New Standards for Electrocardiograms of Adult Males without Evidence of Cardiac Hypertrophy

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SUMMARY

A statistical analysis has been made of 214 adult male subjects, of whom 59 had not shown cardiac hypertrophy at autopsy, and cardiac hypertrophy had been excluded in the remainder by clinical and radiological study. The statistical analysis consisted of a stepwise linear regression analysis, in which the electrocardiographic deflections were the dependent variables, and age, electrical position of the heart, height, weight and ponderal index were the independent variables. The normal limits were established by a combination of the stepwise linear regression equations and the percentile limits. Such an approach offers advantages over methods previously used to establish normal limits for the electrocardiogram.

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The electrocardiogram of a normal subject has been the subject of numerous studies, both before and after the introduction of unipolar limb and chest leads. Simonson[1] reviewed the shortcomings of these studies in regard to the lack of consideration given to biological variables, which may effect the size of the electrocardiographic deflections. These biological variables have been included in the present study, which differs from that of Simonson in that the groups studied were considered as a continuous series where possible. Whereas Simonson treated his normal groups as a discrete series, and made arbitrary subdivisions of the biological variables, in the present study this was avoided with few exceptions. An advantage of the present form of analysis was that it lent itself to multiple linear regression analysis.

PATIENTS AND METHODS

The normal group consisted of 214 adult males, 59 of whom had been subjected to autopsy. All the subjects had been or were involved in the gold mining industry. No evidence of ventricular hypertrophy had been found in the latter group, when dissected and analysed according to the method of Stofer and Hiratzka.[2] The degree of emphysema and silicosis had been judged to be moderate or more marked in 4 cases at autopsy. Evidence of silicosis and emphysema was mild in only a few of the remaining autopsy cases, being absent in the control or normal group.

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Graphs: Requests for copies of 57 graphs depicting the linear regression equations with one entry and their normal limits, will be considered when the number requested and their cost have been taken into account.

Cases were eliminated if any of the following conditions were present:

1. A disease capable of causing acute or subacute cor pulmonale, such as thrombo-embolic disease, primary or secondary cancer of the lung, or substantial pulmonary infection, including tuberculosis.
2. Evidence of a previous myocardial infarction in the electrocardiogram, or the presence of confluent fibrosis in the heart muscle at autopsy consistent with a previous infarction.
3. The presence of left ventricular atrophy at autopsy, associated with a terminal wasting disease, where the left ventricular weight was less than the lower limits of normal.
4. The presence of complete left or right bundle-branch block in the electrocardiogram.

The remaining 155 cases were considered to be clinically normal, with absence of cardiac murmurs, a blood pressure less than 150/90 mmHg, and a normal chest X-ray film.

The means, standard deviations and 95 percentiles for age, height, weight and ponderal index are given in Table I.

TABLE I. MEAN, STANDARD DEVIATION (SD) AND 2,5 PERCENTILE AND 97,5 PERCENTILE FOR THE INDEPENDENT VARIABLES OF THE REGRESSION ANALYSIS

			Percentile	
	Mean	SD	2,5	97,5
Age (years)	**37**	**17**	**20**	**77**
Height (cm)	**175**	**6**	**163**	**188**
Weight (kg)	**71**	**10**	**54**	**91**
Pond. index	**12,8**	**0,54**	**11,6**	**13,8**
Â P	**50**	**25**	**−5**	**83**
Â QRS	**51**	**36**	**−45**	**105**
Â T	**43**	**22**	**2**	**79**
T P	**4**	**1,9**	**1,0**	**8,5**
T QRS	**10**	**1,9**	**6**	**14**
T T	**4**	**1,6**	**1**	**7**

Pond. index—ponderal index; Â = mean frontal electrical axis of the P, QRS and T waves; T = transitional point of the praecordial leads for the P, QRS and T waves.

A step-wise linear regression analysis was made, with the size of the electrocardiographic deflections as the dependent variables, and age (years), mean frontal electrical axis (degrees), transitional point of the praecordial leads (number), height (cm), weight (kg) and ponderal index as the independent variables. Dixon's computing method[3] was used.

The measurements of the electrocardiogram were made according to accepted conventions to an accuracy of 0,25 mm. Appropriate corrections to these measurements were made, where the calibration differed from the accepted standard of 1 mV = 10 mm. The mean frontal axis was estimated visually to an accuracy of 15 degrees. The transitional point of the chest leads was considered to be that site at which the algebraic sum of the positive and negative deflections was zero or close to zero (null potential). These sites were numbered for statistical purposes according to the following convention:

16 — to the left V6, 15 — V6, 14 — between V5 and V6, 13 — V5, 12 — between V4 and V5, 11 — V4, 10 — between V3 and V4, 9 — V3, 8 — between V2 and V3, 7 — V2, 6 — between V1 and V2, 5— V1, 4 — to the right of V1 in the absence of V4R, 3 — between V4R and V1, 2 — V4R, 1 — to the right of V4R.

RESULTS

The means, standard deviations and percentiles of the independent variables used in the step-wise linear regression analysis of the electrocardiographic deflections are given in Table I. Similar estimations were made for the individual electrocardiographic deflections (Table II).

Only 3 steps of the step-wise linear regression analysis are given (Table III). The point at which to stop in such an analysis is arbitrary. For practical purposes it can be chosen as the step at which the standard error of the estimate is at a minimum, and at which point the addition of one or more variables causes a small or inconsequential increase in the square of the multiple correlation coefficient. In effect, the square of the multiple correlation coefficient is a measure of the amount of variation in the data that is accounted for by independent variables in the regression equation. Multiple correlation coefficients of 0,3 and 0,5, when squared, would indicate that 9% and 25% of the variation in the data is attributable to the independent variables involved in the equation. The square of the standard error of the estimate indicates the variance of the data about the regression equation, and is ideal when this estimate is minimal.

Table III includes an analysis of variance, where an estimate of the F value indicated whether the correlation was significant at $P<0,05$, $P<0,01$, or $P<0,001$ level. The regression equations with 1, 2 and 3 entries were significant at the latter level or below, with few exceptions.

DISCUSSION

Simonson[1] reviewed the literature relating to normal standards for the electrocardiogram. In 13 of such studies no consideration was given to age, weight or sex. Normal standards were based on sex in 2 studies, and on age in a further 2 publications. Age and height were considered on one occasion. The electrical position of the heart for the frontal plane formed the basis of analysis in 2 series of cases. Simonson considered that biological and other variables had been under-estimated in the establishment of normal electrocardiographic standards, and his studies included age, weight, relative body weight, sex and the

TABLE II. MEAN, STANDARD DEVIATION (SD) AND 2,5 PERCENTILE AND 97,5 PERCENTILE FOR THE ELECTROCARDIOGRAPHIC DEFLECTIONS P, Q, R, S AND T AND THE R/S RATIO

		I	II	III	R	L	F	V4R	V1	V2	V3	V4	V5	V6
P	Mean	0,5	1,0	0,6	− 0,8	0,2	0,7	0,2	0,4	0,6	0,5	0,4	0,4	0,3
	SD	0,22	0,45	0,40	0,32	0,34	0,45	0,33	0,39	0,34	0,25	0,21	0,21	0,21
	2,5 percentile	0,2	0,2	0,0	− 0,2	− 0,7	0,0	−0,4	− 0,9	− 0,2	0,2	0,1	0,1	0,0
	97,5 percentile	1,0	1,0	1,6	− 1,5	0,7	1,7	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Q	Mean	0,13	0,26	0,48	3,48	0,27	0,27	0,03	—	—	0,05	0,14	0,25	0,84
	SD	0,25	0,39	0,80	3,49	0,65	0,44	0,25	—	—	0,29	0,41	0,39	0,42
	2,5 percentile	—	—	—	—	—	—	—	—	—	—	—	—	—
	97,5 percentile	1,0	1,6	3,4	10,2	2,0	1,7	0,1	—	—	0,6	1,5	1,5	1,5
R	Mean	4,9	8,5	4,7	1,0	2,1	6,3	0,5	2,1	5,2	8,1	13,4	13,2	10,5
	SD	2,53	3,59	3,55	1,05	2,15	3,62	1,15	1,64	3,19	4,32	5,38	4,84	3,84
	2,5 percentile	1,5	3,0	0,3	0,0	0,0	0,7	0,0	0,0	0,5	1,8	4,0	5,0	3,6
	97,5 percentile	12,1	16,3	12,9	3,2	8,9	13,9	2,0	6,1	12,0	18,0	24,0	25,2	18,0
S	Mean	0,9	1,3	1,3	3,3	1,8	1,0	2,6	10,0	16,4	11,2	6,3	3,3	1,3
	SD	1,08	1,35	1,83	4,01	1,92	1,25	3,16	5,13	7,42	5,43	4,00	2,60	1,46
	2,5 percentile	0,0	0,0	0,0	0,0	0,0	0,0	0,0	2,4	5,7	3,0	1,5	0,0	0,0
	97,5 percentile	4,0	4,5	7,0	11,0	6,6	4,0	9,8	22,0	32,0	23,5	17,0	11,0	4,8
T	Mean	2,0	2,5	0,6	− 2,2	0,7	1,5	−0,1	0,9	5,5	5,8	5,1	4,0	2,9
	SD	1,08	1,25	0,99	1,09	0,93	0,97	0,68	1,49	2,84	2,90	2,71	2,15	1,69
	2,5 percentile	0,4	0,7	− 1,5	− 5,0	− 1,5	− 0,8	−1,7	− 2,0	0,8	1,0	0,9	0,8	0,6
	97,5 percentile	4,5	5,5	2,6	− 0,5	2,8	3,4	1,2	4,0	11,5	12,1	11,0	9,0	6,8
R/S														
	2,5 percentile							0,00	0,00	0,04	0,06	0,17	0,44	0,88
	97,5 percentile							0,75	1,47	1,52	3,21	—	—	—

TABLE III. STEP-WISE LINEAR REGRESSION EQUATIONS WITH 1, 2 AND 3 ENTRIES. THE DEPENDENT VARIABLES ARE THE ELECTROCARDIOGRAPHIC DEFLECTIONS Q, R, S, AND T AND THE R/S RATIO

		1st entry	2nd entry	3rd entry	*r*	SEE	F value
Q I	0,2608	−0,0025 Â QRS			0,37	0,230	*** 34,2
	0,4931	−0,0023 Â QRS	−0,0249 T QRS		0,42	0,226	*** 22,0
	0,5671	−0,0021 Â QRS	−0,0020 ÂT	−0,0248 T QRS	0,45	0,222	*** 17,8
Q II	0,1336	+0,0024 Â QRS			0,23	0,386	*** 11,3
	0,0136	+0,0024 Â P	+0,0024 Â QRS		0,27	0,383	*** 8,3
	0,8106	−0,0642 P I	+0,0027 Â P	+0,0026 Â QRS	0,28	0,382	*** 6,1
Q III	3,3440	−0,2246 P I			0,15	0,794	* 4,9
	3,3722	−0,2742 P I	+0,0049 Â P		0,21	0,787	* 4,8
	3,9237	−0,2983 P I	+0,0050 Â P	+0,0022 Â QRS	0,23	0,785	** 3,9
Q aVR	5,6603	−0,0585 AGE			0,29	3,351	*** 19,2
	−0,5136	−0,0580 AGE	+0,4821 P I		0,30	3,349	*** 10,3
	−0,8112	−0,0603 AGE	+0,5315 P I	−0,0492 Â QRS	0,30	3,352	7,0
Q aVL	0,0355	+0,0062 AGE			0,16	0,645	* 5,8
	0,5330	+0,0059 AGE	−0,0497 T QRS		0,22	0,640	** 5,1
	1,2364	+0,0054 AGE	−0,0094 WT	−0,0515 T QRS	0,26	0,635	** 4,9
Q aVF	0,0771	+0,0038 Â QRS			0,32	0,415	*** 23,9
	−0,0942	+0,0034 Â P	−0,0038 Â QRS		0,37	0,407	*** 16,9
	−0,0043	+0,0025 AGE	+0,0037 Â P	+0,0036 Â QRS	0,38	0,406	*** 12,1
Q V4	0,7801	−0,0651 T QRS			0,29	0,398	*** 19,5
	0,6374	+0,0034 AGE	−0,0633 T QRS		0,32	0,394	*** 12,2
	−0,7768	+0,0040 AGE	+0,0081 HT	−0,0663 T Q RS	0,34	0,392	*** 9,2
Q V5	0,8742	−0,0643 T QRS			0,30	0,378	*** 21,0
	0,7643	+0,0022 Â P	−0,0643 T QRS		0,33	0,375	*** 12,9
	0,0785	+0,0022 Â P	−0,0011 Â QRS	−0,0605 T QRS	0,35	0,373	*** 9,5
Q V6	0,8446	−0,0516 T QRS			0,23	0,412	*** 11,4
	−0,7250	+0,0092 HT	−0,0554 T QRS		0,26	0,409	*** 7,7
	−0,8699	+0,0095 HT	+0,0018 Â P	−0,0556 T QRS	0,28	0,408	*** 6,0
R I	6,5218	−0,0319 Â QRS			0,46	2,254	*** 56,7
	28,5974	−1,7449 P I	−0,0280 Â QRS		0,59	2,060	*** 55,4
	24,6504	−1,3444 P I	−0,0260 Â QRS	−0,0294 Â T	0,63	1,974	*** 46,8
R II	6,4012	+0,0420 Â QRS			0,43	3,258	*** 47,0
	9,4484	−0,0717 AGE	+0,0345 Â QRS		0,54	3,034	*** 43,9
	11,9180	−0,0723 AGE	+0,0367 Â QRS	−0,2617 T QRS	0,56	3,003	*** 31,6
R III	1,5804	+0,0607 Â QRS			0,62	2,790	*** 133,6
	3,4287	−0,0435 AGE	+0,0561 Â QRS		0,65	2,699	*** 79,2
	7,9282	−0,0475 AGE	−0,0591 WT	+0,0533 Â QRS	0,67	2,647	*** 58,0
R aVR	0,0043	+0,0997 T QRS			0,17	1,040	* 6,7
	0,3187	−0,0074 AGE	+0,0956 T QRS		0,21	1,034	** 5,0
	2,6793	−0,0075 AGE	−0,1898 P I	+0,1025 T QRS	0,23	1,032	** 4,0
R aVL	3,8304	−0,0352 Â QRS			0,59	1,727	*** 117,4
	4,9374	−0,0324 Â QRS	−0,0291 Â T		0,67	1,611	*** 83,9
	2,5240	+0,0306 WT	−0,0316 Â QRS	−0,0245 Â T	0,68	1,591	*** 59,4
R aVF	3,1710	+0,0611 Â QRS			0,61	2,866	*** 128,6
	5,2714	−0,0494 AGE	+0,0560 Â QRS		0,66	2,749	*** 79,6
	4,5970	−0,0602 AGE	+0,0519 Â QRS	+0,0298 Â T	0,68	2,684	*** 59,5
R V4R	2,2804	−0,1869 T QRS			0,30	1,094	*** 21,2
	1,6076	+0,0158 AGE	−0,1782 T QRS		0,38	1,063	*** 18,2
	1,3266	+0,0192 AGE	+0,0075 Â QRS	−0,2014 T QRS	0,45	1,031	*** 17,5
R VI	3,5347	−0,0378 AGE			0,40	1,513	*** 39,4
	5,5908	−0,0391 AGE	−0,2056 T QRS		0,46	1,468	*** 28,0
	5,3957	−0,0368 AGE	−0,0052 Â QRS	−0,2217 T QRS	0,47	1,460	*** 20,0
R V2	7,8131	−0,0709 AGE			0,38	2,955	*** 36,3
	12,6524	−0,0739 AGE	−0,4838 T QRS		0,47	2,823	*** 30,5
	23,7447	−0,0747 AGE	−0,8916 P I	0,4513 T QRS	0,50	2,789	*** 22,9
R V3	18,9669	−1,1176 T QRS			0,48	3,801	*** 62,8
	20,4933	−0,0358 AGE	−1,1372 T QRS		0,50	3,759	*** 34,9
	29,1864	−0,0364 AGE	−0,6988 P I	−1,1117 T QRS	0,51	3,750	*** 24,1

(continued)

TABLE III (continued)

		1st entry	2nd entry	3rd entry	r	SEE	F value
R V4	27,9437	−1,4904 T QRS			0,51	4,637	*** 75,0
	29,7386	−0,0421 AGE	−1,5136 T QRS		0,53	4,591	*** 40,9
	30,2461	−0,0363 AGE	0,0191 Â T	−1,5034 T QRS	0,53	4,583	*** 27,9
R V5	22,7665	−0,9751 T QRS			0,37	4,504	*** 34,0
	24,8372	−0,0486 AGE	−1,0018 T QRS		0,41	4,436	*** 21,3
	25,5441	−0,0571 AGE	−0,0189 Â QRS	0,9435 T QRS	0,43	4,396	*** 16,1
R V6	16,0967	−0,5746 T QRS			0,28	3,703	*** 17,5
	18,2906	−0,0515 AGE	−0,6030 T QRS		0,36	3,604	*** 15,6
	19,1054	−0,0422 AGE	−0,0307 Â T	−0,5866 T QRS	0,40	3,551	*** 13,2
S I	0,4129	+0,0104 Â QRS			0,35	1,019	*** 29,2
	0,8314	−0,0099 AGE	+0,0093 Â QRS		0,38	1,008	*** 17,8
	0,0079	−0,0096 AGE	+0,0086 Â QRS	+0,0873 T QRS	0,41	0,998	*** 13,9
S II	1,7546	−0,0094 Â QRS			0,25	1,307	*** 14,6
	−4,4628	+0,4914 P I	−0,0105 Â QRS		0,32	1,284	*** 12,0
	−4,9121	+0,4579 P I	...−0,0113 Â QRS	+0,0936 T QRS	0,34	1,276	*** 9,3
S III	2,9127	−0,0325 Â QRS			0,64	1,405	*** 150,7
	−0,4821	+0,2683 P I	−0,0331 Â QRS		0,65	1,401	*** 76,9
	−0,8929	+0,3207 P I	−0,0050 Â P	−0,0332 Â QRS	0,65	1,399	*** 51,9
S aVR	−7,6403	−0,4487 T QRS			0,21	3,932	** 9,5
	19,8004	−0,9802 P I	−0,4124 T QRS		0,24	3,907	** 6,7
	21,0635	−1,1013 P I	+0,0131 Â QRS	−0,4517 T QRS	0,27	3,888	*** 5,5
S aVL	0,2411	+0,0310 Â QRS			0,59	1,555	*** 112,4
	0,9921	−0,0177 AGE	+0,0292 Â QRS		0,61	1,530	*** 62,1
	−0,2229	−0,0174 AGE	+0,0281 Â QRS	+0,1287 T QRS	0,62	1,515	*** 43,9
S aVF	1,8663	−0,0171 Â QRS			0,50	1,085	*** 70,0
	−6,1790	+0,6359 P I	−0,0185 Â QRS		0,57	1,034	*** 49,9
	−6,6459	+0,6011 P I	−0,0193 Â QRS	+0,0972 T QRS	0,58	1,021	*** 36,2
S V4R	−0,7992	+0,0902 AGE			0,49	2,763	*** 67,1
	−6,2832	+0,0906 AGE	+0,4282 P I		0,50	2,760	*** 34,4
	−6,5969	+0,0883 AGE	+0,4803 P I	−0,0052 Â QRS	0,50	2,760	*** 23,2
SV1	12,4916	−0,0680 AGE			0,23	5,004	*** 11,6
	11,8683	−0,0739 AGE	+0,0196 Â T		0,24	4,998	** 6,6
	10,2593	−0,0727 AGE	+0,0189 Â T	+0,1629 T QRS	0,25	5,001	** 4,6
SV2	25,9256	−0,2553 AGE			0,59	5,992	*** 114,6
	15,3934	−0,2487 AGE	+1,0525 T QRS		0,65	5,681	*** 76,1
	22,2598	−0,2530 AGE	−0,0918 WT	+1,0358 T QRS	0,61	5,626	*** 53,5
SV3	−6,8283	+1,8424 T QRS			0,63	4,247	*** 136,6
	−7,2927	+0,0255 Â QRS	+1,7578 T QRS		0,65	4,157	*** 76,5
	−6,3174	−0,0219 AGE	+0,0232 Â QRS	+1,7532 T QRS	0,65	4,151	*** 51,7
SV4	−6,4613	+0,3098 T QRS			0,60	3,197	*** 121,9
	−6,6855	+0,0123 Â QRS	+1,2690 T QRS		0,61	3,174	*** 63,9
	−6,1048	+0,0138	−0,0154 Â T	+1,2696 T QRS	0,62	3,164	*** 43,7
SV5	−3,0963	+0,6550 T QRS			0,47	2,307	*** 58,6
	−3,2982	+0,0111 Â QRS	+0,6182 T QRS		0,49	2,277	*** 33,3
	1,9982	−0,4282 P I	+0,0119 Â QRS	+0,6311 T QRS	0,50	2,271	*** 23,0
SV6	−0,7847	+0,2095 T QRS			0,27	1,408	*** 16,1
	−0,8588	+0,0041 Â QRS	+0,1960 T QRS		0,28	1,403	*** 9,2
	−0,5055	−0,0066 AGE	+0,0034 Â QRS	+0,1946 T QRS	0,29	1,402	*** 6,6
T I	3,1460	−0,0318 AGE			0,50	0,938	*** 72,3
	3,5308	−0,0281 AGE	−0,0121 Â T		0,56	0,903	*** 47,6
	4,3816	−0,0288 AGE	—0,0117 Â T	−0,0862 T QRS	0,58	0,891	*** 34,9
T II	3,5264	−0,0287 AGE			0,40	1,146	*** 39,6
	2,8937	−0,0347 AGE	+0,0199 Â T		0,52	1,067	*** 39,8
	3,8061	−0,0354 AGE	+0,0202 Â T	−0,0924 T QRS	0,54	1,055	*** 29,2
T III	−0,9384	+0,0346 Â T			0,77	0,639	*** 30,25
	−1,0946	+0,0040 Â QRS	+0,0335 Â T		0,78	0,624	*** 164,1
	−0,0928	−0,0127 WT	+0,0037 Â QRS	+0,0317 Â T	0,79	0,615	*** 115,1
T aVR	−3,4245	+0,0317 AGE			0,50	0,943	*** 71,1
	−4,2698	+0,0322 AGE	+0,0845 T QRS		0,52	0,932	*** 39,3
	−4,1191	+0,0339 AGE	−0,0057 Â T	+0,0875 T QRS	0,53	0,926	*** 27,8

TABLE III (continued)

		1st entry	2nd entry	3rd entry	r	SEE	F value
T aVL	1,9621	−0,0291 Â T			0,69	0,675	*** 192,3
	2,4106	−0,0153 AGE	−0,0263 Â T		0,74	0,626	*** 129,6
	1,3472	−0,0153 AGE	+0,0137 WT	−0,0242 Â T	0,75	0,615	*** 192,3
T aVF	0,5793	+0,0209 Â T			0,47	0,857	*** 61,4
	1,2276	−0,0221 AGE	+0,0249 Â T		0,61	0,774	*** 61,9
	1,4199	−0,0209 AGE	−0,0059 Â P	+0,0264 Â T	0,63	0,763	*** 44,8
T V4R	−0,7610	+0,0729 T QRS			0,20	0,664	** 8,8
	−0,9142	+0,0039 Â T	+0,0715 T QRS		0,24	0,660	** 6,2
	−0,7923	−0,0031 Â P	+0,0047 Â T	+0,0712 T QRS	0,26	0,657	** 5,1
TV1	1,5015	−0,0152 AGE			0,17	1,473	* 6,7
	−1,3061	−0,0139 AGE	+0,0158 HT		0,18	1,473	* 3,8
	−0,3095	−0,0138 AGE	+0,0186 HT	−0,1161 P I	0,19	1,475	2,6
T V2	8,4504	−0,0791 AGE			0,48	2,493	*** 63,5
	9,9160	−0,0800 AGE	−0,1465 T QRS		0,49	2,484	*** 33,2
	10,3163	−0,0771 AGE	−0,0105 Â P	−0,1447 T QRS	0,50	2,477	*** 23,0
T V3	7,8281	−0,0553 AGE			0,33	2,746	*** 25,6
	−5,0530	−0,0495 AGE	+0,0725 HT		0,36	2,719	*** 15,6
	−4,4903	−0,0532 AGE	+0,0724 HT	−0,0079 Â QRS	0,37	2,711	*** 11,2
T V4	7,2389	−0,0568 AGE			0,36	2,536	*** 31,6
	−7,2251	−0,0503 AGE	+0,0814 HT		0,40	2,497	*** 20,2
	−6,7768	−0,0508 AGE	+0,0867 HT	−0,1382 T QRS	0,41	2,490	*** 14,2
T V5	5,8492	−0,0490 AGE			0,39	1,983	*** 38,4
	−3,1825	−0,0449 AGE	+0,0509 HT		0,42	1,966	*** 22,0
	−2,6885	−0,0454 AGE	+0,0567 HT	−0,1523 T QRS	0,43	1,950	*** 16,3
T V6	4,2118	−0,0362 AGE			0,37	1,570	*** 33,6
	5,3480	−0,0370 AGE	−0,1136 T QRS		0,39	1,559	*** 18,9
	−0,6651	−0,0343 AGE	+0,0346 HT	−0,1267 T QRS	0,41	1,550	*** 13,9
T V4R	0,9630	−0,2412 T T			0,59	0,536	*** 115,0
	0,2511	+0,0720 T QRS	−0,2392 T T		0,63	0,520	*** 68,0
	0,1340	+0,0031 Â T	+0,0709 T QRS	−0,2402 T T	0,63	0,517	*** 47,1
T V1	3,2380	−0,5582 T T			0,61	1,192	*** 124,3
	4,2481	−0,0229 AGE	−0,5950 T T		0,66	1,129	*** 82,0
	6,8308	−0,0232 AGE	−0,2001 P I	−0,5993 T T	0,67	1,127	*** 55,5
T V2	8,4976	−0,0809 AGE			0,49	2,511	*** 65,4
	11,2371	−0,0891 AGE	−0,0586 T T		0,58	2,342	*** 53,9
	12,9740	−0,0903 AGE	−0,1704 T QRS	−0,5752 T T	0,59	2,326	*** 37,7
T V3	7,8281	−0,0553 AGE			0,33	2,746	*** 25,6
	9,1324	−0,0593 AGE	−0,2707 T T		0,36	2,717	*** 15,8
	−3,1679	−0,0535 AGE	+0,0689 HT	−0,2581 T T	0,39	2,694	*** 12,3
R/S	1,0437	−0,0152 AGE			0,16	1,564	1,7
V 4R	0,7031	−0,0142 AGE	+0,0059 Â QRS		0,21	1,560	1,5
	−2,7303	−0,0145 AGE	+0,2730 P I	−0,0053 Â QRS	0,24	1,563	1,2
R/S	0,3896	−0,0038 AGE			0,24	0,262	* 4,0
V1	0,6251	−0,0042 AGE	−0,0031 WT		0,26	0,262	2,4
	0,7272	−0,0044 AGE	−0,0039 WT	−0,0008 Â QRS	0,28	0,262	1,9
R/S	0,5040	−0,0028 Â QRS			0,37	0,269	** 10,3
V2	0,5810	−0,0018 AGE	−0,0029 Â QRS		0,38	0,269	** 5,5
	1,7570	−0,0024 AGE	−0,0066 HT	−0,0029 Â QRS	0,40	0,269	** 4,1
R/S	3,7285	−0,2850 T QRS			0,72	0,462	*** 73,3
V3	6,3187	−0,0152 HT	−0,2802 T QRS		0,73	0,458	*** 38,5
	7,6040	−0,0073 AGE	−0,0217 HT	−0,2647 T QRS	0,75	0,447	*** 28,4
R/S	13,1587	−1,0278 T QRS			0,60	2,349	*** 36,9
V4	13,9495	−0,0341 AGE	−0,9647 T QRS		0,63	2,300	*** 21,2
	29,4067	−0,0436 AGE	−0,0892 HT	−0,9193 T QRS	0,65	2,267	*** 15,6
R/S	19,3115	−1,4338 T QRS			0,48	4,473	*** 19,8
V5	20,6809	−0,0591 AGE	−1,3246 T QRS		0,51	4,401	*** 11,8
	20,5620	−0,0558 AGE	+0,0119 Â QRS	−1,3858 T QRS	0,52	4,413	*** 8,1
R/S	54,1242	−3,9549 T QRS			0,35	18,060	*** 9,3
V6	18,2329	+0,4535 WT	−3,5591 T QRS		0,42	17,643	*** 7,0
	20,0430	−0,0407 AGE	+0,4425 WT	−3,4934 T QRS	0,42	17,766	** 4,6

r = multiple correlation coefficient, SEE = standard error of the estimate, *$P<0,05$, **$P<0,01$, ***$P<0,001$.

position of the heart in the frontal and horizontal planes of the body. These recommendations have been followed in the present study, except that the ponderal index was used instead of relative body weight. The presentation of the results has also differed from that of Simonson, in that the variables have been considered as a continuous rather than a discrete series, in which arbitrary subdivisions have been made. It was felt, however, that the presentation of the transitional point of the chest leads as degrees of angulation would be inaccurate, because of the lack of a satisfactory reference frame. In this respect, arbitrary subdivisions were made, but in sufficient number to simulate a continuous series.

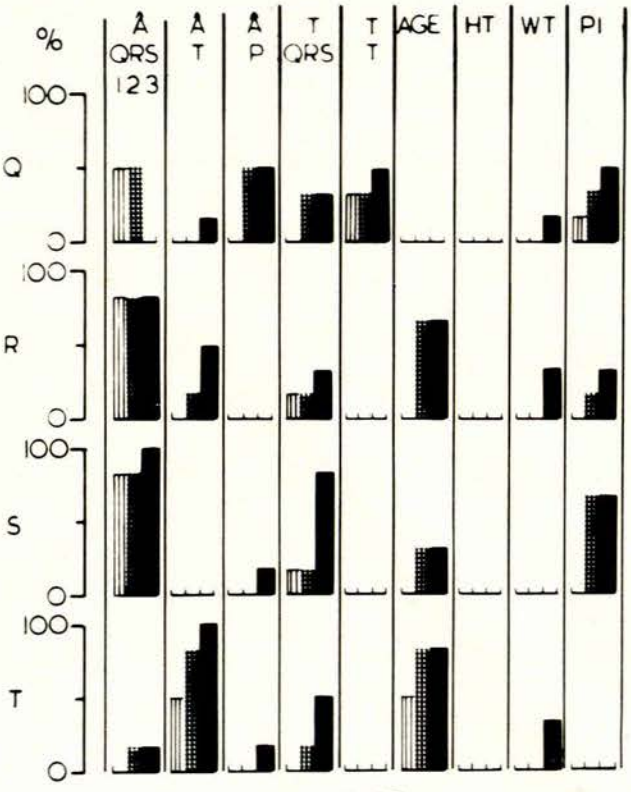
The value of treating each variable as a continuous series is that it lends itself to multiple linear regression analysis. The step-wise analysis adopted in this study has the advantage of assessing the interaction of independent variables in the prediction of the dependent variable. Such a result is not possible where the material has been considered as a discrete series, where the arbitrary subdivisions are made, as in the study of Simonson.

The large dependence of the size of the electrocardiographic deflections on the electrical position of the heart has been demonstrated by Simonson. The present study confirms these findings (Table IV, Fig. 1). The R and S waves in the limb leads depend for their size largely on Â QRS, and to a lesser extent this applied to the Q waves. As would be anticipated, Â T figures prominently in regard to the T wave. Age assumed importance only for the R and T waves, while body build (ponderal index) and T QRS accounted for most of the variation in the size of the S wave, other than that accounted for by Â QRS.

In the chest leads a large degree of the variation of the size of the Q, R and S waves was due to T QRS, and the only other independent variable of importance was age. To a lesser extent this applied to the T wave and the R : S ratio. The transitional point of the T wave (T T) only contributed significantly to the size of the T wave in leads V4R to V3.

Physical characteristics such as height and weight, or the ponderal index, influenced the dependent variables to a lesser extent than did the electrical position of the heart and age. In this respect the weight of the subject had little effect in influencing the size of the electrocardiographic deflections.

Normal limits for the electrocardiographic deflections have been established in the past from the actual extremes in the sample, from some multiple of the standard devia-



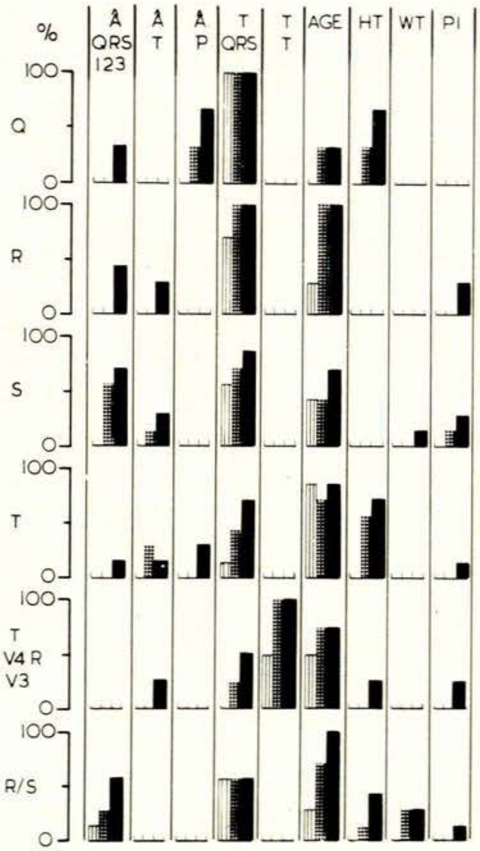


Fig. 1. The percentage incidence of independent variables in the step-wise linear regression equations with 1, 2 and 3 entries. The dependent variable is the electrocardiographic deflection Q, R, S and T. The independent variables are the mean frontal electrical axis of the QRS complex (Â QRS), the T wave (Â T), the P wave (Â P), the transitional point of the QRS complex in the chest leads (T QRS), the transitional point of the T wave in the chest leads (T T), age, height (HT), weight (WT) and the ponderal index (PI). See text for discussion.

tions, or from some percentage of the percentile distribution.[1] The present results suggested that a combination of statistical devices would be advantageous. The normal limits in regard to the regression equations should be placed 1,96 standard deviations above and below the mean regression line. In addition, measurements exceeding the 2,5 and 97,5 percentiles should be considered abnormal. In both instances, the suggested limits would include about 95% of the group studied.

The advantages of a combination of regression limits and percentile limits can be demonstrated by 2 examples. Fifty-nine per cent of the variation of the size of the T wave in lead III is accounted for by the mean frontal axis of the T wave (Â T), where T3 = −0,9384 + 0,0346 Â T ± 0,64, r = 0,77. This regression equation has been depicted graphically with the regression and percentile limits drawn in Fig. 2. It is readily apparent that the limits esta-

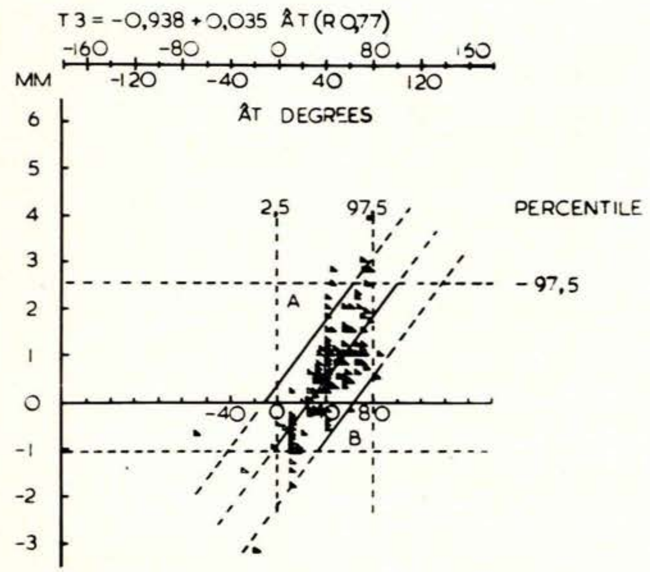


Fig. 2. A graph of the linear regression equation for the size of the T wave in lead III. T III = −0,938 + 0,035 Â T ±0,64. SEE R 0,77, where Â T is the mean frontal electrical axis of the T wave, SEE is the standard error of the estimate, and R is the correlation coefficient. The percentile limits (2,5 and 97,5) for the size of the T wave are indicated by the horizontal broken lines, and for the mean frontal electrical axis of the T wave by the vertical broken lines. The limits of the linear regression equation have been drawn in ± 1,96 standard errors of the estimate above and below the mean regression line. The solid lines of the regression limits pertain to the normal group studied, while the broken line extensions are projections which do not apply to the normal group, with the possible exception of cases following close to the percentile limits. Triangles A and B indicate areas which fall beyond the normal regression limits, but not the percentile limits.

blished in regard to the mean regression line are much narrower than the percentile limits. T-wave sizes falling in segments A and B of this group would be abnormal according to the regression limits, but not according to the percentile limits.

The second example concerns the size of the S wave in lead V3, where S V3 = −6,8283 + 1,842 T QRS ±4,25, r = 0,63 (Fig. 3). Forty per cent of the variation of the

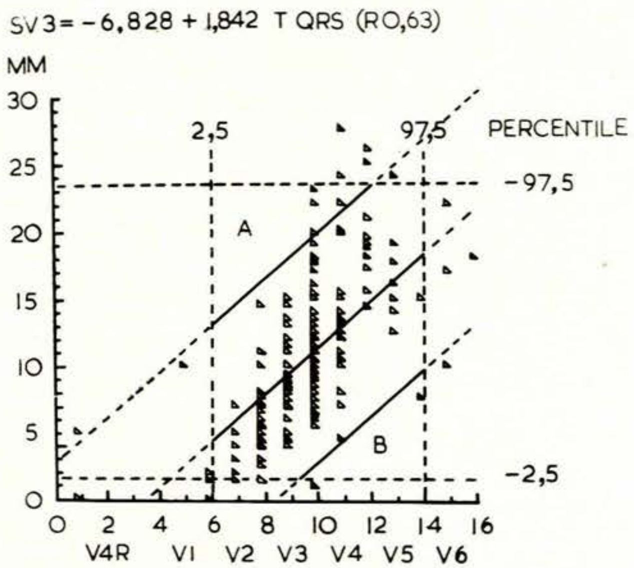


Fig. 3. A graph of the linear regression equation for the size of the S wave in leads V3. SV3 = −6,828 + 1,842 T QRS ± 4,25 SEE, R = 0,63, where T QRS is the transitional point in the chest leads, SEE is the standard error of the estimate, R is the correlation coefficient. The horizontal broken lines indicate the 2,5 and 97,5 percentiles of the size of the S wave, while the broken vertical lines indicate similar limits for the transitional point of the QRS complex in the chest leads. Triangles A and B are areas of the graph which are abnormal for the regression limits, but not for the percentile limits. The lower limits for the size of the S wave is 0 mm to the right of leads V3 for the regression limits, whereas it is 1,5 mm for the percentile limits. The combination of the regression limits and the percentile limits is an advantage under the circumstances.

size of S V3 is accounted for by the transitional point of the QRS complex in the chest leads (T QRS). The graphic representation of the limits is similar to the previous example. Again, measurements falling in segments A and B of the graph are abnormal according to the regression limits, but not according to the percentile limits. However, the regression line limits indicate that no S wave need appear in lead V3, when T QRS falls to the right of lead V3. In fact, the lower (2,5 percentile) limit is 1,5 mm, and as such the lower percentile limit adds appreciably to the accuracy of establishing the normal range of the S wave in lead V3. In the few instances where the relationship between the dependent and independent variables was not significant at the 5% level (P>0,05), the regression limits are valueless, and the normal limits are best described by the percentile limits.

The percentile limits (2,5 and 97,5) of the independent variables can be similarly used to establish if a measurement falls within or beyond that found in the group studied. These limits have been indicated by the vertical broken lines in the examples which have been used (Figs

2 and 3). Although the regression limits and the percentile limits have been extended to cover the complete graphs, this has been done by broken lines to indicate that the regression limits and percentile limits only pertain to the range found in the normal group.

The use of the linear regression equations with only one independent variable has the advantage of graphical representation (Figs 2 and 3). However, equations with 2, 3 or more entries could be utilised where computation facilities exist.

The purpose of the present study was to establish limits for electrocardiographic deflections in the absence of ventricular hypertrophy. The influence of lung diseases, such as silicosis and emphysema, has been neglected. Thus the group studied cannot be considered to be 'normal'. However, only 4 cases had moderate or more marked emphysema and/or silicosis at autopsy, while in the remainder the vast majority had little evidence of those diseases. The influence of these lung diseases was therefore slight, although their effects on the electrocardiogram cannot be entirely discounted.

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REFERENCES

1. Simonson, E. (1961): *Differentiation between Normal and Abnormal in Electrocardiography*. St Louis: C. V. Mosby.
2. Stofer, B. E. and Hiratzka, T. (1952): Amer. J. Clin. Path., **22**, 737.
3. Dixon, W. J. (1970): *Biomedical Computer Programmes*, Programme No. BMDO2R. Los Angeles: University of California Press.