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Physiologic Responses to Arm Ergometry Exercise Relative to Age And Gender

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Arm ergometry exercise testing is a valuable alternative method used in the evaluation and management of patients with both cardiac disease and lower limb impairment. The purpose of this study is to provide information concerning the physiologic responses of normal healthy subjects to arm ergometry relative to age and gender, which could serve as a standard for comparison. Eighty healthy subjects (age 22 to 59 years) cycled at 75 to 80 rpm (on a bicycle adapted for arm ergometry) starting at a power output of 10 W, increasing at 10 W/2 min until exhaustion.

Sixty subjects were classified on the basis of age into three groups, each with 10 men and 10 women. Men achieved significantly ($p < 0.001$) higher power output (95 ± 25 W) and oxygen consumption (20.7 ± 3.9 ml/kg per min) than did women (56 ± 19 W and 15.5 ± 3.1 ml/kg per min, respectively). The heart rate response to total body oxygen demand during arm ergometry was significantly higher in women than in men ($p < 0.001$). These findings were also present when men and women of each age group were analyzed separately. Older subjects reached a significantly ($p < 0.02$) lower peak power output than did younger subjects although they reached a similar level of oxygen consumption.

Separate regression equations for predicting oxygen consumption at each power output were formulated for men and women and validated in 20 other subjects. Small differences in measured and predicted oxygen consumption at each stage were found. These data provide additional information concerning arm ergometry testing and should prove useful in diagnostic exercise testing and cardiac rehabilitation.

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Exercise testing continues to be a widely applied and useful method for evaluating and managing patients with cardiac disease. Although various protocols employing treadmill and bicycle exercise testing are available (1), they have limited utility among individuals with vascular, neurologic or orthopedic conditions that preclude lower limb exercise. Arm ergometry exercise testing has proved a valuable alternative in such patients, particularly in those with coronary artery disease (1–9). Moreover, unlike dipyridamole testing, it has the potential ability to provide information regarding the functional level of stress required to induce myocardial ischemia. However, to date, there are no well defined or widely accepted arm ergometry exercise testing protocols from which data concerning functional capacity can be derived. Such information would provide valuable indexes for use in diagnostic exercise testing, exercise training and possibly the estimation of prognosis.

Previous studies (5,10,11) that attempted to define responses to arm ergometry exercise have been limited by small numbers of subjects and heterogeneous study groups, and they have employed protocols that may not be applicable to patients with coronary artery disease. Therefore, in the present study we attempted to 1) assess the physiologic responses of a well defined subject group, relative to age and gender, to an arm ergometry protocol previously demonstrated (6) to be reliable and widely applicable in testing patients with both coronary artery disease and lower limb impairment; and 2) establish a formula from which oxygen requirements during this protocol could be reliably predicted.

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Methods

Study subjects. Eighty apparently healthy volunteers participated in this study and were classified into two main groups. 1) A "study group" consisting of 60 subjects (30 men and 30 women, aged 22 to 59 years, mean ± SD 36 ± 10) was stratified into three subgroups according to age: group A = age 20 to 29 years (mean 26 ± 3); group B = age 30 to 39 years (mean 33 ± 3); group C = age 40 to 59 years (mean 49 ± 6). There were 10 men and 10 women in each subgroup. No subject had any known medical problem or was taking any medication at the time of the study. All denied having chest discomfort, dyspnea, palpitation or syncope. None were involved in any regular exercise conditioning program. 2) A "validation group" consisting of 20 subjects (mean age 30 ± 5 years) served to test the prediction equation for oxygen consumption at each stage of arm ergometry, as derived from the data obtained from the study group. The validation group consisted of 15 healthy men and 5 healthy women. None had any known medical condition or was taking any medication. All subjects gave informed consent in accordance with the protocol of the Institutional Review Board of The University Hospital.

Exercise protocol. All subjects were weighed on the same scale just before exercise. Subjects performed arm ergometry after a 3 h fast, having refrained from drinking caffeinated beverages for at least 6 h. Exercise was performed on an exercise bicycle (Engineering Dynamics, model 8450) adapted for arm ergometry by replacing the pedals with rubber handles. This ergometer is equipped with an electronic braking system that served to maintain a constant power output per stage despite any variations in cranking rate. Subjects were seated with feet flat on the ground and the fulcrum of the handle adjusted to shoulder height. Exercise was begun at a power output of 10 W for 2 min, followed by 10 W increments every 2 min until the test was terminated. All maintained a handle speed of 75 to 80 rpm, which was chosen to maximize the dynamic component of this exercise. Heart rate and a 12 lead electrocardiogram (ECG) were obtained at rest, at the end of each 2 min, immediately after cessation of exercise and every 3 min during a 9 min recovery period. Continuous heart rhythm monitoring was done throughout the test, and a rhythm strip was recorded at the end of each minute of exercise. Blood pressure was recorded at rest and immediately after exercise by a single observer using a cuff sphygmomanometer.

All subjects exercised until exhaustion, which was defined as the point at which a cranking speed of 75 rpm could no longer be maintained. Although angina, ischemic ST segment responses and complex ventricular arrhythmias were also defined as end points for exercise, none of these events occurred in any subject.

Table 1. Study Group Responses at Peak Exercise (n = 60)

Variable	
Power output (W)	75 ± 30
Heart rate (beats/min)	164 ± 19
% of maximal predicted heart rate	90 ± 10
RPP (beats/min × mm Hg × 10^3)	25.2 ± 5.2
$\dot{V}O_2$ (ml/kg per min)	18.0 ± 4.7
METS	5.1 ± 1.3

Values are mean values ± SD. METS = metabolic equivalents (3.5 ml O_2/kg per min); RPP = heart rate × systolic blood pressure product; $\dot{V}O_2$ = oxygen consumption.

Gas exchange. All subjects had expired gas samples measured every 30 s throughout exercise with a Sensormedics Horizon Metabolic Measurement Cart, which was calibrated before each exercise test using standard gas mixtures. Subjects wore a nose clip and breathed room air through a one-way directional valve system. Expired air was analyzed for oxygen concentrations with an OM-11 oxygen sensor system. Oxygen consumption ($\dot{V}O_2$) is reported in ml/min and ml/kg per min, as specified. A metabolic oxygen equivalent (MET) was defined as 3.5 ml O_2/kg per min.

Peak exercise variables. Oxygen consumption, heart rate and blood pressure data recorded at the highest completed 2 min stage were used for analysis as peak exercise variables. The percent of maximal heart rate reached was defined as the peak heart rate attained divided by the age-specific maximal predicted heart rate × 100.

Statistical methods. The nonpaired *t* test was used to test the differences between men and women. One-way analysis of variance, followed by Newman-Keuls test, was used to evaluate differences among the three age groups. A two-way analysis of variance was used when the variables of gender and age were combined in a factorial design to determine if a gender-age interaction was present in the analysis of peak exercise variables. The prediction equations for oxygen consumption were derived by multiple regression analysis.

Results

All subjects had a normal blood pressure at rest (<140/90 mm Hg) and ECG. No complications occurred during arm ergometry testing. For the 60 subjects of the study group, peak exercise data are outlined in Table 1.

Gender and age differences. Comparisons of the responses to arm ergometry in men and women are outlined in Table 2. Men had greater body weight (79.5 ± 12 kg) than did women (60.2 ± 10 kg, $p < 0.0001$). Men achieved a significantly higher power output than did women (95 ± 25 versus 56 ± 19 W, $p < 0.001$) and had greater peak oxygen consumption (20.7 ± 3.9 versus 15.5 ± 3.1 ml/kg per min, $p < 0.001$). These findings were also present when men and women of each age group were analyzed separately (p <

Table 2. Response to Exercise Relative to Age and Gender

	Group A (age 20 to 29 yr)			Group B (age 30 to 39 yr)			Group C (age 40 to 59 yr)		
	G (n = 20)	M (n = 10)	F (n = 10)	G (n = 20)	M (n = 10)	F (n = 10)	G (n = 20)	M (n = 10)	F (n = 10)
Power output (W)	81 ± 35	103 ± 34*	58 ± 18	82 ± 25	99 ± 21*	65 ± 14	64 ± 26†	83 ± 16*†	44 ± 20†
$\dot{V}O_2$ (ml/kg per min)	18.5 ± 4	21 ± 3.5*	15.9 ± 2.8	17.5 ± 4.7	20 ± 5*	15.1 ± 2.4	18.3 ± 4.5	21.2 ± 3*	15.5 ± 4
% max HR	86 ± 9	92 ± 8*	81 ± 6	92 ± 9	95 ± 10*	89 ± 8	91 ± 10	96 ± 9*	86 ± 10
HR/MET	33 ± 7	30 ± 6*	35 ± 7	34 ± 8	31 ± 7*	37 ± 8	31 ± 6	28 ± 4*	36 ± 6
% max HR/MET	17 ± 4	16 ± 3*	18 ± 4	19 ± 4	16 ± 4*	20 ± 3	18 ± 4	16 ± 2*	20 ± 4

*p < 0.001 men versus women; †p < 0.02 group C versus groups A and B. Values are mean values ± SD. F = female; G = total group; HR = heart rate; M = male; % max = percent of maximal predicted; other abbreviations as in Table 1.

0.001). Additionally, men reached a greater mean peak heart rate than did women (170 ± 20 versus 158 ± 18 beats/min, $p < 0.001$) (Table 3). To evaluate the cardiac response to total body work, peak heart rate was divided by the peak MET level to yield a heart rate/MET index for each subject in the study group. In every age group, the heart rate/MET index for men was significantly lower ($p < 0.001$) than that for women.

The only significant difference found among the age groups was that older subjects (group C) exercised to a significantly lower power output ($p < 0.02$) than did younger subjects (groups A and B). This difference remained when men and women were analyzed separately. Of note, the subjects in group C exercised to a similar oxygen consumption and percent maximal heart rate as did those in groups A and B, despite reaching a significantly lower peak power output. Because maximal heart rate is known to decline with age, the cardiac response to total body work among different age groups was evaluated by using the percent maximal heart rate/MET index rather than the heart rate/MET index. No significant differences in the percent maximal heart rate/MET index were found among the groups.

Table 3. Heart Rate Response at Each Stage of Arm Ergometry

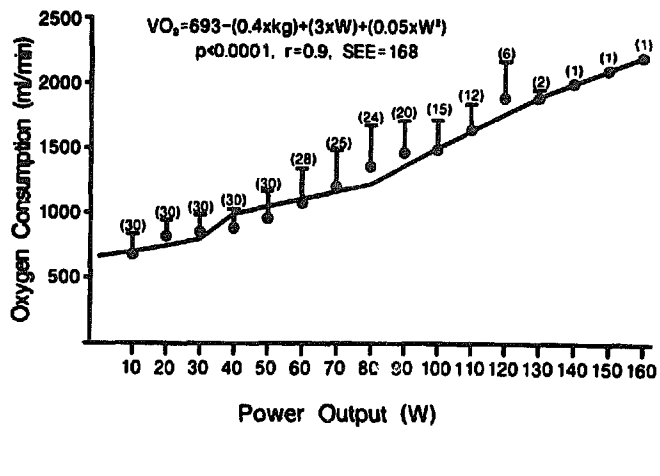
Stage (W)	Men (beats/min)	Women (beats/min)
10	109 ± 15	128 ± 20
20	116 ± 18	137 ± 18
30	120 ± 18	139 ± 20
40	123 ± 18	140 ± 17
50	131 ± 19	143 ± 18
60	140 ± 17	152 ± 17
70	150 ± 15	160 ± 18
80	159 ± 14	164 ± 13
90	163 ± 13	
100	166 ± 11	
110	174 ± 15	
120	179 ± 14	
130	179 ± 30	

Values are mean values ± SD.

Prediction formulas. Multiple regression analysis was used to derive prediction equations for the oxygen requirements at each stage of exercise. This demonstrated that power output and body weight together in a regression model were important predictors of oxygen requirements. Because of the curvilinear nature of the relation of oxygen consumption with power output, an exponential term for power output was included in the regression model. Separate regression analyses were done for men and women to control for the influence of gender on the oxygen consumption versus power output relation. Both regression analyses were significant at $p < 0.0001$ (Fig. 1 and 2). It is noteworthy that the number of subjects completing each stage decreased with increasing power output.

Data from the 20 additional subjects who constituted the validation group were used to assess the accuracy of the oxygen consumption prediction equations. Table 4 shows the percent difference between measured and predicted oxygen consumption at each stage of power output for men

Figure 1. Plot of the relation between oxygen consumption (VO_2) (ml/min) and power output (W) at each exercise stage among men. The numbers in parentheses refer to the number of subjects completing each stage. The regression equation for the relation is noted above. The solid line represents a calculated regression line for men weighing 80 kg.



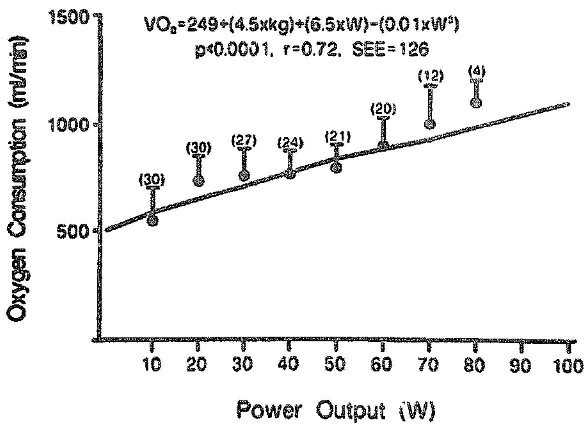


Figure 2. The plot of the relation between oxygen consumption (VO_2) (ml/min) and power output (W) at each stage among women. The numbers in parentheses refer to the number of subjects completing each stage. The solid line represents a calculated regression line for women weighing 60 kg. Format as in Figure 1.

and women separately. The discrepancies are relatively small except among men at 50 and 110 W and among women at the higher power outputs. The number of women in the validation group was small, thus increasing the variability among the differences between the observed and calculated values of oxygen consumption.

Electrocardiographic responses. Only 1 of the 80 subjects demonstrated an abnormal ST segment response to exercise. This was a 55 year old woman who had none of the conventional risk factors for coronary artery disease. She manifested 1 mm of horizontal ST segment depression lasting 80 ms after the J point in ECG leads II, III and aVF at peak exercise. No angina was noted.

Table 4. Differences Between Observed and Calculated Oxygen Consumption at Each Stage of Exercise for the Validation Group (n = 20)

	Men		Women	
Stage (W)	% (ml/min)	No.	% (ml/min)	No.
10	4	15	8	5
20	8	15	14	5
30	4	15	9	5
40	2	15	3	5
50	9	15	1	5
60	7	15	5	5
70	2	15	13	5
80	1	14	20	4
90	3	13		
100	3	11		
110	10	9		
120	3	5		
130	6	2		
140	6	2		
150	4	2		

No. = number of subjects completing that stage of exercise; % = % difference between the mean observed and mean calculated oxygen consumption at each stage.

Discussion

Arm ergometry exercise testing. This method plays an increasingly important role in both diagnostic exercise testing and cardiac rehabilitation. It also offers specific advantages in the evaluation of coronary disease among individuals with lower limb impairment (1–9). To date, physiologic responses and exercise capacity data derived from arm ergometry testing have been difficult to interpret because of the lack of a standard testing protocol. Toward this end, the results of this study provide information regarding the responses of normal healthy men and women of a broad age range to a clinically useful arm ergometry protocol that employs 10 W incremental stages every 2 min. This protocol has been shown to be practical when applied to a group of men and women 37 to 77 years of age undergoing diagnostic evaluation of coronary artery disease. In conjunction with thallium scintigraphy, arm ergometry testing using this series of power outputs yielded a sensitivity of 83% and specificity of 78% in the detection of coronary artery disease (6). For this reason, it is a valuable alternative method of testing in our laboratory. Additionally, arm ergometry can be a useful technique for exercise training of the upper body. Analysis of the physiologic responses and oxygen requirements during arm ergometry can yield valuable information that can be used in counseling patients on the performance of the many occupational and recreational activities that require upper body work.

Exercise responses. Subjects selected for inclusion in the study group were predominately sedentary individuals who were taking no medication and had no athletic conditioning or overt evidence of cardiovascular disease, therefore minimizing variables that might confound interpretation of the results. Because of these strict inclusion criteria and despite our best recruitment efforts, no individual >59 years of age was available for participation in this study. The group data presented in Table 1 demonstrate that subjects made a good effort during exercise, reaching 90% of their maximal predicted heart rate. It is important to note that the peak heart rate and power output data reported here are those of the final 2 min stage completed, which was not always the final stage or heart rate attained. Subgroup analyses provide more useful information in that among the different age groups tested men demonstrated a greater capacity for arm work than women, attaining a higher absolute power output level and oxygen consumption. These findings concur with those of other studies of a smaller number of young men (10) and women (11) using a more vigorous 25 W/stage protocol.

Heart rate responses at each stage of arm ergometry (Table 3) demonstrate that heart rate increases with increas-

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ing power output. However, there is a wide range in heart rate at each stage and a considerable overlap between successive stages. This is likely in part due to the variability of total body oxygen consumption among individuals of different weight at each stage during cycle ergometry. This is best demonstrated in Appendix Tables A and B, which show the influence of body weight on oxygen consumption (MET levels) at each power output. The peak heart rate among men was greater than that in women, although this difference may in part be due to how the peak heart rate in this study was determined, as mentioned. Therefore, the heart rate/MET index provides a more useful variable for comparison among different subjects. The lower heart rate/MET index seen in men demonstrates that the chronotropic response to total body oxygen demand during arm ergometry is greater among women than among men of all age groups tested. This has also been found to be true in other studies (12,13) that evaluated the heart rate responses to other types of exercise testing in men and women. Possible explanations for these observations include gender-related differences in heart size, hemoglobin concentration and muscular conditioning.

The response to arm ergometry testing among different age groups demonstrates that older subjects have a lower capacity for arm work than younger subjects, a finding that was consistent in separate analyses of men and women. Older subjects reached a lower peak power output, although peak oxygen consumption was similar to that in younger subjects. This apparent difference in mechanical efficiency among the older subjects may in part be due to differences in conditioning (that is, older subjects may be less active) and in upper body muscle mass and strength.

Prediction of oxygen consumption. The regression equations for predicting oxygen consumption from power output, as derived in this study, provide a reliable estimate of oxygen requirements during varying amounts of arm work. Use of the electronically braked bicycle at specified cycling speeds reduced the likelihood of potential variability between stated power outputs that might exist using a mechanically braked ergometer. The small differences in observed and calculated oxygen consumption at each stage as derived from validation group data (Table 4) confirm that the regression equations in Figures 1 and 2 can be applied reliably to a somewhat different cohort than the study group. The relation between oxygen consumption and power output does, however, differ between men and women. Vander et al. (11), too, noted such gender differences. Our study and others (14,15) have found that it is important to include weight when using regression equations to determine the predicted oxygen consumption during arm ergometry work. However, some of the differences between men and women may be explained by the relative differences in the amount of that weight that is actually exercising mass.

Study limitations. The aim of this study was to provide information concerning the physiologic responses to arm ergometry in normal healthy subjects that could serve as a standard for comparison. However, whether the prediction equation for oxygen consumption at each power output can be applied with similar accuracy to patients on medication or with coronary artery disease is not known. There are data (16) to suggest that oxygen uptake during treadmill testing does differ between normal subjects and patients with coronary artery disease, but this has not yet been determined for arm ergometry.

The use of a progressive 2 min/stage protocol may imply that measured oxygen consumption at each stage may not have been at steady state. However, the 2 min protocol was chosen to minimize the fatigue factor and maximize the cardiovascular responses during arm ergometry. The small standard error of the regression equations and the generally small prediction errors of oxygen consumption during each stage as shown in the validation group data imply that the possible lack of steady state does not confound our results.

It must be realized that during arm ergometry exercise, varying muscle groups may be involved. Recruitment of torso muscle and stabilizing back, buttock and leg muscles during exercise may well affect peak heart rate, blood pressure, oxygen consumption and power output. This muscle recruitment is difficult to measure, and its impact on the results of this study are acknowledged but not directly assessed.

Conclusions. As the utility of arm ergometry exercise testing continues to grow, the need for a standard testing protocol becomes greater. These data provide additional information concerning the responses of healthy men and women of a broad age range to a clinically reliable arm testing protocol and should prove useful in diagnostic exercise testing and cardiac rehabilitation.

We are grateful to the many men and women who gave their time and effort to participate as study subjects. We also thank Cindy Mangene for her assistance, and Katherine Seropian for her valuable skills in preparing the manuscript.

Appendix

The metabolic equivalent (MET) levels at various power output and body weight values calculated from the equations in Figures 1 and 2 are presented in Appendix Tables A and B for men and women, respectively. The MET levels for men are extrapolated at weights <59 kg and for women at weights >82 kg and power outputs >80 W because these are outside the range of body weight and power output values achieved in the men and women in the study group.

Appendix Table A. MET Levels Calculated at Each Power Output for Men at Various Body Weights

Body Weight		Power Output (W)												
lb	kg	10	20	30	40	50	60	70	80	90	100	110	120	130
100	46	4.5	4.7	5.1	5.5	6.0	6.5	7.1	7.8	8.5	9.3	10.1	11.0	12.0
110	50	4.0	4.3	4.6	5.0	5.4	5.9	6.4	7.0	7.7	8.4	9.2	10.0	10.9
120	55	3.7	3.9	4.2	4.6	5.0	5.4	5.9	6.4	7.1	7.7	8.4	9.2	10.0
130	59	3.4	3.6	3.9	4.2	4.6	5.0	5.4	5.9	6.5	7.1	7.8	8.5	9.2
140	64	3.2	3.4	3.6	3.9	4.2	4.6	5.0	5.5	6.0	6.6	7.2	7.8	8.5
150	68	2.9	3.1	3.4	3.6	3.9	4.3	4.7	5.1	5.6	6.1	6.7	7.3	8.0
160	73	2.7	2.9	3.1	3.4	3.7	4.0	4.4	4.8	5.3	5.8	6.3	6.9	7.5
170	77	2.6	2.7	2.9	3.2	3.5	3.8	4.1	4.5	4.9	5.4	5.9	6.4	7.0
180	82	2.4	2.6	2.8	3.0	3.3	3.6	3.9	4.3	4.7	5.1	5.6	6.1	6.6
190	86	2.3	2.4	2.6	2.8	3.1	3.4	3.7	4.0	4.4	4.8	5.3	5.8	6.3
200	91	2.2	2.3	2.5	2.7	2.9	3.2	3.5	3.8	4.2	4.6	5.0	5.5	5.9
210	96	2.1	2.2	2.4	2.6	2.8	3.0	3.3	3.6	4.0	4.4	4.8	5.2	5.7
220	100	2.0	2.1	2.3	2.4	2.7	2.9	3.2	3.5	3.8	4.2	4.5	5.0	5.4

Appendix Table B. MET Levels Calculated at Each Power Output for Women at Various Body Weights

Body Weight		Power Output (W)												
lb	kg	10	20	30	40	50	60	70	80	90	100	110	120	130
100	46	3.3	3.6	4.0	4.4	4.7	5.1	5.4	5.7	6.0	6.3	6.6	6.8	7.1
110	50	3.1	3.4	3.8	4.1	4.4	4.7	5.0	5.3	5.6	5.9	6.1	6.3	6.6
120	55	2.9	3.3	3.6	3.9	4.2	4.4	4.7	5.0	5.2	5.5	5.7	5.9	6.1
130	59	2.8	3.1	3.4	3.7	3.9	4.2	4.5	4.7	4.9	5.1	5.4	5.6	5.8
140	64	2.7	3.0	3.2	3.5	3.8	4.0	4.2	4.5	4.7	4.9	5.1	5.3	5.4
150	68	2.6	2.9	3.1	3.4	3.6	3.8	4.0	4.2	4.4	4.6	4.8	5.0	5.2
160	73	2.5	2.8	3.0	3.2	3.4	3.7	3.9	4.1	4.2	4.4	4.6	4.8	4.9
170	77	2.4	2.7	2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.7
180	82	2.4	2.6	2.8	3.0	3.2	3.4	3.6	3.7	3.9	4.1	4.2	4.4	4.5
190	86	2.3	2.5	2.7	2.9	3.1	3.3	3.5	3.6	3.8	3.9	4.1	4.2	4.3
200	91	2.3	2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.8	3.9	4.1	4.2
210	96	2.2	2.4	2.6	2.8	2.9	3.1	3.2	3.4	3.5	3.7	3.8	3.9	4.1
220	100	2.2	2.4	2.5	2.7	2.9	3.0	3.2	3.3	3.4	3.6	3.7	3.8	3.9

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