**Female**	**N**	***p*-value**	**Male**	**N**	**Female**	**N**	***p*-value**	**Male**	**N**	**Female**	**N**	***p*-value**
Upper 7	7.63±0.85	89	7.14±0.59	15	0.019*	10.00±0.64	99	9.38±0.51	20	0.000**	11.75±0.75	101	11.05±0.63	20	0.000**
Upper 6	7.52±0.64	91	6.89±0.52	24	0.000**	10.63±0.68	107	10.03±0.72	28	0.000**	11.71±0.66	106	11.10±0.50	29	0.000**
Upper 5	7.80±0.73	105	7.07±0.61	27	0.000**	6.98±0.43	125	6.67±0.37	32	0.000**	9.45±0.69	121	9.10±0.49	31	0.001**
Upper 4	8.28±0.75	103	7.74±0.63	29	0.000**	7.36±0.42	125	6.99±0.39	35	0.000**	9.61±0.58	126	9.26±0.44	34	0.001**
Upper 3	10.65±1.20	99	9.69±0.96	30	0.000**	7.89±0.51	130	7.48±0.48	37	0.000**	8.44±0.55	132	7.91±0.57	38	0.000**
Upper 2	9.91±1.06	90	9.35±1.04	33	0.004**	7.07±0.53	107	6.60±0.58	37	0.000**	6.60±0.44	107	6.25±0.47	36	0.000**
Upper 1	11.04±1.02	90	10.44±0.77	35	0.002**	8.43±0.45	99	8.05±0.46	37	0.000**	7.24±0.41	105	6.92±0.35	40	0.000**
Lower 7	7.35±0.78	116	7.01±0.93	20	0.053	11.03±0.72	127	10.56±0.56	19	0.006**	10.53±0.63	132	10.26±0.68	22	0.015*
Lower 6	7.44±0.78	120	6.95±0.89	24	0.007**	11.33±0.66	131	10.70±0.59	21	0.000**	10.74±0.69	139	10.28±0.57	24	0.000**
Lower 5	7.64±0.89	130	6.96±0.87	31	0.000**	7.15±0.49	158	6.86±0.57	30	0.010*	8.36±0.54	159	8.08±0.67	34	0.014*
Lower 4	8.37±0.99	139	7.88±0.86	38	0.004**	7.18±0.48	169	6.84±0.41	43	0.000**	8.05±0.57	168	7.62±0.56	45	0.000**
Lower 3	10.73±1.18	132	9.58±0.82	46	0.000**	6.97±0.45	169	6.58±0.38	52	0.000**	7.99±0.50	177	7.33±0.54	52	0.000**
Lower 2	8.91±0.97	148	8.29±1.01	43	0.000**	6.04±0.43	165	5.83±0.43	47	0.001**	6.26±0.40	177	6.05±0.35	49	0.002**
Lower 1	8.52±0.94	139	8.06±1.04	44	0.002**	5.45±0.41	152	5.24±0.40	47	0.001**	5.85±0.39	169	5.62±0.40	48	0.000**

Data are presented as mean±SD values. *p*-value, significantly different; *$p<0.05$, **$p<0.01$.

Although the measurements themselves simply show the size of the teeth, the ratio between each measurement shows the approximate morphology of each tooth as seen in each surface. That is, each ratio can represent the morphology of the tooth surface on which the measurements used for calculating each ratio are visible, and by comparing these ratios between males and females, the difference in the approximate morphology of the tooth can be compared (Table 3). For example, for the maxillary 2nd molar (Upper 7), the ratio between crown length and mesiodistal width was calculated to be less than 1. This means that the crown length is shorter than the mesiodistal width. Conversely, for the maxillary canine (Upper 3), the crown length is longer than the mesiodistal width because the ratio between those measurements is greater than 1. That is, when maxillary 2nd molar and canine was compared through the ratio, it can be supposed that the morphology of canine looks longer. According to these results, there was no significant difference overall when comparing the ratio of each tooth crown between males and females, except for the maxillary 2nd premolar (Upper 5) and mandibular canine (Lower 3). In the case of these two teeth, the ratio between crown length and mesiodistal width was significantly greater in males than in females. In addition, in the maxillary 2nd premolar (Upper 5), the ratio between crown length and buccolingual with was also significantly larger in males than in females. Conversely, for the mandibular canine (Lower 3), the ratio between mesiodistal with and buccolingual width was found to be larger in females.

Table 3. Mean values of the three ratios between tooth crown measurements from males and females

Tooth No.	Crown length to Mesiodistal width					Crown length to Buccolingual width					Mesiodistal width to Buccolingual width				
	Male	N	Female	N	*p*-value	Male	N	Female	N	*p*-value	Male	N	Female	N	*p*-value
Upper 7	0.76±0.097	84	0.75±0.063	14	0.843	0.65±0.065	85	0.65±0.054	14	0.980	0.85±0.072	98	0.85±0.066	19	0.801
Upper 6	0.71±0.063	88	0.69±0.060	22	0.135	0.64±0.052	88	0.62±0.046	23	0.031*	0.91±0.055	105	0.90±0.053	27	0.471
Upper 5	1.12±0.096	103	1.06±0.098	26	0.012*	0.83±0.095	101	0.78±0.078	26	0.007**	0.74±0.059	120	0.74±0.044	31	0.855
Upper 4	1.12±0.094	101	1.11±0.080	28	0.266	0.86±0.075	102	0.84±0.056	28	0.236	0.77±0.036	123	0.76±0.038	32	0.180
Upper 3	1.35±0.135	95	1.29±0.114	30	0.038*	1.25±0.126	97	1.22±0.104	30	0.237	0.93±0.058	127	0.95±0.052	37	0.135
Upper 2	1.40±0.159	87	1.43±0.192	33	0.436	1.49±0.157	88	1.50±0.157	32	0.755	1.07±0.077	103	1.06±0.092	36	0.453
Upper 1	1.31±0.115	83	1.30±0.103	32	0.553	1.52±0.128	86	1.52±0.088	34	0.988	1.17±0.061	96	1.16±0.068	36	0.965
Lower 7	0.67±0.068	110	0.67±0.084	18	0.794	0.70±0.073	114	0.70±0.095	20	0.915	1.05±0.062	125	1.04±0.057	19	0.356
Lower 6	0.66±0.061	114	0.65±0.061	19	0.534	0.69±0.093	118	0.70±0.077	21	0.796	1.06±0.098	129	1.04±0.053	18	0.882
Lower 5	1.06±0.107	126	1.01±0.112	27	0.020*	0.91±0.108	127	0.88±0.129	30	0.126	0.86±0.049	153	0.85±0.059	29	0.480
Lower 4	1.16±0.129	136	1.14±0.125	35	0.403	1.04±0.117	135	1.04±0.109	37	0.760	0.89±0.047	163	0.90±0.060	42	0.410
Lower 3	1.53±0.163	129	1.45±0.138	44	0.002**	1.33±0.149	127	1.31±0.139	44	0.257	0.87±0.056	161	0.90±0.053	50	0.002**
Lower 2	1.47±0.145	144	1.42±0.161	41	0.028*	1.42±0.151	146	1.38±0.171	43	0.097	0.96±0.066	163	0.96±0.071	45	0.783
Lower 1	1.56±0.153	134	1.53±0.201	41	0.082	1.46±0.173	137	1.44±0.187	43	0.556	0.94±0.073	149	0.93±0.081	45	0.984

Data are presented as mean±SD values. *p*-value, significantly different; *$p<0.05$, **$p<0.01$.

The correlation between the tooth crown measurements was then divided by gender, analyzed and compared. All measurements were classified as male or female, and correlations were analyzed and quantified through regression analysis (Table 4). Similar to the results shown in Table 1, both males and females showed a relatively high correlation between mesiodistal width and buccolingual width. However, when comparing the coefficient of determination (R^2), most of the male mandibular teeth showed higher R^2 values between the mesiodistal width and the buccolingual width than the female mandibular teeth.

Table 4. Regression analysis for measurements between males and females

Tooth No.	Crown length to Mesiodistal width				Crown length to Buccolingual width				Mesiodistal width to Buccolingual width			
	Male		Female		Male		Female		Male		Female	
	R^2	N	R^2	N	R^2	N	R^2	N	R^2	N	R^2	N
Upper 7	0.152	20	0.138	13	0.027	20	0.138	14	0.030	20	0.015	19
Upper 6	0.119	30	0.087	22	0.058	30	0.087	23	0.376	30	0.344	27
Upper 5	0.133	32	0.028	26	0.111	31	0.028	26	0.497	31	0.192	31
Upper 4	0.223	34	0.229	28	0.132	34	0.229	28	0.356	34	0.308	32
Upper 3	0.090	37	0.238	30	0.149	37	0.238	30	0.301	37	0.532	37
Upper 2	0.001	37	0.142	32	0.189	37	0.142	32	0.189	37	0.205	36
Upper 1	0.181	40	0.063	31	0.250	40	0.063	34	0.293	40	0.141	36
Lower 7	0.260	21	0.071	18	0.104	21	0.071	20	0.734	21	0.227	19
Lower 6	0.102	24	0.069	19	0.235	24	0.069	21	0.214	24	0.371	18
Lower 5	0.200	34	0.213	27	0.045	34	0.213	30	0.509	34	0.347	29
Lower 4	0.118	46	0.067	35	0.094	46	0.067	37	0.549	46	0.333	42
Lower 3	0.146	54	0.022	44	0.155	54	0.022	44	0.417	54	0.328	50
Lower 2	0.294	47	0.149	41	0.166	47	0.149	43	0.262	47	0.144	45
Lower 1	0.292	49	0.119	41	0.000	49	0.119	43	0.109	49	0.042	45

Linear regression analysis. R^2, coefficient of determination; N, number of samples

Finally, discriminant analysis corresponding to each tooth measurement was performed. All discriminant analysis results are shown as scatter plots (Figure 3), and discriminants were derived from these. Table 5 shows the discriminants, and their accuracy, derived according to each measurement (Table 5). The discriminant with the highest accuracy was the one using the crown length and the mesiodistal width of the mandibular 1st premolar (Lower 4), which had an accuracy of 80.2%. All discriminants showed an accuracy of 60% or higher, and among them, around three-fourths of the discriminants had an accuracy of 70% or higher. In particular, all measurements involving the maxillary 1st premolar (Upper 4), 2nd premolar (Upper 5), 2nd molar (Upper 7), mandibular canine (Lower 3), 1st premolar (Lower 4), and 2nd molar (Lower 7) produced discriminants close to or better than 70% accuracy.

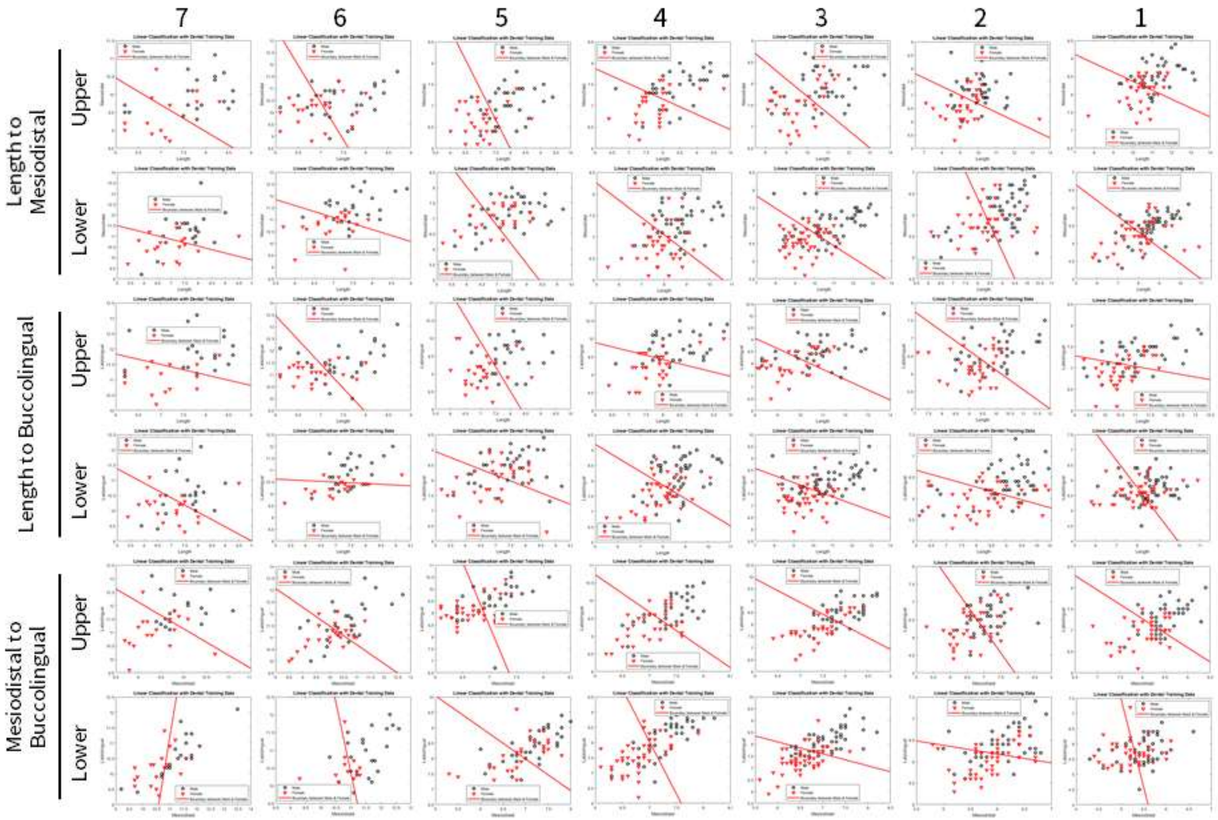

Figure 3. Gender discriminant analysis using measurements with all types of tooth crowns. Gender discriminant analysis of all tooth measurements from the central incisor (1) to the 2nd molar (7) in the maxilla (Upper) and mandible (Lower) is presented as a scatter plot. In the scatter plots labeled 'Length to Mesiodistal' on the left, crown length is the x-axis and mesiodistal width is the y-axis. In the scatter plots labeled 'Length to Buccolingual' on the left, crown length is the x-axis and buccolingual width is the y-axis. In the scatter plots labeled 'Mesiodistal to Buccolingual' on the left, mesiodistal width is the x-axis and buccolingual width is the y-axis. Each black and red dot represents male and female teeth, respectively, and the red line represents the discriminant equation that best differentiates between male and female.

Table 5. Linear discriminants and their accuracies for the measurements of each tooth between males and females

Tooth No.	Crown length to Mesiodistal width			Crown length to Buccolingual width			Mesiodistal width to Buccolingual width		
	Male < 0 < Female	%	N	Male < 0 < Female	%	N	Male < 0 < Female	%	N
Upper 7	20.1963-1.0106*L-1.3521*M	72.7	33	36.5053-0.8952*L-2.6308*B	79.4	34	41.6854-1.9575*M-1.9853*B	71.8	39
Upper 6	15.5994-1.5063*L-0.4856*M	69.2	52	22.2180-1.7547*L-0.8686*B	73.6	53	13.6019-0.5551*M-0.7014*B	63.2	57
Upper 5	24.0014-1.9552*L-1.3984*M	77.6	58	29.0665-2.0648*L-1.4774*B	79.3	58	16.5301-1.9300*M-0.3578*B	69.8	63
Upper 4	20.7568-0.7420*L-2.0721*M	75.8	62	29.1558-0.6059*L-2.5808*B	74.2	62	28.7382-1.7697*M-1.6899*B	69.7	66
Upper 3	18.0998-0.6171*L-1.5484*M	74.6	67	16.0065-0.5561*L-1.2771*B	71.6	67	19.8714-1.2441*M-1.2514*B	68.9	74
Upper 2	17.2631-0.5625*L-1.7438*M	71.4	70	17.3951-0.8223*L-1.5042*B	69.6	69	14.9437-1.2828*M-0.9575*B	65.8	73
Upper 1	23.0344-0.5283*L-2.1221*M	69.4	72	25.0782-0.3695*L-2.9864*B	70.3	74	29.7360-1.5852*M-2.3460*B	71.1	76
Lower 7	14.8846-0.3668*L-1.1349*M	76.9	39	16.8946-0.5862*L-1.2273*B	78.0	41	13.1058-1.4728*M+0.2760*B	75.0	40
Lower 6	28.7641-0.9958*L-1.9658*M	72.1	43	21.4327-0.1228*L-1.9610*B	68.9	45	26.6470-1.9565*M-0.4941*B	73.8	42
Lower 5	7.4478-0.6008*L-0.4790*M	60.7	61	12.7240-0.4515*L-1.1711*B	62.5	64	8.9280-0.6048*M-0.5884*B	57.1	63
Lower 4	22.3806-0.8737*L-2.1843*M	80.2	81	16.7637-0.6502*L-1.4719*B	71.1	83	20.7332-2.2220*M-0.6451*B	70.5	88
Lower 3	22.8718-0.7778*L-2.2256*M	76.5	98	22.9388-0.6411*L-2.1546*B	76.5	98	23.7648-1.0758*M-2.1386*B	74.0	104
Lower 2	8.4294-0.6429*L-0.5152*M	68.2	88	16.5690-0.4167*L-2.1119*B	66.7	90	13.5130-0.3726*M-1.8273*B	60.9	92
Lower 1	9.2026-0.4595*L-1.0397*M	73.3	90	7.4360-0.5162*L-0.5748*B	62.0	92	9.4055-1.4957*M-0.2591*B	63.8	94

Linear discriminant. %, accuracy of discriminant; N, number of samples; L, crown length; M, mesiodistal width; B, buccolingual width

Age analysis with tooth crown measurements

An analysis was performed to investigate the correlation between age and tooth crown measurements. Each scatter plot obtained by regression analysis showed a widely distributed morphology overall (Figure 4). In particular, the distribution between age and crown length was very wide. Although the mesiodistal width and buccolingual width appeared to have a relatively dense morphology compared to the crown length, the difference was not significant and the correlation was also very low. In Table 6, related scatter plots are quantified as coefficients of determination (R^2), and age estimation equations calculated based on regression analysis are included (Table 6). As shown in this table, since the coefficient of determination for each regression analysis is very low, the reliability of the derived age estimation equations can not be said to be high. However, as there are estimation equations corresponding to all teeth and all measurements, it is possible to narrow the range of the estimated age.

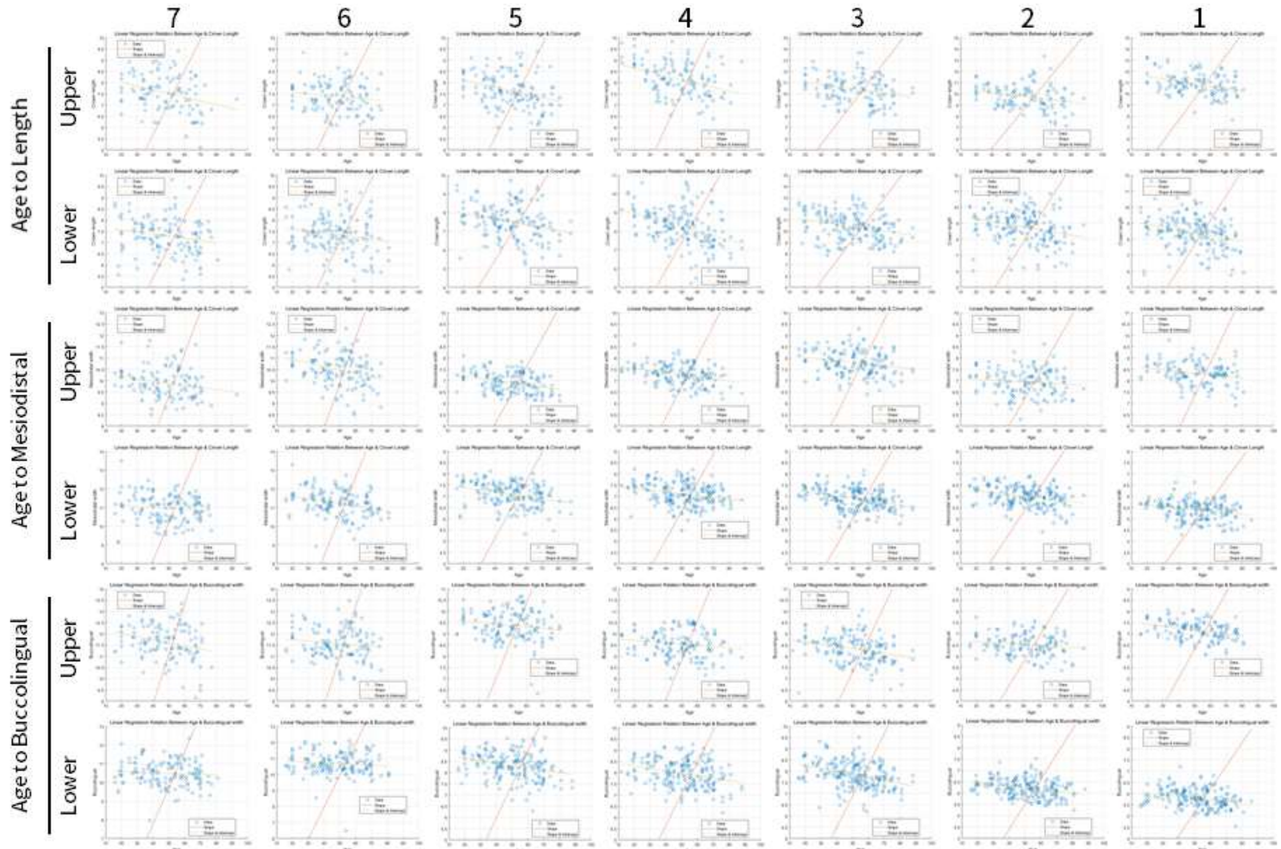

Figure 4. Regression analysis for age based on measurement of tooth crowns. Regression analysis of all tooth measurements from the central incisor (1) to the 2nd molar (7) in the maxilla (Upper) and mandible (Lower) is presented as a scatter plot. In the scatter plots labeled 'Age to Length' on the left, age is the x-axis and crown length is the y-axis. In the scatter plots labeled 'Age to Mesiodistal' on the left, age is the x-axis and mesiodistal width is the y-axis. In the scatter plots labeled 'Age to Buccolingual' on the left, age is the x-axis and buccolingual width is the y-axis. Each blue spot is one tooth corresponding to each age and measurement.

Table 6. Age estimation equations from the regression analysis for age based on measurement of tooth crowns

Tooth No.	Age to Crown length			Age to Mesiodistal width			Age to Buccolingual width		
	Equation	R^2	N	Equation	R^2	N	Equation	R^2	N
Upper 7	age = 91.732-5.864*L	0.096	104	age = 95.924-4.877*M	0.043	119	age = 107.246-5.145*B	0.071	121
Upper 6	age = 69.807-2.991*L	0.019	104	age = 116.132-6.457*M	0.100	119	age = 80.565-2.798*B	0.016	121
Upper 5	age = 100.022-6.562*L	0.103	115	age = 130.075-11.622*M	0.112	135	age = 79.454-3.191*B	0.019	135
Upper 4	age = 113.417-8*L	0.136	115	age = 135.889-11.995*M	0.110	135	age = 90.652-4.403*B	0.025	135
Upper 3	age = 88.183-3.543*L	0.068	132	age = 102.571-6.596*M	0.049	157	age = 113.336-7.441*B	0.075	152
Upper 2	age = 89.008-3.923*L	0.065	132	age = 73.404-3.186*M	0.013	157	age = 84.505-5.074*B	0.023	152
Upper 1	age = 109.185-5.304*L	0.113	132	age = 121.322-8.360*M	0.064	160	age = 140.532-12.444*B	0.108	160
Lower 7	age = 75.751-3.813*L	0.035	132	age = 81.070-2.963*M	0.018	160	age = 69.792-2.020*B	0.007	160
Lower 6	age = 69.655-3.079*L	0.026	129	age = 127.104-7.033*M	0.096	167	age = 75.975-2.577*B	0.013	170
Lower 5	age = 84.938-4.771*L	0.074	129	age = 120.006-9.888*M	0.102	167	age = 115.873-7.901*B	0.082	170
Lower 4	age = 104.396-6.648*L	0.157	123	age = 111.215-8.495*M	0.068	144	age = 111.608-7.617*B	0.080	143
Lower 3	age = 92.524-4.076*L	0.084	123	age = 133.848-11.946*M	0.115	144	age = 129.419-9.954*B	0.133	143
Lower 2	age = 88.626-4.402*L	0.075	125	age = 116.213-10.825*M	0.090	136	age = 122.868-11.503*B	0.086	145
Lower 1	age = 86.033-4.343*L	0.076	125	age = 99.212-8.909*M	0.060	136	age = 115.644-11.134*B	0.084	145

Equation, linear regression equation. R^2, coefficient of determination; N, number of samples; L, crown length; M, mesiodistal width; B, buccolingual width

Ⅳ. DISCUSSION

This study compared and analyzed tooth crown morphology of modern Korean adults, in order to determine gender discriminants and age estimation equations. This study was carried out in three stages; first, analysis of the morphology of the general Korean adult tooth crown; second, setting criteria for gender discrimination based on the comparison of tooth crown morphology; third, analysis of the correlation between the size of the tooth crown and age. The size of the tooth crown, which was the basis of all analysis, was measured using three dimensions: the tooth crown length, mesiodistal width, and buccolingual width.

First, in order to determine the morphological features of the tooth crown of general modern Koreans, the correlation between the measurements of the tooth crown were analyzed. In general, the correlation between crown length and other measurements, such as mesiodistal width or buccolingual width, was very low. However, the correlation between mesiodistal width and buccolingual width was shown to be relatively high. These results may be due to the fact that tooth crown attrition differs greatly in each person. Individuals may have different lifestyles such as awake bruxism or sleep bruxism (Wetselaar et al, 2019), and their eating habits may also vary greatly depending on their preference for hard solid foods (Larsson et al, 2005). Depending on these personal lifestyles, there is a difference in the degree of tooth crown attrition, which directly affects the crown length rather than the mesiodistal width or buccolingual width. Therefore, there were differences in the correlation because only crown length among the three measurements has a large difference depending on each person. On the other hand, in Korean tooth crowns, the correlation between mesiodistal width and buccolingual width was found to be relatively high, so it can be inferred that the cross-sectional morphology of these two measurements is similar in most Koreans.

Next, tooth morphology between males and females was compared and discriminant analysis was performed. When comparing the size of male and female tooth crowns, the results showed that males generally had larger crowns than females. According to previous studies, this size difference tends to be similar globally (Martins Filho et al., 2016; De angelis et al., 2015). Considering this tendency, generally, it can be seen that male tooth crowns are larger than females worldwide regardless of race, that is, congenital factors. However, in the environment where females frequently use teeth like Eskimo of Greenland in the past, there are cases where female teeth are clearly larger than male teeth, so the difference in tendency according to the environment must always be considered (William, 2011).

Regarding the tooth crown ratios, two types of teeth, the maxillary 2nd premolar and mandibular canine, showed characteristic differences, and, most of the other teeth were not significantly different unlike the result with the tooth crown size. The proportions of each tooth are one of the important factors which could characterize approximate morphology. In other words, different teeth which have similar proportions can be considered to have a similar morphology even if their sizes are different. Therefore, the comparison of ratios set in this study can be regarded as comparing how similar the three corresponding surfaces morphology are. In this study, for both the maxillary 2nd premolar and mandibular canine, males showed a longer crown length compared to mesiodistal width than females. Therefore, these two teeth have a longer morphology in males than in females on the buccal surface. In addition, in the maxillary 2nd premolar, males tended to be longer than females on both the buccal and mesial surfaces because the crown length was also longer than the buccolingual width. Although the mandibular canine did not show an elongated morphology on the mesial surface, the ratio of mesiodistal width to buccolingual width was significantly different in males and females. That is, when observed on the occlusal surface, male canines tended to have a thicker buccolingual width than that of females. Therefore, since the maxillary 2nd premolar and mandibular canine clearly and objectively differ in morphology between males and females, these two types of teeth can be important indicators in identifying gender.

Male and female teeth showed a special trend in the correlation between the tooth measurements. When regression analysis was performed with the measurements of male and female teeth separately, the correlation between the mesiodistal width and the buccolingual width of both genders was high compared to the other correlations. However, interestingly, most of the mandibular teeth of males showed a relatively higher correlation than that of females. This means that the mandibular teeth of males maintain a more consistent morphology on the occlusal surface than females.

Finally, valid information about gender discrimination was collected with the Fisher's discriminant method using the crown measurements from all teeth. According to the method of this study, three discriminants could be obtained from one type of intact tooth, which resulted in a total of 42 discriminants. However, not all calculated discriminants had the same value. When gender discrimination was performed on all teeth based on these 42 discriminants, the accuracy of each discriminant was distributed from a minimum of 57.1% to a maximum of 80.2% and this difference between the highest and lowest accuracy of discriminant was 23.1%. These results allowed the identification of the most and less useful teeth in gender discrimination. The three discriminants that were obtained from each tooth also had different accuracies, so the 42 discriminants could be prioritized. Especially, in the case of the maxillary 1st premolar, maxillary 2nd premolar, maxillary 2nd molar, mandibular canine, mandibular 1st premolar, and mandibular 2nd molar, the overall accuracy was relatively high no matter which measurement values were used to discriminate between males and females. On the other hand, since the mandibular lateral incisor and the 2nd premolar had relatively low discrimination accuracy for all measurements, they were given relatively low priority in gender discrimination compared to other teeth.

In addition, in this study, a method for estimating age was also presented by analyzing the correlation between age and tooth measurements. There was an overall low correlation between age and each measurement, which is thought to be attributed to the tooth characteristics pointed out in the previous analysis. Due to the principle of masticatory movements, wear of teeth is generally concentrated on the occlusal surface, and this concentrated wear obviously affects the crown length rather than the mesiodistal width or buccolingual width of the tooth crown. For this reason, it could be inferred that the change in crown length with age varies greatly between each person, and on the contrary, mesiodistal width and buccolingual width show little change with age. This result is also shown in Figure 4. In the scatter plots related to the crown length, the dots were widely distributed, however, in the scatter plots related to the two widths, the distribution tended to be dense. Therefore, the reason for the low correlation between age and each measurement is that the crown length is greatly influenced by external factors, while the mesiodistal width and buccolingual width have little external influence. Although the reliability of each regression analysis was low, it is expected to be important reference data because it presents an objective age estimation equation unlike previous subjective age estimation methods using attrition.

Even if individuals belong to the same race and gender, differences will exist between them unless they are genetically identical, such as twins. It is possible to specify an individual thanks to this specificity, i.e., personality, however, this also makes it difficult to present standardized methods or rules for individual identification. Previous studies have made great efforts to overcome these difficulties and increase the accuracy of identification and have shown meaningful results. However, most of these results require numerous factors or a very complex and specialized process. Although these methods generally show very high accuracy, there is a disadvantage that they can not be used when even one of the required elements is lacking, and accordingly, it is clear that this is a limitation. When an unidentified body is found, it is difficult to expect that it will always be in perfect condition. Depending on the environmental conditions, such as humidity, temperature, and microorganisms, most of the soft tissues of the individual are often decomposed. Moreover, in the case of cadavers found in exhumation, all soft tissues disappear over a long period of time and only bones or teeth remain in the majority of cases. Even the morphology is more difficult to identify because it is often damaged by a strong external impact. These problems make it difficult to use previous methods.

The methods presented in this study have improved such weaknesses and made the discrimination as accurate as possible in a given environment. In this study, 42 gender discrimination equations and 42 age estimation equations corresponding to each tooth were presented using three measurements measured from 14 types of teeth from the maxilla and mandible, and then the accuracy of each was confirmed. In conclusion, all equations do not have the same value because they have different accuracy, and the priority of each equation could be set based on the results of this study. It is not always possible to get all the required evidence in situations when an individual needs to be identified. In general, it is extremely rare that all teeth are obtained from one individual, or, depending on the condition of the teeth, the obtained teeth may not be able to be used for identification. For this reason, in order to identify an individual as accurately as possible with limited personal information, the criterion for identifying must always be clear. The accuracy and priority of equations presented in this study meet those criteria. Even if the accuracy of each equation shown in this study is not comparable to the results of previous studies, very reliable accuracy could be expected if the results for each equation are obtained from all available tooth measurements, sorted in order of the highest priority, and then comprehensively analyzed.

Gender and age identification have been an important issue in physical anthropology for a long time. Teeth are also one of the representative body organs that show differences between males and females, and researchers' persistent research have made it possible to obtain information from a single tooth in various ways. This study focuses on the morphology of teeth among these various approaches. Just as the human skeleton and appearance differ according to race, culture, and region, the morphology of teeth also differs from person to person and represents the distinct characteristic of an individual. Considering these characteristics, this study analyzed the teeth of modern Korean adults and suggested results suitable for practical applications. There are still things that need to be improved and considered. These present results depend to a certain extent on the innate characteristics of the culture and the race. That is, differences reflecting individual lifestyles, such as wear of tooth crowns due to mastication, have not been considered. In the future, it is necessary to consider changes according to individual lifestyle, such as tooth wear.

Ⅴ. CONCLUSION

This study suggests methods for discriminating gender and estimating age only by measuring teeth, especially tooth crowns. There are only 3 dimensions to be measured from the tooth crown: crown length, mesiodistal width, and buccolingual width. For this reason, if someone refers to the gender discriminant and age estimation equations presented in this study, it is easy and simple to estimate without special knowledge, experience, or skills.

Each of the gender and age estimating equation presented in this study seems to have lower accuracy than the previous methods. However, this disadvantage is not a problem because the accuracy greatly improves as the number of teeth used for estimation increases. On the other hand, the most representative advantage of this estimation method is that it has a very high flexibility to estimate in any environment regardless of the number and type of given teeth. In particular, the estimation of age, which is more difficult than gender discrimination, is expected to be useful because the more teeth each individual has, the greater the range of the estimated age can be dramatically reduced without using special equipment.

Both the previous methods and the present methods have their own advantages. it is expected that more accurate individual identification will be possible if they are used as reference materials for each other.

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Abstract (in Korean)

한국인 치아의 전반적인 분석을 통한 성별 판별 및 나이 추정

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안 효 상

이번 연구에서는 기증된 한국인 시신으로부터 발치한 모든 치아의 치아머리 측정치를 사용하여 누구나 쉽고 간단히 개인을 식별할 수 있는 방법, 특히 성별을 판별하고 나이를 추정할 수 있는 방법을 제시하고자 한다.

이 연구에는 남성 127구, 여성 39구, 총 166구의 기증된 시신에서 위턱과 아래턱의 안쪽앞니부터 둘째큰어금니까지의 모든 치아를 발치하였으며, 그 중 치아머리가 온전히 보존된 표본이 선별되었다. 각 치아에서는 치아머리 길이와 안쪽먼쪽 폭, 볼혀쪽 폭을 측정하여 분석에 사용하였다. 각 분석은 SPSS와 MATLAB 통계 분석 프로그램을 통해 진행되었다.

우선 모든 한국인 치아는 공통적으로 안쪽먼쪽 폭과 볼혀쪽 폭 사이에 비교적 높은 상관관계가 있는 것이 관찰되었다. 남성과 여성으로 나눠 치아를 비교했을 때는 남성이 전반적으로 여성보다 치아 크기가 큰 것을 확인할 수 있었으며, 위턱 둘째작은어금니와 아래턱 송곳니에서 특별히 형태적 차이를 보이고 있음을 알 수 있었다. 그리고 남성의 경우 대부분 아래턱 치아에서 여성보다 안쪽먼쪽 폭과 볼혀쪽 폭 사이의 상관관계가 더 높은 경향을 보였기에 교합면에서 관찰했을 때 남성이 여성보다 더 일정한 형태를 취하고 있음을 추측할 수 있다. 최종적으로 남성과 여성의 측정치들을 사용하여 모든 치아와 측정치에 대응하는 성별 판별식을 계산하고 정확도를 확인할 수 있었다. 아래턱 첫째작은어금니의 치아머리 길이와 안쪽먼쪽 폭에서 유도된 판별식은 80.2%로 모든 판별식 중 가장 높은 정확도를 보였으며, 위턱 둘째큰어금니, 둘째작은어금니, 첫째작은어금니, 아래

턱 둘째큰어금니, 첫째작은어금니, 송곳니는 관련된 모든 판별식에서 70% 이상의 높은 정확도를 보였다. 남성과 여성의 치아 비교뿐만 아니라 나이와 각 치아머리 측정치 사이의 상관관계를 회귀분석함으로써 나이에 따른 치아머리의 크기 변화도 관찰할 수 있었다. 나이와 치아머리의 측정치 사이에서는 눈에 띄는 상관관계를 볼 수는 없었지만, 이와 같은 분석을 통해 모든 치아, 모든 측정치에 대한 나이 추정식을 유도할 수 있었다.

치아가 개인 식별을 위해 사용되기 시작한 이래로, 대부분 높은 정확도를 보여줬던 성별 판별과 관련된 연구에서는 다양한 유형의 치아와 측정치를 필요로 했다. 기존의 나이 추정 방법의 경우에도 역시 그 정확도는 높지만 주로 치아의 마모도를 사용하기 때문에 개인의 주관성이 관여된다는 한계가 존재한다. 본 연구에서는 이러한 한계들을 고려하여 모든 치아에서 성별을 판별하고 나이를 추정할 수 있는 방법을 도출하였으며, 이는 주어진 정보가 제한된 상황에서도 쉽고 객관적으로 판별하거나 추정할 수 있는 방법이 있음을 보여주고 있다.

핵심 되는 말 : 개인 식별, 치아머리, 성별 판별식, 나이 추정식