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Age estimation in subadults using teeth eruption examination

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Abstract: In the recent decades, age estimation has become more and more challenging due to an increased migration in developed countries of persons who do not possess official documents to certify their chronological age therefore a scientifc age estimation is neccesary for various reasons (criminal, administrative or humanitarian).

Dental eruption assessed through visual examination of the oral cavity represents a fast, cheap and nonivasive method to determine dental age in subadults. The main goal of the study is to assess the correlation between the dental eruption age and chronological age. The eruption status was asssessed (separately for boys and girls) in 695 cases of subadults (1 – 17 years old) of known chronological age.

Using the Least Squares method, a regression analysis was performed and formulas for dental age estimation were obtained based on the teeth present at the time the examination was performed. Based on the LS (Least Squares) regression method, estimation equations were obtained. In most cases, the exclusion of the correlated factors led to a better fitted model.

Key Words: dental age, subadults, primary teeth, permanent teeth, estimation equations.

The scientific diagnostic of age displays an increase in its demand over the last years, especially in the developed countries of the European Union, due to the massive migration of population from areas of armed conflict, political and religious oppression or poor economic development. In many of such cases, the persons do not have a valid identification document and their chronological age must be assessed for criminal, administrative or humanitarian purposes. This aspect is most challenging in case of an immigrant supposedly minor of age because the United Nations Convention on the Rights of the Child [1] (1989) assure a special treatment of this age category especially when they are unaccompanied [2]. Other areas, presenting over the last years an increase in case numbers and their complexity, in which age diagnostic is relevant, are [1, 3]: age of criminal responsibility, human trafficking (for the purpose of sexual exploitation, illegal labour or domestic labour), child pornography, child adoption from countries without birth certificates.

The methodology for age estimation in the living was proposed by the Study Group of Forensic Age Estimation [4] and consists of physical examination (anthropometric measures, signs of sexual maturation), X-ray examination of the left hand, teeth eruption and dental X-ray examination and additionally, in certain age cases, an X-ray and/or CT scan of the clavicles can be applied.

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Dental maturity and growth has long been an interest for the age estimation of a subadult. Dental development is divided into two main stages: tooth formation and tooth eruption. Tooth eruption is considered to be the dynamic continuous process that involves the movement of the tooth from the developmental position in the alveolar bone towards the occlusal plane in the oral cavity. Tooth emergence represents the clinical appearance of the cusps of a tooth through the gums and it is considered to be a part of tooth eruption [5]. Teeth eruption seem to follow a predictable pattern and timing to the sequence of eruption [6] but there are also a number of factors which can influence the permanent teeth eruption [7]: gender, ethnic origin, physical and sexual development, preterm birth, craniofacial morphology, socioeconomic status, and neonatal factors which influence primary teeth eruption [8-11]: lower birth weight, gestational age, severity of neonatal illness, prolonged mechanical ventilation.

With some exceptions, tooth eruption begins in the anterior and proceeds posteriorly, and maxillary teeth appear after their mandibular counterparts. This sequence in teeth eruption is used to estimate the dental age of a subadult.

The dental eruption status is determined through visual examination of the oral cavity which is an easy, cheap, fast and noninvasive method. But, as any other age estimation method, it has a series of disadvantages, such as long periods of time between eruption of some teeth and divergent opinions about the moment when a tooth should be considered erupted. Therefore in order to optimally estimate the age of a subadult person a combination of methods (listed previously) should be employed.

In Romania, the medico-legal expertise of the age and sex is particularly requested by a court of law on the base of the Number 119 Law, article 21 issued on 16th of October 1996. According to the national law the maternity certificate is not considered an official document therefore, in order to issue an official birth certificate, the authorities request in these cases a medico-legal expertise for age and sex diagnostic.

MATERIALS AND METHODS

The present study was conducted to estimate the age of subadults (1 – 17 years old) based on dental eruption status and using the Least Squares method. Regression analysis was performed to obtain calculation formulas of dental age which was then compared with the chronological age.

The study was carried out within the Medico-Legal Identification Laboratory from the "Mina Minovici" National Institute of Forensic Pathology, Bucharest, Romania. The study group consisted of 695 subadults with age ranging from 1 to 17 years (374 boys and 321 girls), with known chronological age resulting from their maternity certificate, where the date of birth is mentioned, but he/she did not have an official birth certificate and according to the national law the person's age must be medico-legally determined.

The cases of posttraumatic missing teeth were excluded. No other criteria for case selection were used.

Each case was examined once. The presence of tooth eruption was recorded in an Excel database as "1" and the absence as "0". The FDI (Fédération Dentaire Internationale) two-digit system notation was used. A tooth was considered present even if a cusp was emerged. The third molar was excluded from the analysis due to its large variability of eruption. Based on the Excel database a regression analysis using the Least Squares method was performed in EViews 8. Dental age was assessed separately on gender and on primary and permanent teeth, by comparing the teeth present at different ages on each observation set. From the input data we have obtained descriptive statistics (Histograms and Stats), formulas for estimating age (Representation and Estimation Output), correlation between the presence of different teeth (Covariance Matrix) and Actual, Fitted, Residual analysis (Actual, Fitted, Residual Graph and Table).

RESULTS

A. Dental age estimation based on primary teeth

The observations consisting of „no primary tooth presence" were excluded, thus 580 observations remained (280 boys and 230 girls). The group distribution shown in Figure 1 and 3 is not a normal one, based on the most commonly used statistical measures of symmetry, shape and normal distribution goodness-of-fit test (Skewness, Kurtosis and Jarque-Bera Probability).

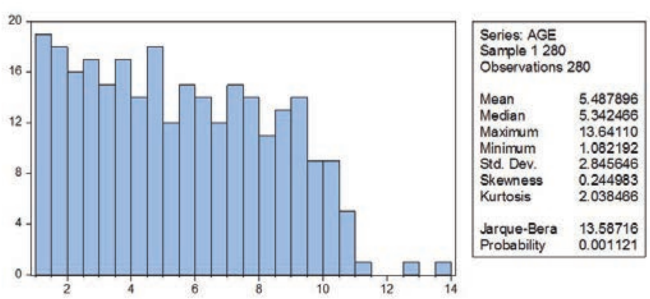

Figure 1. Boys age distribution – primary teeth.

1.Boys

The analysis in Table 1 shows a strong positive correlation between various primary teeth development. The grey squares highlight a correlation higher than 90%.

Regression formula based on the primary teeth presence was estimated and an equation derived:

Estimation Command

LS AGE D51 D52 D53 D54 D55 D61 D62 D63 D64 D65 D71 D72 D73 D74 D75 D81 D82 D83 D84 D85 C

Table 1. Covariance Matrix – boys, primary teeth

	D51	D52	D53	D54	D55	D61	D62	D63	D64	D65	D71	D72	D73	D74	D75	D81	D82	D83	D84	D85	AGE
D51	1	0.781	0.036	0.475	-0.285	0.992	0.797	0.021	0.495	-0.301	0.969	0.818	-0.028	0.540	-0.209	0.961	0.811	0.004	0.521	-0.240	-0.831
D52	0.781	1	0.152	0.638	-0.184	0.788	0.946	0.135	0.658	-0.201	0.794	0.907	0.082	0.669	-0.124	0.784	0.913	0.092	0.650	-0.158	-0.739
D53	0.036	0.152	1	0.375	0.407	0.039	0.145	0.981	0.357	0.414	0.042	0.148	0.754	0.398	0.462	0.044	0.183	0.761	0.387	0.446	0.084
D54	0.475	0.638	0.375	1	0.043	0.480	0.625	0.357	0.955	0.049	0.485	0.602	0.357	0.900	0.110	0.490	0.640	0.364	0.902	0.097	-0.488
D55	-0.285	-0.184	0.407	0.043	1	-0.282	-0.190	0.419	0.052	0.934	-0.280	-0.188	0.450	0.015	0.807	-0.277	-0.158	0.458	0.055	0.856	0.536
D61	0.992	0.788	0.039	0.480	-0.282	1	0.803	0.023	0.500	-0.298	0.976	0.825	-0.026	0.545	-0.206	0.968	0.818	0.006	0.526	-0.237	-0.837
D62	0.797	0.946	0.145	0.625	-0.190	0.803	1	0.129	0.645	-0.207	0.810	0.924	0.076	0.675	-0.109	0.800	0.896	0.085	0.656	-0.142	-0.750
D63	0.021	0.135	0.981	0.357	0.419	0.023	0.129	1	0.339	0.426	0.026	0.132	0.769	0.381	0.475	0.029	0.168	0.777	0.370	0.458	0.100
D64	0.495	0.658	0.357	0.955	0.052	0.500	0.645	0.339	1	0.033	0.505	0.622	0.309	0.922	0.095	0.510	0.660	0.318	0.902	0.082	-0.498
D65	-0.301	-0.201	0.414	0.049	0.934	-0.298	-0.207	0.426	0.033	1	-0.296	-0.204	0.458	-0.004	0.844	-0.293	-0.175	0.465	0.036	0.868	0.545
D71	0.969	0.794	0.042	0.485	-0.280	0.976	0.810	0.026	0.505	-0.296	1	0.832	-0.023	0.550	-0.204	0.992	0.825	-0.015	0.531	-0.234	-0.830
D72	0.818	0.907	0.148	0.602	-0.188	0.825	0.924	0.132	0.622	-0.204	0.832	1	0.081	0.669	-0.109	0.823	0.958	0.089	0.649	-0.141	-0.750
D73	-0.028	0.082	0.754	0.357	0.450	-0.026	0.076	0.769	0.309	0.458	-0.023	0.081	1	0.265	0.475	-0.021	0.116	0.963	0.313	0.490	0.174
D74	0.540	0.669	0.398	0.900	0.015	0.545	0.675	0.381	0.922	-0.004	0.550	0.669	0.265	1	0.105	0.556	0.708	0.274	0.957	0.069	-0.540
D75	-0.209	-0.124	0.462	0.110	0.807	-0.206	-0.109	0.475	0.095	0.844	-0.204	-0.109	0.475	0.105	1	-0.201	-0.079	0.481	0.143	0.948	0.435
D81	0.961	0.784	0.044	0.490	-0.277	0.968	0.800	0.029	0.510	-0.293	0.992	0.823	-0.021	0.556	-0.201	1	0.832	-0.012	0.536	-0.231	-0.826
D82	0.811	0.913	0.183	0.640	-0.158	0.818	0.896	0.168	0.660	-0.175	0.825	0.958	0.116	0.708	-0.079	0.832	1	0.123	0.687	-0.111	-0.730
D83	0.004	0.092	0.761	0.364	0.458	0.006	0.085	0.777	0.318	0.465	-0.015	0.089	0.963	0.274	0.481	-0.012	0.123	1	0.320	0.496	0.138
D84	0.521	0.650	0.387	0.902	0.055	0.526	0.656	0.370	0.902	0.036	0.531	0.649	0.313	0.957	0.143	0.536	0.687	0.320	1	0.108	-0.505
D85	-0.240	-0.158	0.446	0.097	0.856	-0.237	-0.142	0.458	0.082	0.868	-0.234	-0.141	0.490	0.069	0.948	-0.231	-0.111	0.496	0.108	1	0.473
AGE	-0.831	-0.739	0.084	-0.488	0.536	-0.837	-0.750	0.100	-0.498	0.545	-0.830	-0.750	0.174	-0.540	0.435	-0.826	-0.730	0.138	-0.505	0.473	1

Estimation Equation

AGE = C(1)*D51 + C(2)*D52 + C(3)*D53 + C(4)*D54 + C(5)*D55 + C(6)*D61 + C(7)*D62 + C(8)*D63 + C(9)*D64 + C(10)*D65 + C(11)*D71 + C(12)*D72 + C(13)*D73 + C(14)*D74 + C(15)*D75 + C(16)*D81 + C(17)*D82 + C(18)*D83 + C(19)*D84 + C(20)*D85 + C(21)

Table 2. Estimated regression coefficients and the statistics associated with each coefficient – boys, primary teeth

Dependent Variable: AGE
Method: Least Squares
Sample: 1 280
Included observations: 280

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D51	0.415977	1.136859	0.365900	0.7147
D52	-0.704608	0.579999	-1.214845	0.2255
D53	0.904015	1.146953	0.788188	0.4313
D54	-1.196791	0.647506	-1.848310	0.0657
D55	1.331800	0.563010	2.365497	0.0187
D61	-1.872396	1.347947	-1.389072	0.1660
D62	-0.328718	0.569894	-0.576806	0.5646
D63	-0.698514	1.205682	-0.579352	0.5629
D64	0.501100	0.689581	0.726673	0.4681
D65	0.967724	0.596673	1.621866	0.1060
D71	-0.116170	1.505796	-0.077149	0.9386
D72	-0.980847	0.666149	-1.472415	0.1421
D73	3.473862	0.914635	3.798086	0.0002
D74	-1.025859	0.744300	-1.378286	0.1693
D75	0.125331	0.612158	0.204736	0.8379
D81	-1.574047	1.327459	-1.185759	0.2368
D82	1.159119	0.704295	1.645786	0.1010
D83	-3.029896	0.919590	-3.294834	0.0011
D84	0.303695	0.628153	0.483473	0.6292
D85	0.318176	0.680188	0.467776	0.6403
C	6.404669	0.273212	23.44211	0.0000

R-squared	0.852920	Mean dependent var	5.487896
Adjusted R-squared	0.841563	S.D. dependent var	2.845646
S.E. of regression	1.132686	Akaike info criterion	3.159099
Sum squared resid	332.2911	Schwarz criterion	3.431708
Log likelihood	-421.2738	Hannan-Quinn criter.	3.268443
F-statistic	75.09752	Durbin-Watson stat	0.652687
Prob(F-statistic)	0.000000		

Substituted Coefficients

AGE = 0.415976814477 * D51 - 0.704608352726 * D52 + 0.904015091898 * D53 - 1.19679101556 * D54 + 1.3317998687 * D55 - 1.87239553509 * D61 - 0.32871831136 * D62 - 0.698514447635 * D63 + 0.501099745449 * D64 + 0.967723769841 * D65 - 0.116170305546 * D71 - 0.9808472213 * D72 + 3.47386166619 * D73 - 1.02585879533 * D74 + 0.125330729792 * D75 - 1.57404659325 * D81 + 1.15911937337 * D82 - 3.02989579377 * D83 + 0.303695070129 * D84 + 0.318175969062 * D85 + 6.40466892276

However, if we exclude the correlated factors (with the correlation higher than 90% as shown in Table 1) and perform a second analysis, the new obtained model does not show a significant improvement *versus* the one presented.

Figure 2 shows the actual *versus* fitted values based on the estimated equation and the obtained residual values.

2.Girls

Statistical analysis performed showed a strong positive correlation between various primary teeth

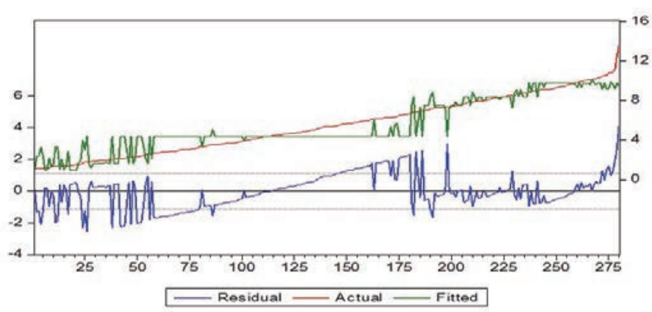

Figure 2. Actual, Fitted, Residual graph - boys, primary teeth.

development. The grey squares highlight a correlation higher than 90%. Between the right and left maxillary second primary molar the correlation is 100%. The equation can only be estimated after excluding the correlated factors shown in Table 3.

Table 4. Estimated regression coefficients and the statistics associated with each coefficient – girls, primary teeth

Dependent Variable: AGE
Method: Least Squares
Sample: 1 230
Included observations: 230

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D51	-0.981575	0.366036	-2.681633	0.0079
D52	-0.716902	0.373096	-1.921493	0.0560
D53	-0.295336	0.418480	-0.705736	0.4811
D54	-1.603636	0.456488	-3.512983	0.0005
D55	2.741188	0.259696	10.55537	0.0000
D81	-2.113972	0.383664	-5.509962	0.0000
D82	0.026437	0.374330	0.070626	0.9438
D83	0.837284	0.373959	2.238974	0.0262
D84	0.082724	0.448052	0.184631	0.8537
C	6.527137	0.283145	23.05227	0.0000

R-squared	0.831883	Mean dependent var	5.601823
Adjusted R-squared	0.825006	S.D. dependent var	2.783222
S.E. of regression	1.164286	Akaike info criterion	3.184598
Sum squared resid	298.2237	Schwarz criterion	3.334080
Log likelihood	-356.2288	Hannan-Quinn criter.	3.244896
F-statistic	120.9571	Durbin-Watson stat	0.844842
Prob(F-statistic)	0.000000		

Estimation Command

LS AGE D51 D52 D53 D54 D55 D81 D82 D83 D84 C

Estimation Equation

AGE = C(1)*D51 + C(2)*D52 + C(3)*D53 + C(4)*D54 + C(5)*D55 + C(6)*D81 + C(7)*D82 + C(8)*D83 + C(9)*D84 + C(10)

Substituted Coefficients

AGE = -0.981574569528 * D51 - 0.716902006774 * D52 - 0.295336125091 * D53 - 1.60363600431 * D54 + 2.74118812563 * D55 - 2.11397225279 * D81 + 0.0264373922399 * D82 + 0.83728428446 * D83 + 0.0827243122878 * D84 + 6.52713743149

Figure 4 shows the actual *versus* fitted values based on the estimated equation and the obtained residual values.

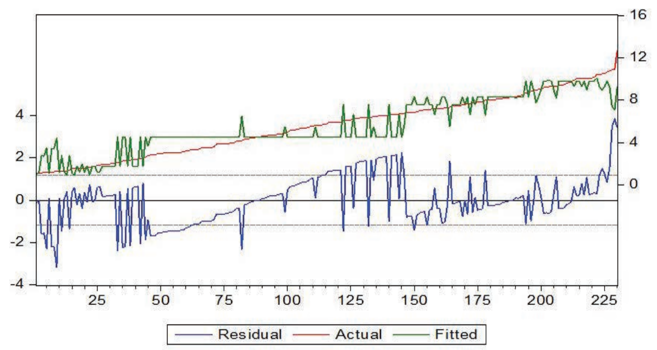

Figure 4. Actual, Fitted, Residual graph – girls, primary teeth.

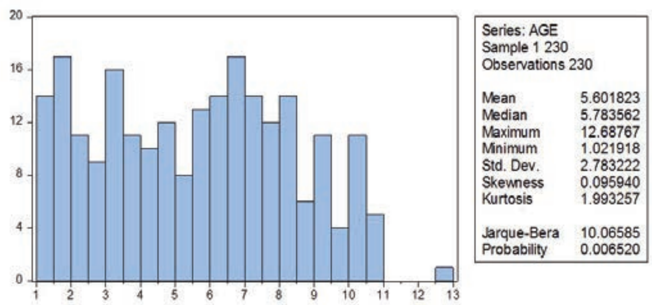

Figure 3. Girls age distribution - primary teeth.

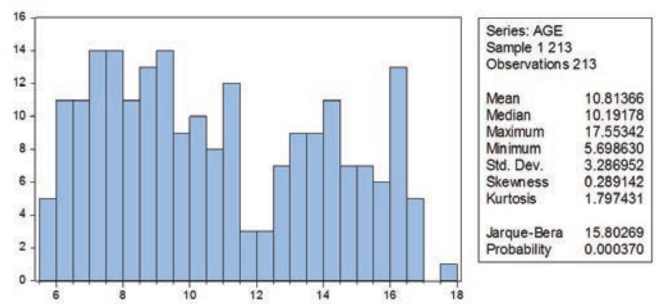

Figure 5. Boys age distribution – permanent teeth.

Table 3. Covariance Matrix – girls, primary teeth.

	D51	D52	D53	D54	D55	D61	D62	D63	D64	D65	D71	D72	D73	D74	D75	D81	D82	D83	D84	D85	AGE
D51	1	0.728	-0.023	0.423	-0.294	0.963	0.755	-0.040	0.413	-0.294	0.890	0.723	0.026	0.372	-0.253	0.890	0.723	-0.014	0.361	-0.253	-0.784
D52	0.728	1	0.171	0.626	-0.117	0.728	0.969	0.153	0.615	-0.117	0.704	0.863	0.224	0.577	-0.074	0.709	0.860	0.181	0.566	-0.074	-0.663
D53	-0.023	0.171	1	0.382	0.531	-0.023	0.158	0.980	0.390	0.531	-0.044	0.187	0.791	0.504	0.521	-0.050	0.166	0.805	0.496	0.521	0.176
D54	0.423	0.626	0.382	1	0.086	0.423	0.605	0.360	0.985	0.086	0.386	0.584	0.393	0.863	0.110	0.400	0.573	0.404	0.879	0.080	-0.440
D55	-0.294	-0.117	0.531	0.086	1	-0.294	-0.129	0.510	0.092	1	-0.311	-0.107	0.497	0.194	0.955	-0.317	-0.123	0.508	0.188	0.955	0.575
D61	0.963	0.728	-0.023	0.423	-0.294	1	0.755	-0.040	0.413	-0.294	0.890	0.742	0.026	0.372	-0.253	0.872	0.742	-0.014	0.361	-0.253	-0.786
D62	0.755	0.969	0.158	0.605	-0.129	0.755	1	0.140	0.594	-0.129	0.731	0.872	0.209	0.555	-0.086	0.736	0.870	0.167	0.544	-0.086	-0.671
D63	-0.040	0.153	0.980	0.360	0.510	-0.040	0.140	1	0.367	0.510	-0.062	0.171	0.809	0.485	0.501	-0.068	0.150	0.823	0.477	0.501	0.204
D64	0.413	0.615	0.390	0.985	0.092	0.413	0.594	0.367	1	0.092	0.375	0.574	0.402	0.877	0.116	0.389	0.562	0.412	0.893	0.086	-0.429
D65	-0.294	-0.117	0.531	0.086	1	-0.294	-0.129	0.510	0.092	1	-0.311	-0.107	0.497	0.194	0.955	-0.317	-0.123	0.508	0.188	0.955	0.575
D71	0.890	0.704	-0.044	0.386	-0.311	0.890	0.731	-0.062	0.375	-0.311	1	0.758	-0.015	0.338	-0.293	0.963	0.739	-0.056	0.327	-0.270	-0.808
D72	0.723	0.863	0.187	0.584	-0.107	0.742	0.872	0.171	0.574	-0.107	0.758	1	0.227	0.577	-0.066	0.761	0.961	0.187	0.565	-0.066	-0.651
D73	0.026	0.224	0.791	0.393	0.497	0.026	0.209	0.809	0.402	0.497	-0.015	0.227	1	0.464	0.518	0.002	0.211	0.917	0.485	0.518	0.147
D74	0.372	0.577	0.504	0.863	0.194	0.372	0.555	0.485	0.877	0.194	0.338	0.577	0.464	1	0.243	0.350	0.568	0.476	0.960	0.215	-0.333
D75	-0.253	-0.074	0.521	0.110	0.955	-0.253	-0.086	0.501	0.116	0.955	-0.293	-0.066	0.518	0.243	1	-0.277	-0.082	0.530	0.236	0.970	0.532
D81	0.890	0.709	-0.050	0.400	-0.317	0.872	0.736	-0.068	0.389	-0.317	0.963	0.761	0.002	0.350	-0.277	1	0.761	-0.038	0.361	-0.277	-0.809
D82	0.723	0.860	0.166	0.573	-0.123	0.742	0.870	0.150	0.562	-0.123	0.739	0.961	0.211	0.568	-0.082	0.761	1	0.170	0.579	-0.082	-0.656
D83	-0.014	0.181	0.805	0.404	0.508	-0.014	0.167	0.823	0.412	0.508	-0.056	0.187	0.917	0.476	0.530	-0.038	0.170	1	0.497	0.498	0.183
D84	0.361	0.566	0.496	0.879	0.188	0.361	0.544	0.477	0.893	0.188	0.327	0.565	0.485	0.960	0.236	0.361	0.579	0.497	1	0.208	-0.335
D85	-0.253	-0.074	0.521	0.080	0.955	-0.253	-0.086	0.501	0.086	0.955	-0.270	-0.066	0.518	0.215	0.970	-0.277	-0.082	0.498	0.208	1	0.536
AGE	-0.784	-0.663	0.176	-0.440	0.575	-0.786	-0.671	0.204	-0.429	0.575	-0.808	-0.651	0.147	-0.333	0.532	-0.809	-0.656	0.183	-0.335	0.536	1

Table 5. Covariance Matrix – boys, permanent teeth.

	D11	D12	D13	D14	D15	D16	D17	D21	D22	D23	D24	D25	D26	D27	D31	D32	D33	D34	D35	D36	D37	D41	D42	D43	D44	D45	D46	D47	AGE
D11	1	0.652	0.338	0.493	0.320	0.398	0.282	0.956	0.689	0.338	0.483	0.317	0.351	0.285	0.881	0.698	0.335	0.469	0.323	0.298	0.296	0.885	0.672	0.342	0.483	0.317	0.351	0.293	0.484
D12	0.652	1	0.519	0.733	0.490	0.244	0.432	0.623	0.947	0.519	0.718	0.486	0.212	0.437	0.637	0.933	0.514	0.696	0.495	0.177	0.454	0.632	0.892	0.502	0.718	0.486	0.212	0.450	0.647
D13	0.338	0.519	1	0.686	0.945	0.138	0.833	0.324	0.491	0.981	0.680	0.936	0.175	0.841	0.330	0.485	0.953	0.702	0.935	0.105	0.875	0.346	0.478	0.953	0.680	0.917	0.122	0.867	0.850
D14	0.493	0.733	0.686	1	0.648	0.222	0.571	0.472	0.717	0.686	0.980	0.642	0.200	0.577	0.482	0.707	0.679	0.950	0.654	0.176	0.600	0.505	0.696	0.672	0.959	0.642	0.200	0.594	0.767
D15	0.320	0.490	0.945	0.648	1	0.128	0.882	0.306	0.464	0.926	0.661	0.991	0.165	0.891	0.312	0.458	0.935	0.682	0.991	0.096	0.926	0.327	0.451	0.936	0.661	0.972	0.112	0.917	0.863
D16	0.398	0.244	0.138	0.222	0.128	1	0.106	0.381	0.261	0.138	0.216	0.126	0.656	0.107	0.329	0.265	0.136	0.209	0.129	0.265	0.114	0.312	0.270	0.140	0.216	0.126	0.518	0.112	0.215
D17	0.282	0.432	0.833	0.571	0.882	0.106	1	0.270	0.409	0.814	0.583	0.871	0.146	0.970	0.275	0.404	0.841	0.601	0.873	0.076	0.933	0.289	0.398	0.825	0.583	0.851	0.092	0.942	0.859
D21	0.956	0.623	0.324	0.472	0.306	0.381	0.270	1	0.658	0.324	0.462	0.303	0.335	0.272	0.842	0.633	0.321	0.448	0.309	0.285	0.283	0.846	0.607	0.327	0.462	0.303	0.335	0.280	0.462
D22	0.689	0.947	0.491	0.717	0.464	0.261	0.409	0.658	1	0.491	0.702	0.460	0.227	0.414	0.672	0.957	0.487	0.681	0.469	0.190	0.430	0.669	0.914	0.473	0.702	0.460	0.227	0.426	0.631
D23	0.338	0.519	0.981	0.686	0.926	0.138	0.814	0.324	0.491	1	0.680	0.917	0.175	0.822	0.330	0.485	0.934	0.702	0.916	0.105	0.856	0.346	0.478	0.934	0.680	0.898	0.122	0.847	0.841
D24	0.483	0.718	0.680	0.980	0.661	0.216	0.583	0.462	0.702	0.680	1	0.655	0.195	0.589	0.472	0.692	0.654	0.949	0.668	0.172	0.613	0.495	0.682	0.667	0.959	0.655	0.195	0.607	0.767
D25	0.317	0.486	0.936	0.642	0.991	0.126	0.871	0.303	0.460	0.917	0.655	1	0.164	0.880	0.309	0.453	0.926	0.676	0.981	0.094	0.916	0.324	0.447	0.927	0.655	0.981	0.111	0.907	0.862
D26	0.351	0.212	0.175	0.200	0.165	0.656	0.146	0.335	0.227	0.175	0.195	0.164	1	0.147	0.360	0.231	0.173	0.188	0.167	0.128	0.153	0.342	0.235	0.177	0.195	0.164	0.409	0.152	0.220
D27	0.285	0.437	0.841	0.577	0.891	0.107	0.970	0.272	0.414	0.822	0.589	0.880	0.147	1	0.278	0.408	0.849	0.607	0.882	0.078	0.942	0.291	0.402	0.834	0.589	0.880	0.093	0.951	0.864
D31	0.881	0.637	0.330	0.482	0.312	0.329	0.275	0.842	0.672	0.330	0.472	0.309	0.360	0.278	1	0.682	0.327	0.458	0.315	0.215	0.289	0.954	0.692	0.303	0.472	0.309	0.275	0.286	0.470
D32	0.698	0.933	0.485	0.707	0.458	0.265	0.404	0.633	0.957	0.485	0.692	0.453	0.231	0.408	0.682	1	0.480	0.671	0.462	0.193	0.424	0.679	0.957	0.466	0.692	0.453	0.231	0.420	0.626
D33	0.335	0.514	0.953	0.679	0.935	0.136	0.841	0.321	0.487	0.934	0.654	0.926	0.173	0.849	0.327	0.480	1	0.676	0.925	0.103	0.883	0.343	0.473	0.963	0.674	0.907	0.121	0.875	0.846
D34	0.469	0.696	0.702	0.950	0.682	0.209	0.601	0.448	0.681	0.702	0.949	0.676	0.188	0.607	0.458	0.671	0.676	1	0.689	0.165	0.632	0.480	0.662	0.690	0.970	0.676	0.188	0.626	0.769
D35	0.323	0.495	0.935	0.654	0.991	0.129	0.873	0.309	0.469	0.916	0.668	0.981	0.167	0.882	0.315	0.462	0.925	0.689	1	0.097	0.917	0.330	0.456	0.926	0.668	0.981	0.114	0.908	0.870
D36	0.298	0.177	0.105	0.176	0.096	0.265	0.076	0.285	0.190	0.105	0.172	0.094	0.128	0.078	0.215	0.193	0.103	0.165	0.097	1	0.084	0.202	0.197	0.106	0.172	0.094	0.764	0.082	0.160
D37	0.296	0.454	0.875	0.600	0.926	0.114	0.933	0.283	0.430	0.856	0.613	0.916	0.153	0.942	0.289	0.424	0.883	0.632	0.917	0.084	1	0.303	0.418	0.867	0.613	0.916	0.100	0.990	0.866
D41	0.885	0.632	0.346	0.505	0.327	0.312	0.289	0.846	0.669	0.346	0.495	0.324	0.342	0.291	0.954	0.679	0.343	0.480	0.330	0.202	0.303	1	0.689	0.320	0.495	0.324	0.260	0.300	0.483
D42	0.672	0.892	0.478	0.696	0.451	0.270	0.398	0.607	0.914	0.478	0.682	0.447	0.235	0.402	0.692	0.957	0.473	0.662	0.456	0.197	0.418	0.689	1	0.459	0.682	0.447	0.235	0.414	0.615
D43	0.342	0.502	0.953	0.672	0.936	0.140	0.825	0.327	0.473	0.934	0.667	0.927	0.177	0.834	0.303	0.466	0.963	0.690	0.926	0.106	0.867	0.320	0.459	1	0.687	0.908	0.124	0.858	0.841
D44	0.483	0.718	0.680	0.959	0.661	0.216	0.583	0.462	0.702	0.680	0.959	0.655	0.195	0.589	0.472	0.692	0.674	0.970	0.668	0.172	0.613	0.495	0.682	0.687	1	0.655	0.195	0.607	0.764
D45	0.317	0.486	0.917	0.642	0.972	0.126	0.851	0.303	0.460	0.898	0.655	0.981	0.164	0.880	0.309	0.453	0.907	0.676	0.981	0.094	0.916	0.324	0.447	0.908	0.655	1	0.111	0.907	0.869
D46	0.351	0.212	0.122	0.200	0.112	0.518	0.092	0.335	0.227	0.122	0.195	0.111	0.409	0.093	0.275	0.231	0.121	0.188	0.114	0.764	0.100	0.260	0.235	0.124	0.195	0.111	1	0.098	0.186
D47	0.293	0.450	0.867	0.594	0.917	0.112	0.942	0.280	0.426	0.847	0.607	0.907	0.152	0.951	0.286	0.420	0.875	0.626	0.908	0.082	0.990	0.300	0.414	0.858	0.607	0.907	0.098	1	0.866
AGE	0.484	0.647	0.850	0.767	0.863	0.215	0.859	0.462	0.631	0.841	0.767	0.862	0.220	0.864	0.470	0.626	0.846	0.769	0.870	0.160	0.866	0.483	0.615	0.841	0.764	0.869	0.186	0.866	1

Table 6. Estimated regression coefficients and the statistics associated with each coefficient – boys, permanent teeth

Dependent Variable: AGE
Method: Least Squares
Sample: 1 213
Included observations: 213

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D11	0.562213	0.574431	0.978731	0.3289
D12	0.486962	0.430625	1.130826	0.2595
D13	0.283941	0.600155	0.473112	0.6367
D14	1.431298	0.590829	2.422525	0.0163
D15	-2.457308	0.858010	-2.863960	0.0046
D16	0.508334	0.577825	0.879737	0.3801
D17	2.710836	0.474549	5.712444	0.0000
D26	-0.119372	0.590477	-0.202162	0.8400
D36	0.320703	0.751389	0.426813	0.6700
D41	0.326098	0.550643	0.592213	0.5544
D42	0.414147	0.446327	0.927898	0.3546
D43	0.522795	0.557084	0.938449	0.3492
D44	-0.040727	0.579568	-0.070272	0.9440
D45	3.194911	0.665082	4.803784	0.0000
D46	-0.077276	0.777440	-0.099399	0.9209
D47	0.583505	0.564006	1.034572	0.3021
C	5.818225	0.588688	9.883373	0.0000

R-squared	0.898217	Mean dependent var	10.81366
Adjusted R-squared	0.889908	S.D. dependent var	3.286952
S.E. of regression	1.090614	Akaike info criterion	3.087806
Sum squared resid	233.1300	Schwarz criterion	3.356078
Log likelihood	-311.8513	Hannan-Quinn criter.	3.196223
F-statistic	108.1040	Durbin-Watson stat	0.822198
Prob(F-statistic)	0.000000		

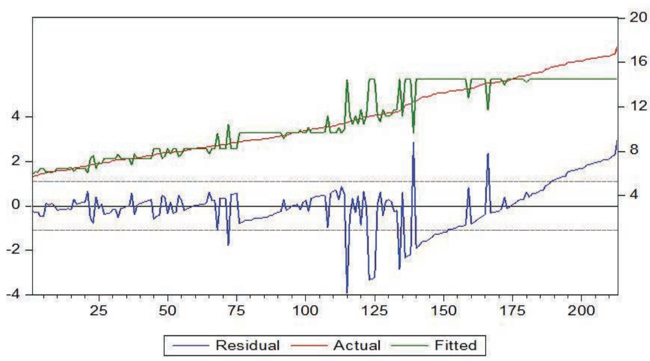

Figure 6. Actual, Fitted, Residual graph – boys, permanent teeth.

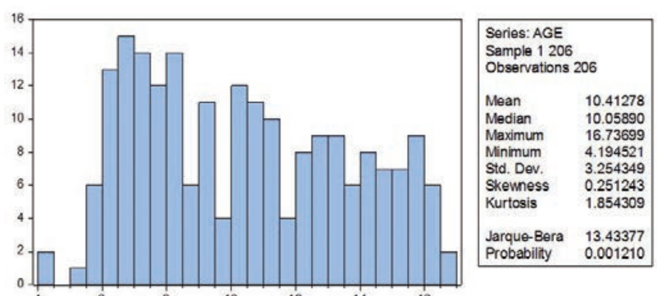

Figure 7. Girls age distribution – permanent teeth.

B. Dental age estimation based on permanent teeth

The observations containing „no permanent tooth presence" were excluded, thus 419 observations remained (213 boys and 206 girls). The group distribution shown in Figure 5 and 7 is not a normal one, based on the most commonly used statistical measures of symmetry, shape and normal distribution goodness-of-fit test (Skewness, Kurtosis and Jarque-Bera Probability).

Table 7. Covariance Matrix – girls, permanent teeth

	D11	D12	D13	D14	D15	D16	D17	D21	D22	D23	D24	D25	D26	D27	D31	D32	D33	D34	D35	D36	D37	D41	D42	D43	D44	D45	D46	D47	AGE
D11	1	0.669	0.409	0.512	0.389	0.289	0.328	0.928	0.702	0.409	0.497	0.389	0.277	0.328	0.866	0.693	0.425	0.507	0.385	0.231	0.338	0.806	0.693	0.429	0.484	0.389	0.172	0.314	0.544
D12	0.669	1	0.611	0.765	0.582	0.293	0.490	0.665	0.905	0.611	0.742	0.582	0.352	0.490	0.606	0.823	0.635	0.736	0.576	0.154	0.506	0.593	0.823	0.641	0.721	0.582	0.190	0.489	0.714
D13	0.409	0.611	1	0.779	0.933	0.179	0.803	0.424	0.582	0.981	0.783	0.933	0.215	0.803	0.370	0.518	0.942	0.747	0.924	0.094	0.828	0.362	0.518	0.933	0.759	0.933	0.116	0.817	0.859
D14	0.512	0.765	0.779	1	0.760	0.224	0.641	0.530	0.729	0.759	0.971	0.760	0.269	0.641	0.463	0.649	0.791	0.930	0.753	0.118	0.661	0.453	0.649	0.779	0.920	0.760	0.145	0.648	0.827
D15	0.389	0.582	0.933	0.760	1	0.170	0.843	0.403	0.554	0.913	0.764	1	0.205	0.843	0.352	0.493	0.877	0.728	0.990	0.090	0.869	0.345	0.493	0.868	0.741	1	0.110	0.858	0.861
D16	0.289	0.293	0.179	0.224	0.170	1	0.143	0.350	0.247	0.179	0.217	0.170	0.581	0.143	0.324	0.345	0.186	0.222	0.168	0.255	0.148	0.251	0.281	0.188	0.169	0.170	0.425	0.149	0.260
D17	0.328	0.490	0.803	0.641	0.843	0.143	1	0.340	0.467	0.803	0.640	0.843	0.173	0.979	0.297	0.416	0.772	0.606	0.831	0.076	0.907	0.291	0.416	0.765	0.620	0.843	0.093	0.898	0.852
D21	0.928	0.665	0.424	0.530	0.403	0.350	0.340	1	0.669	0.424	0.515	0.403	0.325	0.340	0.835	0.693	0.440	0.525	0.399	0.223	0.351	0.776	0.693	0.445	0.504	0.403	0.164	0.327	0.561
D22	0.702	0.905	0.582	0.729	0.554	0.247	0.467	0.669	1	0.582	0.708	0.554	0.319	0.467	0.636	0.838	0.605	0.700	0.549	0.162	0.482	0.622	0.838	0.611	0.685	0.554	0.199	0.464	0.695
D23	0.409	0.611	0.981	0.759	0.913	0.179	0.803	0.424	0.582	1	0.764	0.913	0.215	0.803	0.370	0.518	0.942	0.728	0.904	0.094	0.828	0.362	0.518	0.933	0.739	0.913	0.116	0.817	0.852
D24	0.497	0.742	0.783	0.971	0.764	0.217	0.640	0.515	0.708	0.764	1	0.764	0.262	0.640	0.450	0.630	0.796	0.921	0.756	0.115	0.661	0.440	0.630	0.785	0.911	0.764	0.141	0.648	0.820
D25	0.389	0.582	0.933	0.760	1	0.170	0.843	0.403	0.554	0.913	0.764	1	0.205	0.843	0.352	0.493	0.877	0.728	0.990	0.090	0.869	0.345	0.493	0.868	0.741	1	0.110	0.858	0.861
D26	0.277	0.352	0.215	0.269	0.205	0.581	0.173	0.325	0.319	0.215	0.262	0.205	1	0.173	0.314	0.415	0.224	0.267	0.203	0.438	0.178	0.254	0.362	0.226	0.224	0.205	0.161	0.180	0.289
D27	0.328	0.490	0.803	0.641	0.843	0.143	0.979	0.340	0.467	0.803	0.640	0.843	0.173	1	0.297	0.416	0.772	0.606	0.831	0.076	0.928	0.291	0.416	0.765	0.620	0.843	0.093	0.918	0.850
D31	0.866	0.606	0.370	0.463	0.352	0.324	0.297	0.835	0.636	0.370	0.450	0.352	0.314	0.297	1	0.714	0.385	0.459	0.349	0.255	0.306	0.935	0.680	0.388	0.434	0.352	0.313	0.280	0.513
D32	0.693	0.823	0.518	0.649	0.493	0.345	0.416	0.693	0.838	0.518	0.630	0.493	0.415	0.416	0.714	1	0.538	0.642	0.488	0.182	0.429	0.699	0.972	0.544	0.625	0.493	0.224	0.409	0.650
D33	0.425	0.635	0.942	0.791	0.877	0.186	0.772	0.440	0.605	0.942	0.796	0.877	0.224	0.772	0.385	0.538	1	0.760	0.868	0.098	0.796	0.376	0.538	0.990	0.771	0.877	0.120	0.785	0.847
D34	0.507	0.736	0.747	0.930	0.728	0.222	0.606	0.525	0.700	0.728	0.921	0.728	0.267	0.606	0.459	0.642	0.760	1	0.741	0.117	0.627	0.449	0.642	0.748	0.970	0.728	0.144	0.614	0.793
D35	0.385	0.576	0.924	0.753	0.990	0.168	0.831	0.399	0.549	0.904	0.756	0.990	0.203	0.831	0.349	0.488	0.868	0.741	1	0.089	0.858	0.341	0.488	0.859	0.733	0.990	0.109	0.847	0.857
D36	0.231	0.154	0.094	0.118	0.090	0.255	0.076	0.223	0.162	0.094	0.115	0.090	0.438	0.076	0.255	0.182	0.098	0.117	0.089	1	0.078	0.111	0.064	0.099	0.018	0.090	-0.012	0.079	0.167
D37	0.338	0.506	0.828	0.661	0.869	0.148	0.907	0.351	0.482	0.828	0.661	0.869	0.178	0.928	0.306	0.429	0.796	0.627	0.858	0.078	1	0.300	0.429	0.789	0.641	0.869	0.096	0.969	0.850
D41	0.806	0.593	0.362	0.453	0.345	0.251	0.291	0.776	0.622	0.362	0.440	0.345	0.254	0.291	0.935	0.699	0.376	0.449	0.341	0.111	0.300	1	0.699	0.380	0.453	0.345	0.320	0.273	0.492
D42	0.693	0.823	0.518	0.649	0.493	0.281	0.416	0.693	0.838	0.518	0.630	0.493	0.362	0.416	0.680	0.972	0.538	0.642	0.488	0.064	0.429	0.699	1	0.544	0.649	0.493	0.224	0.409	0.641
D43	0.429	0.641	0.933	0.779	0.868	0.188	0.765	0.445	0.611	0.933	0.785	0.868	0.226	0.765	0.388	0.544	0.990	0.748	0.859	0.099	0.789	0.380	0.544	1	0.759	0.868	0.122	0.777	0.843
D44	0.484	0.721	0.759	0.920	0.741	0.169	0.620	0.504	0.685	0.739	0.911	0.741	0.224	0.620	0.434	0.625	0.771	0.970	0.733	0.018	0.641	0.453	0.649	0.759	1	0.741	0.145	0.627	0.782
D45	0.389	0.582	0.933	0.760	1	0.170	0.843	0.403	0.554	0.913	0.764	1	0.205	0.843	0.352	0.493	0.877	0.728	0.990	0.090	0.869	0.345	0.493	0.868	0.741	1	0.110	0.858	0.861
D46	0.172	0.190	0.116	0.145	0.110	0.425	0.093	0.164	0.199	0.116	0.141	0.110	0.161	0.093	0.313	0.224	0.120	0.144	0.109	-0.012	0.096	0.320	0.224	0.122	0.145	0.110	1	0.097	0.169
D47	0.314	0.489	0.817	0.648	0.858	0.149	0.898	0.327	0.464	0.817	0.648	0.858	0.180	0.918	0.280	0.409	0.785	0.614	0.847	0.079	0.969	0.273	0.409	0.777	0.627	0.858	0.097	1	0.835
AGE	0.544	0.714	0.859	0.827	0.861	0.260	0.852	0.561	0.695	0.852	0.820	0.861	0.289	0.850	0.513	0.650	0.847	0.793	0.857	0.167	0.850	0.492	0.641	0.843	0.782	0.861	0.169	0.835	1

Table 8. Estimated regression coefficients and the statistics associated with each coefficient – girls, permanent teeth

Dependent Variable: AGE
Method: Least Squares
Sample: 1 206
Included observations: 206

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D11	0.490580	0.392351	1.250360	0.2127
D12	0.337267	0.348751	0.967071	0.3347
D13	0.585267	0.561698	1.041960	0.2988
D14	1.653719	0.437012	3.784152	0.0002
D15	0.202869	0.475643	0.426515	0.6702
D16	0.558824	0.555017	1.006860	0.3153
D17	2.244499	0.363250	6.178944	0.0000
D26	-0.171090	0.475992	-0.359438	0.7197
D36	1.669413	0.891168	1.873288	0.0626
D41	0.391881	0.418125	0.937235	0.3498
D42	0.665175	0.360235	1.846502	0.0664
D43	0.392957	0.425884	0.922685	0.3573
D44	-0.169762	0.404251	-0.419943	0.6750
D46	0.242827	0.722879	0.335916	0.7373
D47	0.989730	0.378315	2.616155	0.0096
C	3.983430	0.996788	3.996265	0.0001

R-squared	0.903956	Mean dependent var	10.41278
Adjusted R-squared	0.896374	S.D. dependent var	3.254349
S.E. of regression	1.047607	Akaike info criterion	3.005382
Sum squared resid	208.5212	Schwarz criterion	3.263857
Log likelihood	-293.5543	Hannan-Quinn criter.	3.109918
F-statistic	119.2180	Durbin-Watson stat	0.782358
Prob(F-statistic)	0.000000		

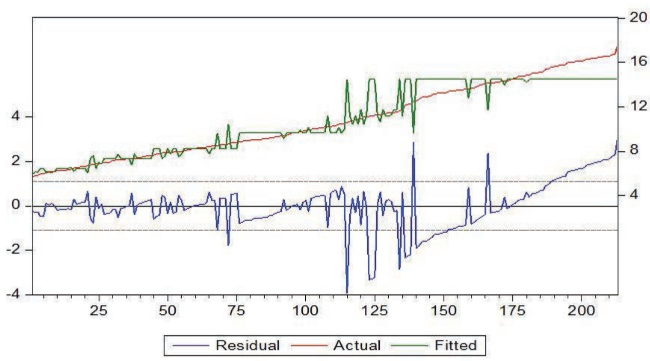

Figure 8. Actual, Fitted, Residual graph – girls, permanent teeth.

1.Boys

Statistical analysis performed showed a strong positive correlation between various permanent teeth development (see Table 5). The grey squares highlight a correlation higher than 90%. A strong correlation does not exist regarding the first permanent molar (left *versus* right side).

If we exclude the correlated factors with correlation higher than 90%, except for the first molars (26 *vs.* 16, 36 *vs.* 46) which are not strongly correlated, we can obtain a better fitted regression model.

Estimation Command

LS AGE D11 D12 D13 D14 D15 D16 D17 D26 D36 D41 D42 D43 D44 D45 D46 D47 C

Estimation Equation

AGE = C(1)*D11 + C(2)*D12 + C(3)*D13 + C(4)*D14 + C(5)*D15 + C(6)*D16 + C(7)*D17 + C(8)*D26 + C(9)*D36 + C(10)*D41 + C(11)*D42 + C(12)*D43 + C(13)*D44 + C(14)*D45 + C(15)*D46 +

C(16)*D47 + C(17)

Substituted Coefficients

AGE = 0.562213225871 * D11 + 0.486961870884 * D12 + 0.28394071007 * D13 + 1.43129835439 * D14 - 2.45730773646 * D15 + 0.5083339303 * D16 + 2.71083592855 * D17 - 0.119371658849 * D26 + 0.32070288689 * D36 + 0.326097757018 * D41 + 0.414146534245 * D42 + 0.5227946786 * D43 - 0.0407272637775 * D44 + 3.19491054939 * D45 - 0.0772763497593 * D46 + 0.583504774679 * D47 + 5.81822535339

Figure 6 shows the actual *versus* fitted values based on the estimated equation and the obtained residual values. Because the fit is good, the fitted values nearly cover up the actual values on the graph.

2.Girls

Based on Table 7, a high correlation both in mandibular and maxillary left *versus* right teeth groups (1-2, 4-3) is detected.

Statistical analysis performed showed a strong positive correlation between various permanent teeth development. The grey squares highlight a correlation higher than 90%. A strong correlation does not exist regarding the first permanent molar (left *versus* right side).

If we exclude the correlated factors with correlation higher than 90%, except for the first molars (26 *vs.* 16, 36 *vs.* 46) which are not strongly correlated, we can obtain a better fitted regression model.

Estimation Command

LS AGE D11 D12 D13 D14 D15 D16 D17 D26 D36 D41 D42 D43 D44 D46 D47 C

Estimation Equation

AGE = C(1)*D11 + C(2)*D12 + C(3)*D13 + C(4)*D14 + C(5)*D15 + C(6)*D16 + C(7)*D17 + C(8)*D26 + C(9)*D36 + C(10)*D41 + C(11)*D42 + C(12)*D43 + C(13)*D44 + C(14)*D46 + C(15)*D47 + C(16)

Substituted Coefficients

AGE = 0.490580186851 * D11 + 0.337267464149 * D12 + 0.585266520993 * D13 + 1.65371858995 * D14 + 0.202868506891 * D15 + 0.558823882475 * D16 + 2.24449886683 * D17 - 0.171089778158 * D26 + 1.66941326963 * D36 + 0.39188140313 * D41 + 0.66517474617 *D42 + 0.392957163656 * D43 - 0.169762319093 * D44 + 0.242826511237 * D46 + 0.989729665681 * D47 + 3.98342970092

Figure 8 shows the actual *versus* fitted values based on the estimated equation and the obtained residual values. Because the fit is good, the fitted values nearly cover up the actual values on the graph.

DISCUSSION

After analysing the correlation obtained (Tabels 1, 3, 5, 7) between the right and left maxillary and mandibular teeth, it can be observed that an age estimation using the Least Squares regression method can be performed on the presence of teeth recorded on either left or right side. The exception is in case of permanent teeth in which all first molars must be taken into consideration because in their case a strong correlation does not occur.

Two of the most important values in measuring the success of the regression in predicting the age estimated values, are: „R-squared" and „S.E. of regression" (see Tables 2, 4, 6, 8).

The R-squared statistic may be interpreted as the fraction of the variance of the dependent variable explained by the independent variables. The statistic will equal 1 (100%) if the regression fits perfectly.

The value of the R-squared is between 83 and 90%, showing that the model is highly significant. This means that the chronological age is explained by the teeth presence observations in :

85% cases based on primary teeth and in 89% cases based on permanent teeth in boys,

83% cases based on primary teeth and in 90% cases based on permanent teeth in girls.

The „S.E. of regression" (standard error of the regression) is approximately 1 (see Tables 2, 4, 6, 8), which means that the age can be estimated with a standard deviation error of ± one year.

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