

An attempt to estimate gestational age of newborns using physical characteristics

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ABSTRACT

Objective: To investigate the validity of using some physical characteristics to estimate gestational age of the Yemeni newborn babies and to compare the results with the findings of other similar studies.

Methods: By using the definitions of 12 physical characteristics and the simple and multiple regression methods, the gestational ages of 184 Yemeni newborns were estimated.

Results: The study has proved that, with reasonable estimation precision, only 5 physical characteristics namely skin texture, skin opacity, plantar creases, ear firmness and skull hardness can be used to estimate the

gestational age of the Yemeni newborn babies. Further, estimation precision will be very slightly affected by dropping out both skin opacity and skull hardness from the estimation process.

Conclusion: As this study is the first of its kind in Yemen, it is important to take its findings into consideration and to use these findings as a base line for relative future research.

Keywords: Newborn babies, gestational age, physical characteristics, regression analysis.

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According to the Yemeni Demographic and Maternal and Child Health Survey 1991/1992 (YDMCHS), the overall neonatal mortality rate (NNMR) in Yemen was 43.9.¹ There are, of course, several reasons that may cause death to babies at birth. However, some of these causes could be cured whilst others could not. For instance, if the level of maturity of a newborn is carefully and accurately determined, it may play an important role in reducing the risk factor of death. For such reasons, the need for accurate methods to estimate the gestational age (GA) seems crucial. In the absence of advanced techniques such as Length of the Dorsal Spine of the newborn (Martell, Fescina, and Bolivar, 1997),² estimating GA is often carried out with the aid of one or more of the following: Date of the mother's last menstrual period (LMP); Birth weight; Neurological

characteristics and Physical characteristics. The LMP date is often unavailable: particularly in developing countries where mothers may be illiterate (illiteracy rate in Yemen among women in the age group 15-45 is approximately 80%)³ and very few of them record the date of their periods. Sometimes the date is inaccurate and so gives misleading information. While the percentage of the Yemeni children under 5 years of age who are below the normal weight is 38%, the percentage of the Yemeni newborn babies who have low-birth weight is 19%.⁴⁻⁶ In a study conducted by Makki in collaboration with the International Research Center, Ottawa, Canada, (1997), the percentage of low-birth weight in a sample of 2256 newborn babies in Sana'a Hospitals was found to be 22%.⁷ Accordingly, using birth weight alone as an index of maturity for the Yemeni

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newborn babies seems inaccurate. In fact, some other researchers have concluded that birth weight is an unreliable index of maturity of GA.^{8,9} Many other studies, on the other hand, have relied on some physical or neurological signs, or both to estimate GA.⁸⁻²² However, Finnstrom (1972 a, b) and Parkin, Hey and Clowes (1976) concluded in their studies that the physical characteristics have several advantages over neurological tests; the examination is easier to perform, less disturbing to the baby, less likely to be affected by illness, independent of the state of the infant and can be performed immediately after birth.^{9,11,14} In Yemen, due to the very difficult economic situation, there are always shortages in every walk of life. In the health sector shortages are not only on trained staff but also on appropriate medical equipment, medicine, healthcare centres, healthcare workers, etc. The situation is much worse in the rural areas. Under such circumstances it is clear that using any advance or difficult techniques to estimate GA would be very limited. Therefore, for the present study, the physical characteristics and their scoring system that were defined by Farr, Mitchell, Neligan and Parkin (1966b, Table 1) along with the chest circumference (CC) and birth weight (BW) were used in the assessment.⁸ Definition of each score for each characteristic can be seen in Appendix I. The scoring system was designed in a way that the higher the score the more mature is the baby. To avoid excessive handling of the baby which may be harmful, the number of criteria should be kept to a minimum. Hence, the aims of the present investigation are to: investigate the validity of using these criteria, recognize the most likely of them, search for quick, easy to apply and accurate method to estimate GA of the Yemeni newborns, and compare the results with the findings of other similar studies.

Methods. The study data have been collected in the Neonatal Ward of Al-Thowra Hospital, Sana'a,

Table 1 - Farr et al scoring system of some physical characteristics.

Characteristics	Scoring system				
Edema	0	1	2		
Skin texture	0	1	2	3	4
Skin opacity	0	1	2	3	
Lanugo	0	1	2	3	4
Plantar creases	0	1	2	3	4
Nipple formation	0	1	2	3	4
Breast size	0	1	2	3	
Ear formation	0	1	2	3	
Ear firmness	0	1	2	3	
Genitalia					
Men	0	1	2		
Women	0	1	2		
Skull hardness	0	1	2	3	4

Republic of Yemen during the period from 26th November 1997 to 9th June 1998. This hospital is well equipped and is considered as the biggest and the best governmental hospital in Yemen. It receives cases from all around the country. The date of LMP was unknown to the investigator at the time of the assessment and was recorded later. All babies whose mothers were not sure of their LMP and those babies whose mothers were using contraceptive facilities for at least 5 months before the conception such as pills, coils etc, were excluded. All investigations were performed immediately or within 24 hours of delivery. The collected data has no twins. To the nipple of each baby, the chest circumference was measured once. Two doctors conducted a pilot study. Soon after they scored similar values, the pilot study was terminated. The babies of the pilot study were excluded. To maintain consistency, only one doctor was in charge of collecting the study data. However, to ensure that the process of assessment is progressing accurately, the other doctor was invited from time to time to reassess some cases. Descriptive statistics, correlation analysis, simple, multiple, stepwise, forward selection and backward elimination regression analysis were applied. The Statistical Package for Social Sciences (SPSS) was used to analyze the data.²³ A significance level was set to be 5% throughout the study.

Sampling. It is known that the interval estimation of a population proportion is calculated by:

$$\bar{p} \pm z_{\alpha/2} \sqrt{\frac{\bar{p}(1-\bar{p})}{n}}$$

where \bar{p} is the sample proportion (since the population proportion is unknown), α is the confidence level, and $z_{\alpha/2}$ is the z value providing an area of $\alpha/2$ of the standard normal probability distribution. If one needs to estimate p (the population proportion) to within E (a specified maximum sampling error) with 95% confidence, then the sample size n should be chosen to satisfy:

$$E = z_{0.025} \sqrt{\frac{p(1-p)}{n}} = 1.96 \sqrt{\frac{p(1-p)}{n}}$$

Solving this equation for n results in:

$$n = p(1-p) \left[\frac{1.96}{E} \right]^2$$

Which means that in order to determine the sample size, a preliminary idea of the value of the population proportion p should be known.²⁴⁻²⁶ The key information of the present study is that the anticipated mothers should know exactly the date of their LMP. Taking into consideration the high illiteracy rate among mothers and other relative difficulties, it was decided to choose p (the

proportion of mothers who know the date of their LMP) as no more than 10%. Accordingly, the required sample size with maximum sampling error as 5% is:

$$n = (0.1)(0.9) \left[\frac{1.96}{0.05} \right]^2 \sim 138 \text{ Babies}$$

However, in light of the sample size of many other studies and to eliminate any possible errors, it was decided later to sample more babies. The target was up to 200 babies but because of time constraints and lack of funds, it was decided that 184 babies would be enough. The data collection stage was full of difficulties, among them: very few mothers were able to remember for sure the date of their LMP. Many mothers refused to participate; perhaps because of religious or social beliefs. These difficulties explain why the data collection process took a long time.

Results. Among the 184 newborns there were 79 males and 105 females. The CC ranged from 26-37cm with mean and standard deviation (SD) 32.41±2.13 cm. The GA ranged from 234-300 days with mean and S.D. 279±11 days approximately. The mean and SD of the birth weights were 2.85±0.44 Kg with minimum and maximum values of 1.6 and 4.6 Kg. The means of the physical characteristic scores showed that most of the investigated babies were apparently mature. Table 2 shows the correlation coefficients (r) between GA and CC, BW and physical characteristics used. The correlation

coefficient between GA and BW suggests that BW is not a significant indicator of maturity for the Yemeni babies. Beside CC, only skin opacity, plantar creases, breast size, ear firmness and skull hardness are reasonably correlated with GA. It was a surprise to find a negative correlation between skin color and GA. The highest correlation was between GA and the total sum of scores of the physical characteristics X. Due to the nature of the underlying study and in light of other similar studies, the linear regression analysis seems appropriate. So, a multiple linear regression relationship between GA and the criteria used here could be modeled in our setting as:

$$GA = B_0 + B_1BW + B_2CC + B_3X_1 + B_4X_2 + \dots + B_{14}X_{12} + \epsilon$$

Where B_0, B_1, \dots, B_{14} are called the regression coefficients and would be estimated and ϵ is the noise or error term which is normally distributed.^{27,28} In a simple linear form the relationship could be written as:

$$GA = B_0 + B_1Y + \epsilon$$

Where Y could be any one of the criteria or the total scores of some or all the physical characteristics. As stated earlier, the aim is to search for methods that are accurate and easy to apply. Further, since the results here are expected to be applied by non-mathematical professionals, using simple linear regression equations would be preferred. Table 3 summarizes the whole regression analysis results. These results suggest that although the best predictive equation is the one that contains all the physical characteristics plus CC and BW, very little is lost (specifically, 3%) in the estimation accuracy when the total scores of only 5 of the physical characteristics have been utilized. It is clear that the best predictive equations are 11, 13, 15 and 17. By comparing the correlation coefficients (r), it is easy to spot that equation 17 is the best. However, the accuracy losses are only 1% in using equation 15, 3% with equation 13 and 4% with equation 11. Noticing that in using equation 13 or 15 the remaining criteria are only 4 and 5 instead of 6 with equation 17, this result shows equation 15 is probably the best reasonable choice. So, one can conclude that GA of the Yemeni newborns could be, to some extent, reliably estimated by the following regression equation:

$$GA = 235.327 + 2.962 (\text{skin texture} + \text{skin opacity} + \text{plantar creases} + \text{ear firmness} + \text{Skull hardness})$$

The significant tests of the regression coefficients and regression analysis of variance ANOVA (Tables 4 and 5) strongly suggest the validity of the above regression equation. Figure 1 demonstrates the scatter plot of the total scores of the 5 best physical characteristics with the GA along with the best fitted linear regression equation and the 95% confidence

Table 2 - Correlation coefficients (r) between gestational age and chest circumference, birth weight and 12 physical characteristics.

Characteristics		Gestational Age	
Chest circumference (CC)		0.404	
Birth weight (BW)		0.450	
Edema (X1)		0.201	
Skin-texture (X2)		0.323	
Skin-color (X3)		-0.079	
Skin-opacity (X4)		0.443	
Lanugo (X5)		0.106	
Plantar-creases (X6)	r	0.553	
Nipple-formation (X7)		0.331	
Breast-size (X8)		0.427	
Ear-Formation (X9)		0.338	
Ear-Firmness (X10)		0.515	
Genitalia (X11)		0.186	
Skull-Hardness (X12)		0.444	
$X = (x_1 + x_2 + \dots + x_{12}) = \sum_{i=1}^{12} x_i$			0.631

Table 3 - The results of simple, multiple and stepwise, forward selection and backward elimination regression analysis.

No.	A. Simple and multiple regression	R ²	r	S.E.	F-value
1	$GA = B_0 + B_1W + B_2CC + B_3x_1 + B_4x_2 + \dots + B_{14}x_{12}$	0.493	0.702	8.27	11.719
2	$GA = B_0 + B_{1x_1} + B_{1x_2} + \dots + B_{12}x_{12}$	0.480	0.693	8.27	13.144
3	$GA = B_0 + B_1W$	0.203	0.450	9.93	46.272
4	$GA = B_0 + B_1CC$	0.163	0.404	10.17	35.473
5	$GA = B_0 + B_1W + B_2CC$	0.215	0.464	9.88	24.778
6	$GA = B_0 + B_1X$	0.393	0.631	8.62	120.379
7	$GA = B_0 + B_1W + B_2CC + B_3X$	0.415	0.644	8.55	42.555
8	$GA = B_0 + B_1X + B_2W$	0.413	0.643	8.54	63.555
9	$GA = B_0 + B_1X + B_2CC$	0.411	0.641	8.56	63.020
10	$GA = B_0 + B_{1x_4} + B_{2x_6} + B_{3x_8} + B_{4x_{10}} + B_{5x_{12}}$ The highly correlated characteristics with GA	0.431	0.657	8.48	27.020
11	$GA = B_0 + B_1(x_4 + x_6 + x_8 + x_{10} + x_{12})$	0.416	0.645	8.50	129.383
12	$GA = B_0 + B_{1x_4} + B_{2x_6} + B_{3x_{10}} + B_{4x_{12}}$	0.430	0.656	8.46	33.805
13	$GA = B_0 + B_1(x_4 + x_6 + x_{10} + x_{12})$	0.425	0.652	8.43	134.620
B. Stepwise Regression (Physical Characteristics)					
14	$GA = B_0 + B_{1x_2} + B_{2x_4} + B_{3x_6} + B_{4x_{10}} + B_{5x_{12}}$	0.464	0.681	8.23	30.835
15	$GA = B_0 + B_1(x_2 + x_4 + x_6 + x_{10} + x_{12})$	0.455	0.675	8.20	152.073
C. Forward selection regression method (physical characteristics) Same results as Stepwise Regression					
D. Backward elimination method (Physical characteristics)					
16	$GA = B_0 + B_{1x_2} + B_{2x_4} + B_{3x_6} + B_{4x_7} + B_{5x_{10}} + B_{6x_{12}}$	0.473	0.688	8.19	26.449
17	$GA = B_0 + B_1(x_2 + x_4 + x_6 + x_7 + x_{10} + x_{12})$	0.466	0.683	8.12	159.001
GA = Gestational Age SE = Standard Error					

Table 4 - Significance of the regression coefficients.

	Value	Standard Error SE	t-value	p-value
B_0	235.327	3.556	66.179	<0.0001
B_1	2.692	0.240	12.332	<0.0001

Table 5 - Analysis of variance (ANOVA).

	Sum of squares SS	Degrees of freedom d.f.	Mean sum of squares MSS	F-value	P-value
Regression	10237.524	1	10237.524	152.073	<0.0001
Residual	12252.210	182	67.320		

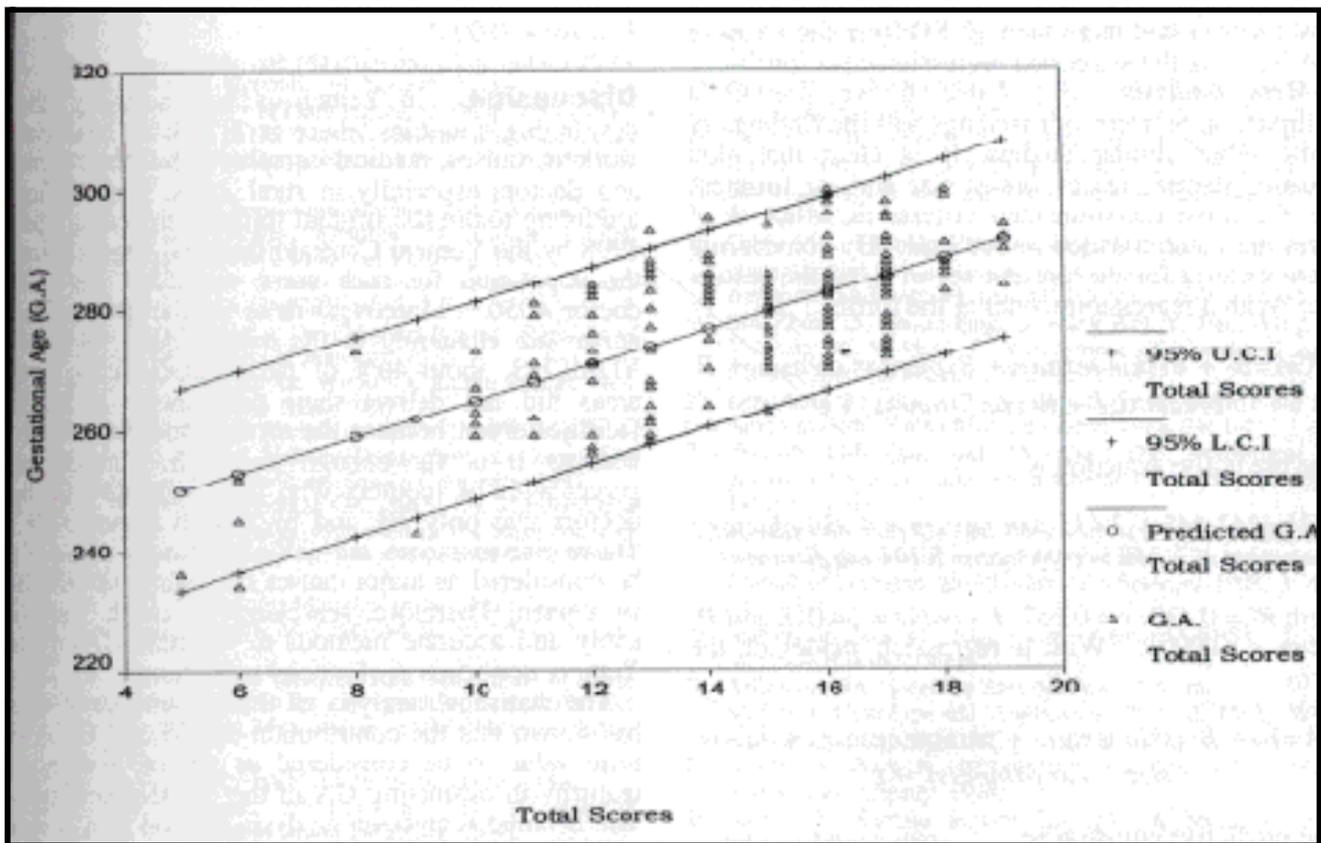


Figure 1 - Scatter plot of gestational age with total scores. Fitted line and 95% confidence interval.

Table 6 - Meta analysis.

Characteristics	Parkin 1971		Finnstrom 1972 a		Parkin, Hey and Clowes 1976		Shu-Zhong et al 1982		Elshibly et al 1985		The present study	
	*	**	*	**	*	**	*	**	*	**	*	**
Edema (x1)	+	+			+		+		+		+	
Skin-texture (x2)	+	+			+	+	+	+	+		+	+
Skin-color (x3)					+	+	+		+		+	
Skin-opacity (x4)			+	+			+		+		+	+
Lanugo (x5)	+	+			+		+		+		+	
Plantar-creases (x6)	+	+	+	+	+		+	+	+		+	+
Nipple-formation (x7)			+	+			+	+	+		+	
Breast-size (x8)	+	+	+	+	+	+	+		+	+	+	
Ear-formation (x9)							+		+	+	+	
Ear-firmness (x10)	+	+			+	+	+		+	+	+	+
Genitalia (x11)	+	+			+		+		+	+	+	
Skull-hardness (x12)	+				+						+	+

* - Used characteristic
** - Recommended characteristics

interval band. The figure shows that only about 5 observations had more than ± 2 SD from the mean of GA by using the suggested regression equation.

Meta analysis. In Table 6 we present a comparison between our findings and the findings of some other similar studies. It is clear that skin texture, plantar creases, breast size and ear firmness are the most recommended criteria in which 3 of them are recommended in our study. By considering these criteria for the present set of data, the results are: With a regression model of the form:

$$GA = B_0 + B_1 \text{skin texture} + B_2 \text{plantar creases} + B_3 \text{breast size} + B_4 \text{ear firmness} + \varepsilon$$

The predictive equation is:

$$GA = 242.645 + 2.433 \text{skin texture} + 4.339 \text{plantar creases} + 1.332 \text{breast size} + 5.101 \text{ear firmness}$$

With $R^2 = 0.432$, $r = 0.657$, F - value = 34.018 and P -value < 0.0001. With a regression model of the form:

$$GA = B_0 + B_1 (\text{skin texture} + \text{plantar creases} + \text{breast size} + \text{ear firmness}) + \varepsilon$$

The predictive equation is:

$$GA = 245.274 + 3.24 (\text{skin texture} + \text{plantar creases} + \text{breast size} + \text{ear firmness})$$

With $R^2 = 0.410$, $r = 0.640$, F - value = 126.386 and P -value < 0.0001. Furthermore, when only the common characteristics of our study, ie, skin texture, plantar creases and ear firmness are taken, the results are: With a regression model of the form:

$$GA = B_0 + B_1 \text{skin texture} + B_2 \text{plantar creases} + B_3 \text{ear firmness} + \varepsilon$$

The predictive equation is:

$$GA = 243.011 + 2.491 \text{skin texture} + 4.768 \text{plantar creases} + 5.579 \text{ear firmness}$$

With $R^2 = 0.426$, $r = 0.653$, F - value = 44.599 and P -value < 0.0001.

With a regression model of the form:

$$GA = B_0 + B_1 (\text{skin texture} + \text{plantar creases} + \text{ear firmness}) + \varepsilon$$

The predictive equation is:

$$GA = 246.134 + 4.120 (\text{skin texture} + \text{plantar creases} + \text{ear firmness})$$

With $R^2 = 0.401$, $r = 0.634$, F - value = 122.004 and P -value < 0.0001.

Discussion. In Yemen as well as many other developing countries, there is a lack of healthcare workers, nurses, medical equipment, healthcare units and doctors especially in rural areas. For instance, according to the last official statistics issued on April 1998 by the Yemeni Central Statistical Organization, the population for each nurse was 3304 and each doctor 4050.²⁹ Moreover, most of the doctors and nurses are clustering in the main cities. From the YDMCHS, about 40% of the mothers in the rural areas did not deliver their pregnancies in health facilities either because the service does not exist or because it is far enough to reach. Further, the percentages of mothers who had postnatal care by doctors was only 3% and by trained nurses 0.4%.¹ These circumstances are self-explanatory and could be considered as major causes of raising the NNMR in Yemen. Therefore, searching for quick, easy to apply and accurate methods to estimate GA of the Yemeni newborns is of crucial importance.

The statistical analysis of the present set of data has shown that the contribution of BW and CC is of little value to be considered as reliable indices of maturity in estimating GA of the Yemeni newborns. The detailed regression analysis has led to a simple predictive equation which depends only on 5 physical characteristics namely skin texture, skin opacity, plantar creases, ear firmness and skull hardness through summing their scores. This equation has satisfied most of the statistical requirements that enable it to be reliable enough to estimate the GA of an Yemeni newborn baby. In comparing our results with the results of some other similar studies, it was clear that skin texture, plantar creases and ear firmness are the most common used characteristics. The regression analysis has shown that by using these characteristics for the present data, the estimation accuracy loss was only 4% ($r = 0.634$) compared with 5 characteristics ($r = 0.675$). So, for a rapid assessment the predictive equation

$$GA = 246.134 + 4.120 (\text{skin texture} + \text{plantar creases} + \text{ear firmness})$$

could be used. As noticed, each similar study has come with a different predictive equation. So, our findings could be suitable only for the Yemeni babies. Furthermore, as the present study is the first of its kind in Yemen, the findings here could be considered as a baseline for future research.

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Appendix I - The Physical Criteria and their Scores (Farr et al 1966b).

<p>Edema 0 = Obvious edema of hands and feet; pitting over tibia. 1 = No obvious edema of hands and feet; pitting over tibia. 2 = No edema.</p> <p>Skin-Texture 0 = Very thin, gelatinous. 1 = Thin and smooth. 2 = Smooth; medium thickness. Rash or superficial peeling. 3 = Slight thickening. Superficial cracking and peeling especially of hand and feet. 4 = Thick and parchment like superficial or deep cracking.</p> <p>Skin-Color 0 = Dark red. 1 = Uniformly pink. 2 = pale pink; variable over body. 3 = pale; only pink over ears, palms, or soles.</p> <p>Skin-Opacity (trunk) 0 = Numerous veins and venules clearly seen, especially over abdomen. 1 = veins and tributaries seen. 2 = A few large vessels clearly seen over abdomen. 3 = A few large vessels seen indistinctly over abdomen. 4 = No blood vessels seen.</p> <p>Lanugo (over back) 0 = No lanugo. 1 = Abundant; long and thick over whole back. 2 = Hair thinning especially over lower back. 3 = Small amount of lanugo and bald areas. 4 = At least 1/2 of back devoid of lanugo.</p> <p>Plantar-Creases 0 = No skin creases. 1 = Faint red marks over anterior half of sole. 2 = Definite red marks over > anterior 1/2; indentations over < anterior 1/3. 3 = Indentations over > anterior 1/3. 4 = Definite deep indentations over > anterior 1/3.</p> <p>Nipple-Formation 0 = Nipple barely visible; no areola. 1 = Nipple well defined; areola smooth and flat, diameter <0.75 cm.</p>	<p>2 = Areola stippled edge raised, diameter > 0.75 cm. 3 = Areola stippled, edge not raised, diameter < 0.75 cm.</p> <p>Breast-Size 0 = No breast tissue palpable. 1 = Breast tissue on one or both sides, < 0.5 cm diameter. 2 = Breast tissue both sides; one or both 0.5-1.0 cm. 3 = Breast tissue both sides; one or both >1 cm.</p> <p>Ear-Formation 0 = Pinna flat and shapeless, little or no incurving of edge. 1 = Incurving of part of edge of pinna. 2 = Partial incurving whole of upper pinna. 3 = Well-defined incurving whole of upper pinna.</p> <p>Ear-Firmness 0 = Pinna soft, easily folded, no recoil. 1 = Pinna soft, easily folded, slow recoil. 2 = Cartilage to edge of pinna, but soft in places, ready recoil. 3 = Pinna firm, cartilage to edge; instant recoil.</p> <p>Genitalia (i) Male 0 = Neither testis in scrotum. 1 = At least one testis high in scrotum. 2 = At least one testis right down. (ii) Female (with hips 1/2 abducted) 0 = Labia majora widely separated, labia minora protruding. 1 = Labia majora almost cover labia minora. 2 = Labia majora completely cover labia minora.</p> <p>Skull-Hardness 0 = Skull bones feel soft to at 1 inch from the anterior fontanelle, with only moderate resistance to pressure. 1 = Skull bones appear springy, along the edges of the fontanelle, while the centers of the bones feel hard. 2 = Bones hard up, other springy, along the edge of the fontanelle. 3 = Bones hard up to suture, but can be displaced easily with gentle pressure. 4 = Bones hard, and cannot be readily displaced with gentle pressure.</p>
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