

Development and validation of an age estimation model based on dental characteristics using panoramic radiographs

Sehyun Oh^{1,2,7}, Jaehan Park^{3,7}, Byung-Yoon Roh⁴, Akiko Kumagai⁵, and Sang-Seob Lee^{1,6*}

¹Department of Anatomy, College of Medicine, The Catholic University of Korea, Seoul, 06591, Republic of Korea

²Department of Medical Sciences, Graduate School of The Catholic University of Korea, Seoul, 06591, Republic of Korea

³Department of Prosthodontics, College of Dentistry, Dankook University, Chungcheongnam-do, 31116, Republic of Korea

⁴Forensic Medicine Division, National Forensic Service Gwangju Institute, Jeollanam-do, 57248, Republic of Korea

⁵Division of Forensic Odontology and Disaster Oral Medicine, Department of Forensic Science, Iwate Medical University, Iwate, 028-3694, Japan

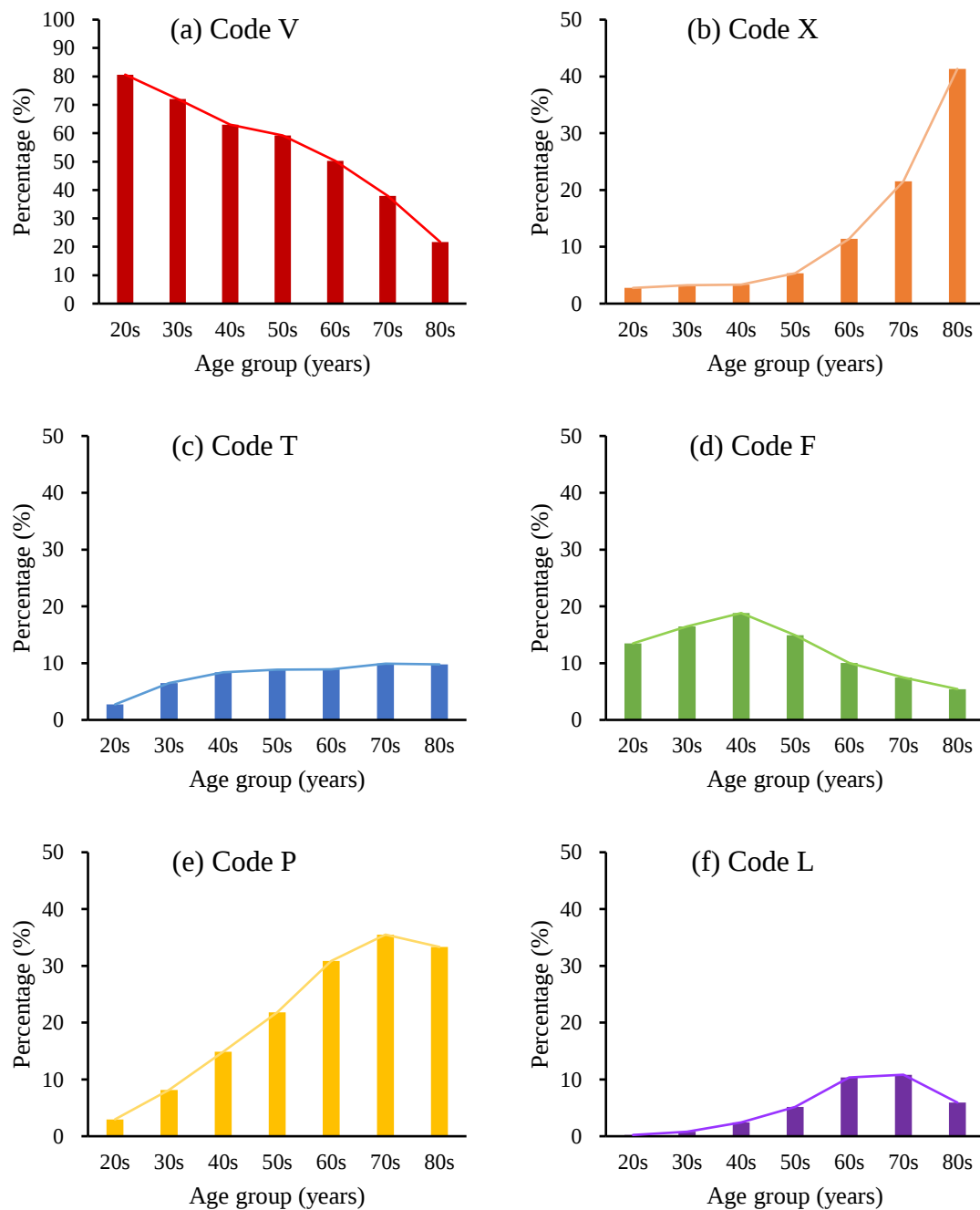
⁶Catholic Institute for Applied Anatomy, College of Medicine, The Catholic University of Korea, Seoul, 06591, Republic of Korea

⁷Sehyun Oh and Jaehan Park have contributed equally to this work.

*Corresponding Author: Sang-Seob Lee

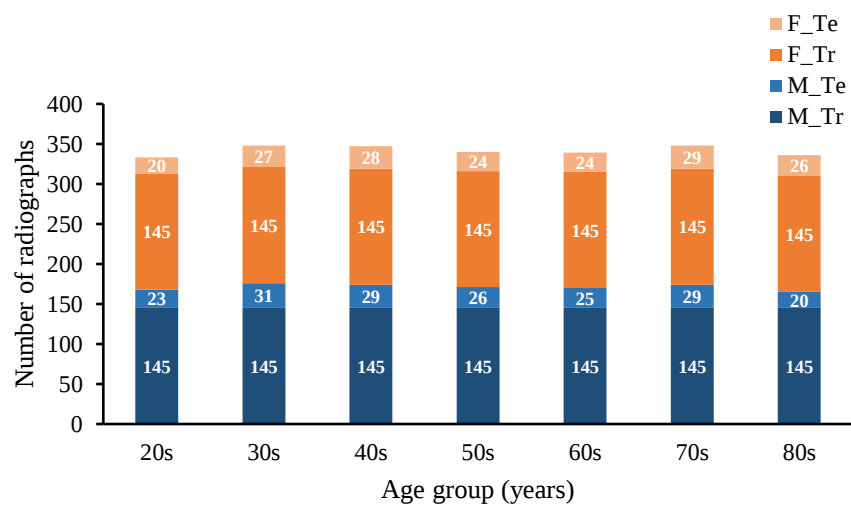
Email: sslee1418@gmail.com, sslee1418@catholic.ac.kr

Supplementary information



Supplementary Figure S1. Age-related changes in the frequency of observed dental codes across all radiographs in the training set

A description of the dental codes is provided in Table 2. Code V was excluded from the regression analysis due to the multicollinearity problem.



Supplementary Figure S2. Age and sex distribution of each dataset

M radiographs of males, *F* radiographs of females, *Tr* training set, *Te* test set

Supplementary Table S1. Comparison of the number of dental codes between sexes by age group according to the Mann–Whitney U test

Age group (years)	<i>P</i> -value					
	V	X	T	F	P	L
20s	0.017*	0.303	0.686	0.254	0.171	0.308
30s	0.002**	0.008**	0.139	0.138	0.361	0.627
40s	0.988	0.767	0.230	0.012*	0.018*	0.040*
50s	0.135	0.050	0.398	0.154	0.012*	0.005**
60s	0.605	0.068	0.080	<0.001**	0.955	0.010*
70s	0.188	0.804	0.877	0.030*	0.327	0.171
80s	0.795	0.713	0.295	0.909	0.852	0.728
Total	0.211	0.840	0.789	<0.001**	0.504	0.030*

* $P < 0.05$, ** $P < 0.01$. *P* values below 0.05 indicate a statistically significant difference in the number of dental codes between the sexes. A description of the dental codes is provided in Table 2.

Supplementary Table S2. Comparison of the number of dental codes between the left and right sides in each sex and for the entire sample population by age group using the Wilcoxon signed-rank test

Age group (years)	<i>P</i> -values for the male population					
	V	X	T	F	P	L
20s	0.859	0.153	0.901	0.576	0.995	0.405
30s	0.819	0.883	0.759	0.981	0.998	0.893
40s	0.942	0.375	0.698	0.789	0.178	0.858
50s	0.358	0.095	0.101	0.733	0.907	0.766
60s	0.098	0.577	0.710	0.090	0.431	0.944
70s	0.110	0.266	0.934	0.201	0.635	0.564
80s	0.668	0.774	0.763	0.392	0.097	0.491
Total	0.161	0.308	0.349	0.126	0.274	0.748
Age group (years)	<i>P</i> -values for the female population					
	V	X	T	F	P	L
20s	0.052	0.317	0.721	0.049*	0.370	0.655
30s	0.817	0.782	0.410	0.079	0.107	0.861
40s	0.004**	0.093	0.159	0.002**	0.506	0.433
50s	0.237	0.364	0.578	0.170	0.873	0.917
60s	0.194	0.751	0.942	0.764	0.626	0.912
70s	0.083	0.709	0.726	0.722	0.062	0.472
80s	0.775	0.534	0.162	0.748	0.416	0.461
Total	0.970	0.928	0.441	0.085	0.129	0.404
Age group (years)	<i>P</i> -value for the entire sample population					
	V	X	T	F	P	L
20s	0.127	0.087	0.864	0.076	0.505	0.637
30s	0.735	0.992	0.717	0.210	0.277	0.822
40s	0.034*	0.705	0.482	0.036*	0.552	0.524
50s	0.858	0.580	0.409	0.202	0.987	0.858
60s	0.039*	0.813	0.752	0.173	0.370	0.854
70s	0.019*	0.306	0.763	0.282	0.300	0.942
80s	0.621	0.509	0.230	0.729	0.081	0.990
Total	0.301	0.478	0.901	0.814	0.796	0.780

* $P < 0.05$, ** $P < 0.01$. *P* values below 0.05 indicate a statistically significant difference in the number of dental codes between the left and right sides. A description of the dental codes is provided in Table 2.

Supplementary Table S3. Comparison of the number of dental codes between the upper and lower jaws in each sex and for the entire sample population by age group using the Wilcoxon signed-rank test

Age group (years)	<i>P</i> -value for the male population					
	V	X	T	F	P	L
20s	0.396	0.007**	0.153	0.021*	0.212	0.739
30s	0.055	0.075	0.003**	0.89	0.016*	0.976
40s	<0.001**	0.859	0.002**	0.101	0.056	0.749
50s	<0.001**	0.099	0.969	0.152	0.012*	0.272
60s	<0.001**	<0.001**	0.33	0.451	0.149	0.691
70s	<0.001**	0.001**	0.599	0.245	<0.001**	0.041*
80s	<0.001**	0.217	0.219	0.018*	0.105	0.493
Total	<0.001**	<0.001**	<0.001**	0.060	<0.001**	0.162

Age group (years)	<i>P</i> -value for the female population					
	V	X	T	F	P	L
20s	0.022*	0.013*	0.003**	0.832	0.006**	0.096
30s	<0.001**	0.012*	0.092	0.012*	0.087	0.884
40s	<0.001**	0.226	0.021*	0.006**	0.134	0.516
50s	<0.001**	0.245	0.040*	0.036*	0.175	0.312
60s	<0.001**	0.197	0.032*	<0.001**	0.744	0.299
70s	<0.001**	<0.001**	0.833	0.089	0.600	0.829
80s	<0.001**	0.042*	0.106	0.520	0.529	0.454
Total	<0.001**	<0.001**	<0.001**	<0.001**	0.148	0.249

Age group (years)	<i>P</i> -value for the entire sample population					
	V	X	T	F	P	L
20s	<0.001**	<0.001**	0.002**	0.126	0.004**	0.157
30s	<0.001**	0.003**	0.001**	0.063	0.003**	0.928
40s	<0.001**	0.359	<0.001**	0.002**	0.016*	0.897
50s	<0.001**	0.044*	0.147	0.011*	0.006**	0.815
60s	<0.001**	<0.001**	0.027*	<0.001**	0.193	0.723
70s	<0.001**	<0.001**	0.601	0.039*	0.035*	0.299
80s	<0.001**	0.024*	0.045*	0.032*	0.500	0.977
Total	<0.001**	<0.001**	<0.001**	<0.001**	<0.001**	0.820

* $P < 0.05$, ** $P < 0.01$. P values below 0.05 indicate a statistically significant difference in the number of dental codes between the upper and lower jaws. A description of the dental codes is provided in Table 2.

Supplementary Table S4. Frequency of dental codes in the training set for each sex

Age group (years)	Percentages (number of dental codes in male radiographs)					
	V	X	T	F	P	L
20s	82.2 (3338)	2.3 (92)	2.6 (107)	12.8 (519)	2.6 (105)	0.3 (11)
30s	74.6 (3027)	2.1 (85)	6.0 (242)	15.4 (626)	8.0 (326)	0.7 (30)
40s	63.1 (2560)	3.5 (140)	9.1 (371)	17.2 (697)	16.6 (674)	3.1 (127)
50s	57.6 (2338)	6.2 (251)	9.1 (368)	14.2 (575)	23.9 (970)	6.5 (263)
60s	49.3 (2000)	13.5 (547)	7.9 (319)	8.3 (337)	31.1 (1263)	12.4 (503)
70s	39.6 (1609)	21.8 (883)	10.2 (413)	6.3 (255)	34.1 (1383)	9.3 (376)
80s	21.5 (871)	40.7 (1653)	10.7 (433)	5.6 (226)	33.6 (1365)	6.2 (251)
Total	55.4 (15743)	12.8 (3651)	7.9 (2253)	11.4 (3235)	21.4 (6086)	5.5 (1561)

Age group (years)	Percentages (number of dental codes in female radiographs)					
	V	X	T	F	P	L
20s	79.1 (3210)	3.3 (132)	2.8 (114)	14.2 (575)	3.4 (136)	0.2 (7)
30s	69.5 (2823)	4.4 (177)	7.0 (283)	17.5 (711)	8.2 (334)	0.8 (33)
40s	63.1 (2560)	3.2 (131)	7.6 (310)	20.5 (831)	13.2 (535)	1.7 (69)
50s	60.8 (2467)	4.5 (184)	8.7 (351)	15.7 (638)	19.7 (800)	3.9 (157)
60s	51.3 (2084)	9.3 (378)	10.0 (404)	11.8 (478)	30.6 (1242)	8.3 (337)
70s	36.3 (1473)	21.4 (868)	9.7 (392)	8.6 (350)	37.0 (1500)	12.4 (503)
80s	22.0 (893)	42.0 (1703)	8.9 (361)	5.3 (215)	33.0 (1341)	5.7 (232)
Total	54.6 (15510)	12.6 (3573)	7.8 (2215)	13.4 (3798)	20.7 (5888)	4.7 (1338)

A description of the dental codes is provided in Table 2. Percentage represents the proportion of observations of each code relative to the total number of codes observed in each age group.

Supplementary Table S5. Spearman correlation coefficients between the number of dental codes and chronological age in the training set for each sex

Age group (years)	Spearman correlation coefficient in male population					
	V	X	T	F	P	L
20s	-0.057	0.018	0.098	0.011	0.166*	-0.076
30s	-0.173*	-0.010	0.146	0.095	0.196*	0.243**
40s	0.117	-0.025	-0.241**	-0.069	-0.019	0.035
50s	-0.128	0.149	0.043	-0.056	0.127	-0.022
60s	-0.177*	0.169*	-0.070	-0.051	0.156	0.183*
70s	-0.350**	0.233**	0.081	0.015	0.054	-0.129
80s	-0.059	0.134	-0.021	-0.113	-0.082	-0.067
Total	-0.734**	0.630**	0.267**	-0.375**	0.615**	0.354**

Age group (years)	Spearman correlation coefficient in female population					
	V	X	T	F	P	L
20s	-0.160	0.098	-0.005	0.145	0.012	0.189*
30s	-0.176*	-0.077	0.187*	0.172*	0.176*	0.059
40s	0.049	-0.143	0.002	0.023	-0.057	0.051
50s	-0.024	0.071	-0.019	-0.064	-0.002	-0.037
60s	-0.193*	0.206*	0.182*	-0.113	0.226**	0.102
70s	-0.083	0.153	-0.099	-0.069	-0.074	-0.230**
80s	-0.159	0.217**	-0.140	-0.059	-0.200*	-0.216**
Total	-0.720**	0.572**	0.247**	-0.369**	0.623**	0.369**

* $P < 0.05$, ** $P < 0.01$. A description of the dental codes is provided in Table 2.

Supplementary Table S6. Regression coefficients, intercepts, and performance of developed model for each sex

Model	Regression coefficient in male population					Intercept	Training set		Test set		Adj. R^2
	X	T	F	P	L		RMSE	MAE	RMSE	MAE	
	(95% CI)	(95% CI)	(95% CI)	(95% CI)	(95% CI)		(95% CI)	(95% CI)	(95% CI)	(95% CI)	
Model 1	1.586** (0.156)	0.211 (0.448)	0.197 (0.301)	1.712** (0.249)	-0.013 (0.422)	37.997 (1.902)	13.482 (0.132)	11.111 (0.122)	15.616 (0.380)	12.702 (0.341)	0.535 (0.042)
Model 2	2.854** (0.240)	0.260 (0.604)	-0.122 (0.345)	2.457** (0.361)	0.355 (0.512)	37.118 (2.022)	13.147 (0.141)	10.621 (0.124)	15.222 (0.398)	12.260 (0.339)	0.558 (0.040)
Model 3	5.196** (0.440)	-0.078 (1.003)	0.435 (0.611)	4.041** (0.602)	0.515 (0.855)	38.468 (1.861)	14.048 (0.148)	11.427 (0.130)	16.034 (0.421)	12.895 (0.358)	0.496 (0.043)
Model 4	4.947** (0.519)	1.016 (1.031)	-1.067** (0.659)	3.054** (0.690)	1.721** (0.984)	42.864 (2.045)	14.660 (0.148)	11.980 (0.135)	16.473 (0.396)	13.286 (0.366)	0.451 (0.036)
Model	Regression coefficient in female population					Intercept	Training set		Test set		Adj. R^2
	X	T	F	P	L		RMSE	MAE	RMSE	MAE	
	(95% CI)	(95% CI)	(95% CI)	(95% CI)	(95% CI)		(95% CI)	(95% CI)	(95% CI)	(95% CI)	
Model 1	1.669** (0.148)	-0.251 (0.456)	0.336* (0.273)	2.129** (0.241)	0.005 (0.424)	36.062 (1.971)	12.903 (0.124)	10.634 (0.450)	16.046 (0.434)	12.978 (1.400)	0.583 (0.039)
Model 2	2.932** (0.241)	-0.392 (0.605)	0.334* (0.323)	2.820** (0.354)	0.310 (0.534)	34.709 (2.190)	13.096 (0.136)	10.649 (0.470)	16.053 (0.442)	12.945 (1.408)	0.570 (0.040)
Model 3	5.319** (0.476)	0.199 (1.039)	0.713** (0.580)	3.943** (0.665)	1.637** (0.985)	37.556 (2.112)	14.481 (0.143)	11.944 (0.505)	16.828 (0.434)	13.366 (1.517)	0.475 (0.044)
Model 4	5.306** (0.506)	-0.301 (1.022)	0.329 (0.653)	4.095** (0.579)	1.247** (0.895)	38.548 (2.202)	14.212 (0.152)	11.502 (0.514)	16.649 (0.404)	13.680 (1.407)	0.494 (0.043)

* $P < 0.05$, ** $P < 0.01$. *RMSE* root mean square error, *MAE* mean absolute error, *Adj. R^2* adjusted R^2 , *CI* confidence interval. A description of the

dental codes is provided in Table 2.

Supplementary Table S7. Distribution of excluded radiographs with only sound teeth by age group and sex

Age group (years)	M (n)	F (n)	T (n)
20.00–29.99	81	60	141
30.00–39.99	15	15	30
40.00–49.99	21	15	36
50.00–59.99	22	21	43
60.00–69.99	30	22	52
70.00–79.99	9	16	25
80.00–89.99	17	14	31
Total	195	163	358

M radiographs of males, *F* radiographs of females, *T* radiographs of the entire sample

Supplementary Table S8. Mean age of samples according to age group and sex in each dataset

Age group (years)	Training set								
	M			F			T		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
20.00–29.99	145	25.61	3.01	145	25.53	2.82	290	25.57	2.91
30.00–39.99	145	34.77	2.83	145	35.03	2.91	290	34.90	2.87
40.00–49.99	145	45.38	2.94	145	44.55	2.68	290	44.97	2.84
50.00–59.99	145	55.23	2.91	145	54.87	2.87	290	55.05	2.89
60.00–69.99	145	65.58	2.58	145	65.38	3.05	290	65.48	2.82
70.00–79.99	145	75.31	2.68	145	75.59	2.87	290	75.45	2.78
80.00–89.99	145	83.43	2.45	145	84.06	2.54	290	83.75	2.51
Total	1015	55.04	19.84	1015	55.00	20.04	2030	55.02	19.93

Age group (years)	Test set								
	M			F			T		
	n	Mean	SD	n	Mean	SD	n	Mean	SD
20.00–29.99	23	24.74	3.26	20	24.17	2.92	43	24.47	3.09
30.00–39.99	31	35.40	3.01	27	34.65	2.92	58	35.05	2.97
40.00–49.99	29	45.41	2.97	28	44.91	3.13	57	45.17	3.04
50.00–59.99	26	55.29	2.99	24	55.60	2.71	50	55.44	2.83
60.00–69.99	25	64.96	2.71	24	64.91	2.69	49	64.94	2.68
70.00–79.99	29	74.85	3.00	29	74.59	3.04	58	74.72	3.00
80.00–89.99	20	84.61	3.04	26	84.48	2.60	46	84.54	2.77
Total	183	54.14	19.40	178	55.78	19.95	361	54.98	19.70

M radiographs of males, *F* radiographs of females, *T* radiographs of the entire sample, *SD* standard deviation

Supplementary Table S9. Variance inflation factors for dental characteristics variables in regression models by each sex and for the entire sample population

Variable	VIF in male population			
	Model 1	Model 2	Model 3	Model 4
X	1.246	1.278	1.218	1.212
T	1.620	1.711	1.707	1.611
F	1.317	1.406	1.284	1.340
P	2.796	2.856	2.538	2.585
L	1.927	2.126	1.925	1.983

Variable	VIF in female population			
	Model 1	Model 2	Model 3	Model 4
X	1.215	1.304	1.252	1.264
T	1.651	1.817	1.760	1.541
F	1.306	1.461	1.368	1.454
P	2.730	3.078	2.639	2.433
L	1.925	2.182	1.915	1.780

Variable	VIF in entire sample population			
	Model 1	Model 2	Model 3	Model 4
X	1.225	1.285	1.230	1.234
T	1.627	1.762	1.730	1.564
F	1.305	1.424	1.320	1.388
P	2.754	2.950	2.584	2.470
L	1.922	2.146	1.922	1.859

VIF variance inflation factor. A description of the dental codes is provided in Table 2.