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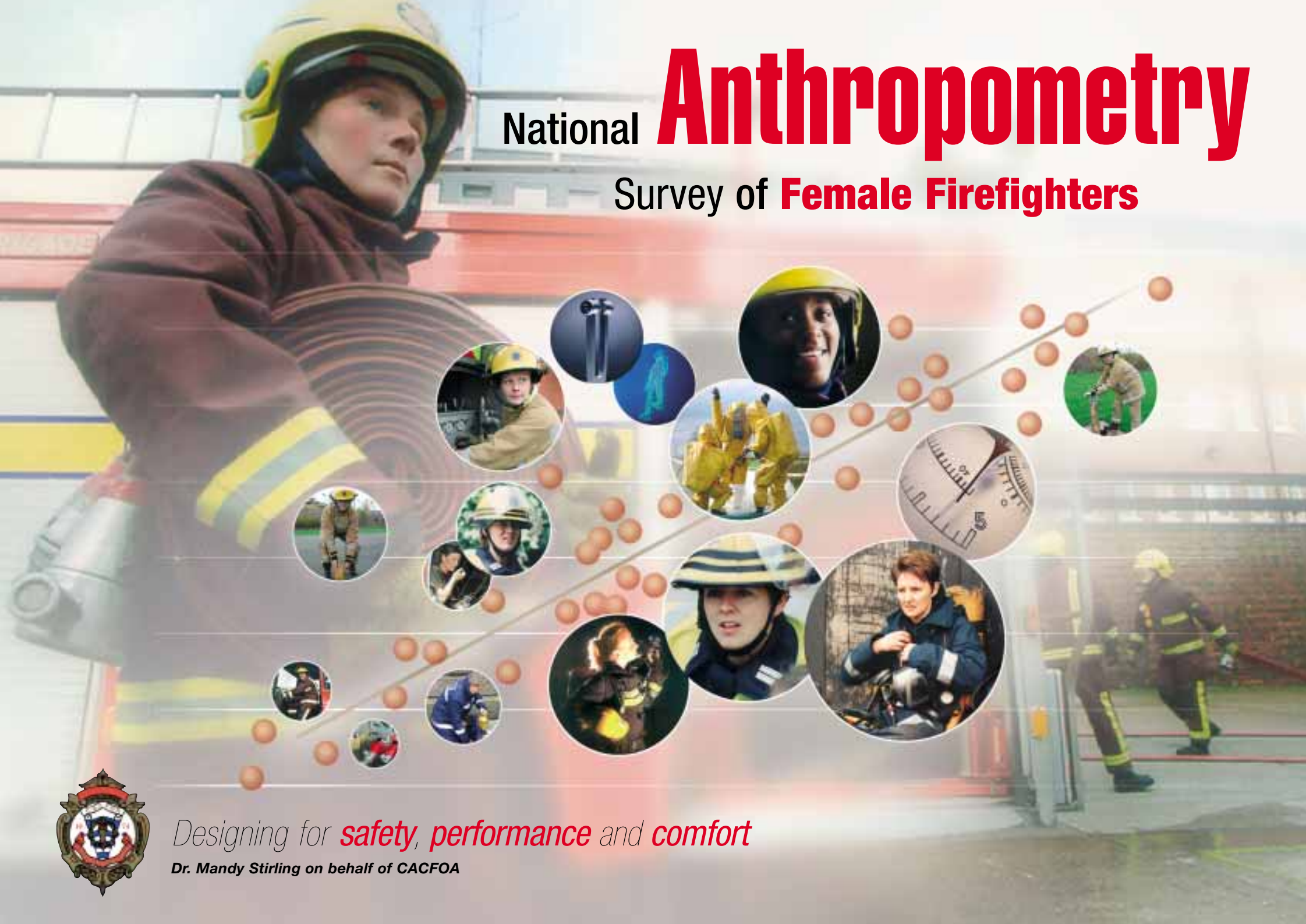
National Anthropometry Survey of Female Firefighters



*Designing for **safety**, **performance** and **comfort***

Dr. Mandy Stirling on behalf of CACFOA

National Anthropometry Survey of Female Firefighters

Designing for safety, performance and comfort

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This study was initiated by CACFOA

It was supported and jointly funded by CACFOA and participating Fire Authorities

Foreword

This report provides data that will assist in the design of products used by the Fire Service every day. As the Fire Service becomes an increasingly heterogeneous organisation, in terms of sex, ethnicity, age and fitness, the report is a step towards ensuring that products accommodate as many of the user population as possible. It specifically addresses the current lack of information that is needed to ensure that female firefighters are included in design parameters, which are generally tailored around the male user. It is in no way intended to provide criteria for exclusion of Fire Service personnel. The removal of height restrictions as entry criteria, as well as product design weaknesses, mean that the male firefighting population also may not be adequately designed for, and this will be addressed in a subsequent report. The survey's main aim was to provide a data set that could facilitate the advancement of suitable personal protective equipment (PPE) for female firefighters. However, the data can also be applied by manufacturers to the design of appliances, equipment and work-wear, and by brigades for in-house projects in order to increase safety, performance and comfort for the firefighter at work.

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1. Introduction

In any profession a person should be able to carry out their work safely, efficiently and comfortably. The fact that firefighters provide an emergency service should not preclude them from being provided with such a working environment, as far as is reasonably practicable. The increasing complexity of equipment used within the Fire Service and the inherently hazardous nature of the work mean that the application of ergonomic principles to all aspects of a firefighter's job is vitally important. Aside from brigade responsibility for risk management and employee health & safety, reliance on the assumption that individuals will adapt to their working environment and the tools they use is not acceptable. Rather, a more proactive, systems approach is necessary where products are designed around the user population.

In the past, most PPE and equipment designed by manufacturers for use by the Fire Service has been constructed for a male end user. Although the proportion of female personnel is increasing, many still have to make do with PPE and equipment designed for males; this practice may be unsafe and uncomfortable in some circumstances, and is clearly unacceptable. This database of operational female anthropometrics will allow manufacturers to specifically design for female personnel, should they have differing needs. A subsequent male database will allow manufacturers to verify, extend or change their current sizing charts and equipment patterns. In addition, the combination of both male and female databases will ensure that certain items of equipment and appliances can be designed for use by all personnel.

Therefore, the need to obtain an up-to-date and comprehensive anthropometric database of current female operational personnel within the Fire Service has been identified. However, this report is relevant to all other areas of firefighting work in addition to PPE.

Firefighting as a profession is becoming a more viable career option for females. There may be for several reasons for this, including wider recognition that females are able to carry out firefighting tasks, career publicity and also the removal of height restrictions. These factors mean that the proportion of female personnel in the Fire Service is increasing. As this happens, it is likely that their anthropometric characteristics become more diverse. Some of the issues that create a more diverse user population are relevant to males as well. Full adult stature is attained in both sexes before or around the youngest age a person can join the Fire Service. However, body breadths continue to increase until the mid-twenties and body weight and related dimensions may increase throughout life. Generally, there is a decline in stature from youth to old age, and each new generation is taller than the last (6) (the numbers in brackets are references, which are found in section 9). Therefore, a further anthropometry survey may be required in three or four years time to ensure that at that time the existing female firefighting population are being included in product design.

1.1 What are ergonomics and anthropometry?

Ergonomics is simply defined as ‘designing for human use’ (1) and it is applied with the intention of improving human safety, comfort, and performance. It is a diverse field that takes a user centred approach to design, considering information on human physical, physiological, and mental capabilities (2), and how these factors affect the way people interact with their surroundings, their products and tools, the buildings they work and live in, the information they receive, and the organisation of all these activities (3). One of the fundamentals of this approach is the study of human measurements or anthropometry. Anthropometry is a branch of ergonomics that deals specifically with the measurement of people, particularly with measurements of body size, shape, strength and working capacity (4). This measurement data is used to describe or paint a picture of the user population for a particular measure of the body.

1.2 How can anthropometry help us?

By applying anthropometry, we attempt to design the working environment around the person, rather than placing constraints on them because they have to adapt to what is provided. If anthropometric factors are taken into consideration when products are designed, the outcome is likely to be increased acceptability, improved ease and efficiency of use, and therefore greater operational safety and cost effectiveness.

When considering the design and use of equipment, the term ‘average person’ is often referred to and used. However, very few people would actually fit such a pattern. The body is made up anthropometrically of several functional parts, such as sitting height, forward grip reach, waist height and head circumference. Height is often used as a design criterion, but a ‘tall’ person can either have a long or short body and long or short legs. Thus, although many people will fit average garments (using clothing as an example), and garments can be sized to increase the probability of a reasonable fit, the efficiency of the garment or ensemble may be compromised, especially when free movement is further influenced by, for example, wearing breathing apparatus and a harness. When products are designed around the ‘average person’, many of the population are excluded from using them, since they fall well outside of this average.

1.3 How do we use anthropometric data?

The aim of applying anthropometry is to accommodate as many of the user population as possible. If we look at a particular anthropometric measure, such as female stature, we find that most individuals will be of average stature, and there will be fewer individuals who are very tall or very short. The graph below (Figure 1.3.1) illustrates this. The horizontal axis shows a person’s height (stature) and the vertical axis shows how many people would be of a particular height, or the frequency with which they occur in the sample of people you are measuring. For this reason, this type of graph is called a frequency distribution.

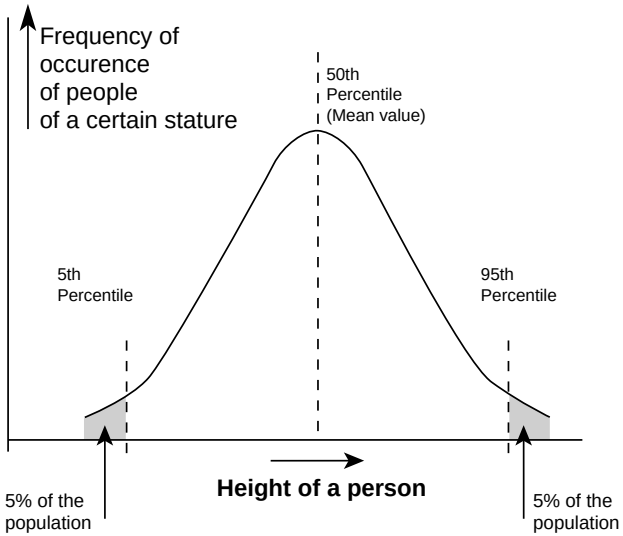


Figure 1.3.1: An example of a frequency distribution

When an anthropometric measure produces a symmetrical curve like the one above, the average (or mean) value is also the 50th percentile value. This means that 50% of the people you are measuring are shorter than this value and 50% are taller than this value. The line on Figure 1.3.1 marked 5th percentile denotes that 5% of the people you are measuring (ie. 1 in 20) are shorter than this value. Similarly, the line marked 95th percentile denotes that 5% of the people you are measuring (ie. 1 in 20) are taller than this value. Therefore, 90% of the people you are measuring have a height between the 5th and 95th percentile values. When designing products, this is often referred to as providing for the middle 90% of the population; that is to exclude the smallest 5% (5th percentile figure) and the largest 5% (95th percentile figure). This is done because accommodating those people with measures at the tail ends of the distribution would drastically increase the length of that variable, and may mean the product will become very complex and costly. Usually, it is easier to cater separately for those people that fall below the 5th and above the 95th percentiles with tailor-made or specially adapted items. However, in critical situations a safety margin must be added to the extreme percentiles. For example, any gaps in a machine guard must be smaller than an un-gloved 1st percentile finger/hand from the user population. Methods of escape must be wider than a fully clothed person (including PPE and relevant equipment) with a 100th percentile shoulder (bi-deltoid) width from the user population (this will usually be a male).

Many anthropometric measures, such as female stature, produce a symmetrical, bell-shaped curve like the one in Figure 1.3.1, and these measures are said to have a normal distribution. The exact shape of the normal distribution depends on the mean and the standard deviation values for the set of people being measured. The standard deviation is a measure of spread and indicates the amount of departure of the values from the mean, so differences in standard deviation create the shape of the distribution. Although the distribution remains symmetrical, the distribution becomes flatter if we increase the standard deviation. Examples of normal distributions are shown in Figure 1.3.2. Notice that they differ in how spread out they are, but the area under each curve is the same. A useful piece of information is that if an anthropometric measure is normally distributed, we know that approximately 68% of those people measured will lie within one standard deviation either side of the mean (±1SD) and approximately 95% will lie within two standard deviations either side of the mean (± 2SD).

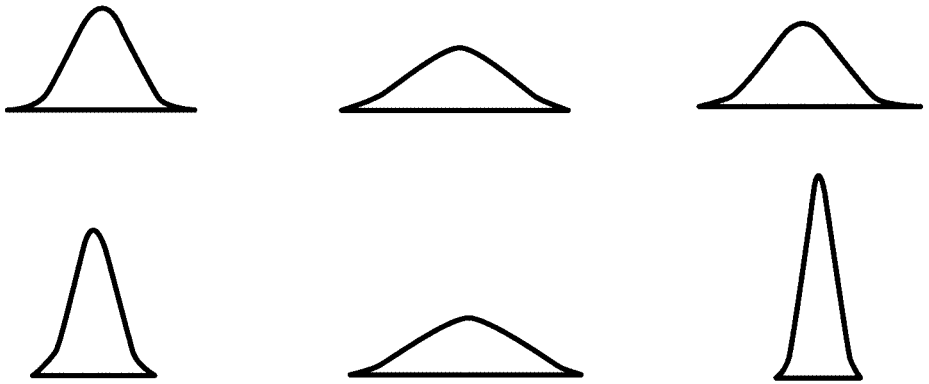


Figure 1.3.2: Examples of normal distributions

1.4 Types of anthropometric measure

There are several types of anthropometric measure that have been addressed in this survey:

Static measures – these are body dimensions measured with the body held in standardised, static postures. Measures include stature, weight, body breadths, depths, circumferences, seating dimensions, head, hand and foot dimensions (3). This is the main type of data used to ensure the physical fit of items to be used by or with adults.

Functional (dynamic) measures – these are measures of the limits of movement of the human body, such as the distance that can be reached overhead, in front or to the side of the body (3). This type of data can provide key information about the space immediately surrounding a person and is often used to ensure that equipment is operable or accessible by adults. This information would be particularly useful for appliance layout (by manufacturer or brigade) or equipment loading/unloading procedures, which would provide a solid foundation on which to base health and safety, and risk management material.

Strength measures – due to practical constraints only hand grip strength was measured in this survey. However, comprehensive strength data can be found in two Department of Trade and Industry publications. These are: 'ADULTDATA' and 'Strength Data', which are both available free of charge (see reference list for contact details). As these publications show, there are many ways in which strength can be measured. It can be the force exerted with a specific part of the body, in a specific action (eg. pushing) or when applied to a specific object (eg. opening jars). Strength capabilities can be measured in standardised postures or by allowing 'free' postures to be adopted by the individual in order to produce maximum force (3). Data are included on the strength of the arms, hands and fingers and include pushing, pulling, lifting, pressing, gripping and pinching forces. It should be noted, however, that these publications provide data on whole populations and are not specific to Fire Service personnel.

1.5 Differences between the sexes

It is a common belief amongst designers that for all practical design purposes women are scaled down versions of men, having a proportionate approximate body size of 93% of that of males on average. Another rule of thumb often used is that a 50th percentile woman is equivalent in size to a 5th percentile man, and that a 95th percentile woman is equal in size to a 50th percentile man.

However, a study carried out in 1979 (10) found that while male height and weight dimensions can be scaled down for females with some reliability, many other dimensions cannot, particularly those involving body tissues and dimensions of the head, hands and feet. This has been illustrated (11) using a sample of data from the 1988 ANSUR survey of US army personnel (12, 13). A comparison of men and women matched closely in height and weight (individuals matched within ± 2.5cm in height and ± 5kg in weight) revealed similarities and differences for selected dimensions (Table 1.5.1). For example, for those measures at the top of the table, such as neck and biceps circumference, women are scaled down versions of men, while for those measures at the bottom of the table, such as buttock circumference and hip breadth, women are scaled up versions of men.

Table 1.5.1: Mean values for male and female measures, and female values as a percentage of the equivalent male values

	Men (n=91)		Women (n=153)		
	Mean	SD	Mean	SD	
Age	25.6	0.67	25.7	0.57	
Stature	168.0	1.50	167.2	1.34	
Weight	65.3	2.67	64.7	2.79	**%**
					(F/M x 100)
Neck circumference	36.5	1.28	31.7	1.09	**86.8**
Biceps circumference	31.6	1.36	28.2	1.50	**89.2**
Underbust circumference	87.2	3.15	78.4	3.11	**89.9**
Shoulder circumference	111.6	3.17	103.8	2.95	**93.0**
Bi-deltoid breadth	46.5	1.48	43.7	1.50	**93.8**
Chest breadth	30.0	1.40	28.5	1.35	**95.0**
Waist to hip length	17.1	1.61	16.4	2.00	**95.9**
Bi-acromial breadth	38.4	1.37	36.9	1.32	**96.1**
Elbow-wrist length	25.2	0.91	24.4	0.77	**96.8**
Sleeve outseam	57.0	1.78	55.5	1.56	**97.4**
Shoulder-elbow length	35.1	1.06	34.3	1.03	**97.7**
Head circumference	55.9	1.22	54.6	1.16	**97.7**
Hand length	18.4	0.64	18.1	0.56	**98.4**
Acromion-wrist length	32.3	0.91	31.8	1.03	**98.5**
Knee height	47.2	1.26	46.7	1.25	**98.9**
Chest height	121.3	1.89	120.3	2.31	**99.2**
Crotch height	79.0	2.22	78.4	1.75	**99.2**
Cervicale height	194.5	1.41	194.4	1.46	**99.9**
Acromial height	136.8	1.80	136.8	1.81	**100.0**
Shoulder length	14.6	1,06	14.6	1.00	**100.0**
Waist height – navel	100.3	2.27	100.7	2.00	**100.4**
Calf circumference	35.6	1.47	35.9	1.58	**100.8**
Buttock height	83.6	2.10	84.8	1.97	**101.4**
Waist circumference	79.0	4.01	80.4	5.51	**101.8**
Waist breadth	28.7	1.29	29.8	1.91	**103.8**
Buttock circumference	91.8	2.37	99.1	3.58	**108.0**
Hip breadth	32.2	0.93	35.5	1.51	**110.2**

1.6 Specific details of this survey

1.6.1 Clothing

All anthropometric measures detailed in this survey were taken whilst subjects wore shorts and t-shirts (and their own underwear) only. It is therefore important to take into account the situation in which the end user will be. For example, when selecting items of PPE, an important consideration should be the items of station wear to be worn underneath (these may differ in summer and winter months). When ascertaining the seating requirements in the cab of an appliance, consideration should be given to the height increment caused by wearing a helmet and the thickness of firefighting garments, in addition to the anthropometric characteristics of the user population.

As the PPE and equipment used by each brigade varies, item specific measures should ideally be taken. However, general guidelines for work-wear shoes are to add approximately 25 mm to stature for heels and approximately 30 mm to foot length for shoe length. Firefighting boots add approximately 40-50 mm on to stature, and 30-45 mm on to foot length. Helmets can add as much as 90 mm to height, and thick clothing (for example, firefighting clothing) can add as much as 100 mm to shoulder breadth and other body dimensions concerned with clearance, access and egress. Glove thickness may require an addition of around 25 mm.

In the design of PPE and clothing it is important to make allowances for movement in order that the wearer and item function optimally. For example, if you bend your knee, your leggings ride up (and also may become tight at the front and rear), and if you reach forward, your sleeves ride up, potentially creating a gap and your tunic may become tight at the back. If you bend forward, the waist of your leggings rides down and the bottom of your tunic rides up at the back. While the latter example should be catered for with a 30 cm overlap according to EN 469 (8), all-in-one items, such as CP suits, boiler suits and one piece fire garments, need further consideration. Some typical allowances for movement from NASA (9) are given in Table 1.6.1.

Table 1.6.1: Typical allowances for movement in clothing

Measurement	Action	Increment (mm)
Across elbow	Full flexion	85
Vertically across hip		
-front	90o flexion	-65
-back	90o flexion	85
-back	Full flexion	150
Vertically across knee		
-front	90o flexion	60
-front	Full flexion	105
Nape to coccyx	Full trunk flexion	100
Interscye	Reaching forwards with both arms	150

1.6.2 Units of measurement

Anthropometric data is presented in millimetres (mm), weight is presented in kilograms (kg) and strength is presented in Newtons (N).

1.6.3 Age distribution

Age was recorded for each of the firefighters measured (although several subjects declined to supply their age). The age group distribution of the population is illustrated in Figure 1.6.1.

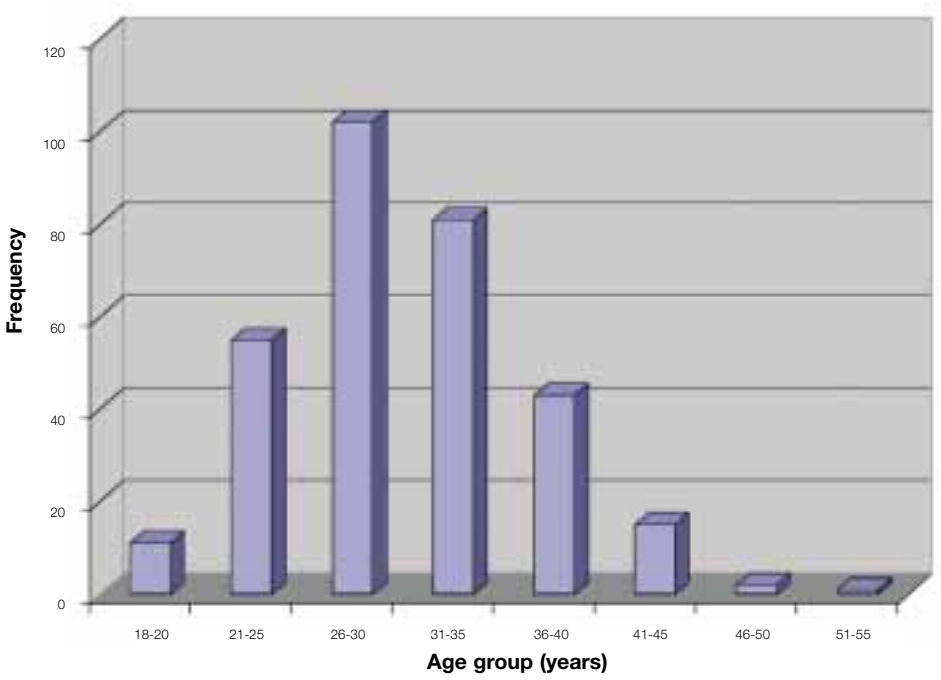


Figure 1.6.1: Age groupings for female firefighters that took part in the study

1.7 How the data is set out

1.7.1 Data tables

The data tables are set out in the following three sections:

Static anthropometry

Functional anthropometry

Strength

Each of these sections is broken down and detailed in the Classification of Measures listing. The static anthropometry section is separated into body parts, functional anthropometry measures are grouped according to the action being carried out, and the strength section presents the grip strength associated with each hand. All measures are numbered in the Classification of Measures listing and these numbers are used throughout the report when referring to particular measures. The description of each measure and a diagram are provided on each page.

It should be noted that the data represents approximately half of the national female firefighting population. While this gives us a good idea of the shape and size of our firefighters, occasionally it may mean that for any measure the value for a particular person will be lesser or greater than the minimum or maximum value stated in the appropriate data table.

1.7.2 Scatter diagrams

The anthropometry and strength data tables are followed by a selection of scatter diagrams. These are graphs that plot one measure against another in order to demonstrate their relationship with one another, or how well they correlate. This allows us to calculate the correlation coefficient (r). Two measures with a correlation coefficient

of r = 0 are not related at all. Two measures with a correlation coefficient of r = 1 have a perfect, positive linear relationship (ie. as one measure increases, so does the other), and two measures with a correlation coefficient of r = -1 have a perfect, negative linear relationship (ie. as one measure increases, the other decreases). The correlation coefficient can be very useful in the design of PPE and clothing. The scatter diagrams are listed in the Scatter Diagram Index in alphabetical order according to which measure is on the x axis (the horizontal axis). Each measure is labelled using the number system from the Classification of Measures.

It should be noted that each data point on the scatter diagrams represents a person. Some of the scatter diagrams seem to have less data points than others, and this is because several people happened to have the same values for the two measures plotted on each diagram. Measures involving the face, hands and feet, which have a lesser range of values, are typical of this pattern.

Anthropometric measures can be grouped into obvious categories, such as trunk and limb circumferences, trunk breadths, and limb lengths together with the height above ground of various parts of the anatomy. In general we would expect the members of any particular category to correlate well with one another, but poorly with members of other categories (6). So, for example, lengths correlate well with other lengths, but poorly with circumferences. We would also expect members of a particular category that involve closely related landmarks to have a higher correlation than those that involve distantly related ones. So, for example, stature has a better correlation with eye height standing than it does with knee height (6).

1.7.3 Worked examples

Towards the back of the report are some worked examples to give an idea of how anthropometry data can be applied to improve the fit and performance of PPE, and also increase the ease of use and safety of appliances and equipment for female firefighters.

2. Classification of Measures

Static anthropometry

Whole body

1 Body mass
2 Stature
3 Sitting height

Head and neck

Head

4 Head length
5 Head breadth
6 Head height
7 Head circumference
8 Bitragion arc length
9 Sagittal arc length

Face

10 Eye height sitting
11 Face length- menton to brow ridge
12 Face length-menton to naison
13 Face breadth
14 Jaw width

Neck

15 Neck circumference
16 Cervicale height standing

Torso

Shoulder

17 Shoulder height standing
18 Shoulder height sitting
19 Bi-acromial width
20 Bi-deltoid width

Chest

21 Chest circumference
22 Chest circumference – max
23 Female underbust circumference

Abdomen

24 Waist circumference
25 Waist height

Back

26 Waist-back height

Hip

27 Hip circumference
28 Hip breadth sitting - max
29 Crotch height
30 Vertical trunk circumference

Arms

Whole arm

31 Axilla height standing

Upper arm

32 Arm circumference
33 Shoulder-elbow length

Elbow

34 Elbow rest height

Lower arm

35 Elbow-wrist length

Hand

36 Hand length
37 Palm breadth
38 Palm breadth - max
39 Palm length
40 Hand thickness - max

Thumb

41 Thumb length
42 Thumb width

Middle finger

43 Finger length
44 Finger width

Legs

Upper leg

45 Thigh circumference
46 Buttock to front of knee
47 Buttock to back of knee

Knee

48 Knee height
49 Back of knee height sitting

Lower leg

50 Calf circumference

Foot

51 Foot length
52 Foot breadth

Functional anthropometry

Reach

53 Overhead grip reach sitting
54 Overhead grip reach standing
55 Forward grip reach
56 Acromion to grip length

Span

57 Functional arm span

Strength

Handgrip strength

58 Right hand
59 Left hand
60 Dominant hand
61 Non-dominant hand

3. Scatter Diagram Index

No	Measure	vs	No	Measure
31	Axilla height standing		25	Waist height
19	Bi-acromial width		20	Bi-deltoid width
46	Buttock to front of knee		47	Buttock to back of knee
22	Chest circumference- max		23	Female underbust circumference
21	Chest circumference		32	Arm circumference
21	Chest circumference		20	Bi-deltoid width
21	Chest circumference		22	Chest circumference- max
21	Chest circumference		23	Female underbust circumference
21	Chest circumference		27	Hip circumference
21	Chest circumference		15	Neck circumference
21	Chest circumference		30	Vertical trunk circumference
21	Chest circumference		24	Waist circumference
29	Crotch height		48	Knee height
29	Crotch height		30	Vertical trunk circumference
13	Face breadth		14	Jaw width
11	Face length- menton to brow ridge		13	Face breadth
12	Face length- menton to naison		13	Face breadth
43	Finger length		44	Finger width
43	Finger length		39	Palm length
43	Finger length		41	Thumb length
51	Foot length		52	Foot breadth
55	Forward grip reach		56	Acromion to grip length
55	Forward grip reach		35	Elbow-wrist length
55	Forward grip reach		57	Functional arm span
55	Forward grip reach		54	Overhead grip reach standing
55	Forward grip reach		33	Shoulder-elbow length
36	Hand length		43	Finger length
36	Hand length		37	Palm breadth
36	Hand length		38	Palm breadth- max
36	Hand length		39	Palm length
36	Hand length		41	Thumb length
5	Head breadth		8	Bitragion arc length

No	Measure	vs	No	Measure
5	Head breadth		14	Jaw width
5	Head breadth		13	Face breadth
5	Head breadth		6	Head height
7	Head circumference		8	Bitragion arc length
7	Head circumference		15	Neck circumference
7	Head circumference		9	Sagital arc length
6	Head height		11	Face length- menton to brow ridge
6	Head height		12	Face length- menton to naison
4	Head length		11	Face length- menton to brow ridge
4	Head length		12	Face length- menton to naison
4	Head length		5	Head breadth sitting - max
4	Head length		7	Head circumference
4	Head length		6	Head height
4	Head length		9	Sagital arc length
27	Hip circumference		50	Calf circumference
27	Hip circumference		28	Hip breadth
27	Hip circumference		45	Thigh circumference
27	Hip circumference		30	Vertical trunk circumference
48	Knee height		49	Back of knee height sitting
54	Overhead grip reach standing		57	Functional arm span
37	Palm breadth		40	Hand thickness
33	Shoulder to elbow length		34	Elbow rest height
33	Shoulder to elbow length		35	Elbow to wrist length
3	Sitting height		18	Shoulder height sitting
3	Sitting height		10	Eye height sitting
3	Sitting height		53	Overhead grip reach sitting
2	Stature		56	Acromion to grip length
2	Stature		31	Axilla height standing
2	Stature		49	Back of knee height sitting
2	Stature		20	Bi-deltoid width
2	Stature		47	Buttock to back of knee length
2	Stature		46	Buttock to front of knee length

No	Measure	vs	No	Measure
2	Stature		16	Cervicale height standing
2	Stature		21	Chest circumference
2	Stature		29	Crotch height
2	Stature		34	Elbow rest height
2	Stature		35	Elbow-wrist length
2	Stature		10	Eye height sitting
2	Stature		51	Foot length
2	Stature		55	Forward grip reach
2	Stature		57	Functional arm span
2	Stature		36	Hand length
2	Stature		48	Knee height
2	Stature		54	Overhead grip reach
2	Stature		53	Overhead grip reach sitting
2	Stature		18	Shoulder height sitting
2	Stature		17	Shoulder height standing
2	Stature		33	Shoulder-elbow length
2	Stature		3	Sitting height
2	Stature		30	Vertical trunk circumference
2	Stature		24	Waist circumference
2	Stature		25	Waist height
2	Stature		26	Waist-back height
45	Thigh circumference		50	Calf circumference
24	Waist circumference		50	Calf circumference
24	Waist circumference		27	Hip circumference
24	Waist circumference		45	Thigh circumference
25	Waist height		49	Back of knee height sitting
25	Waist height		47	Buttock to back of knee length
25	Waist height		46	Buttock to front of knee length
25	Waist height		29	Crotch height
25	Waist height		48	Knee height
25	Waist height		26	Waist-back height
26	Waist-back height		16	Cervicale height standing
26	Waist-back height		3	Sitting height

4. Anthropometric Data

Whole Body

Head & Neck

Torso

Arms

Legs

Functional Anthropometry

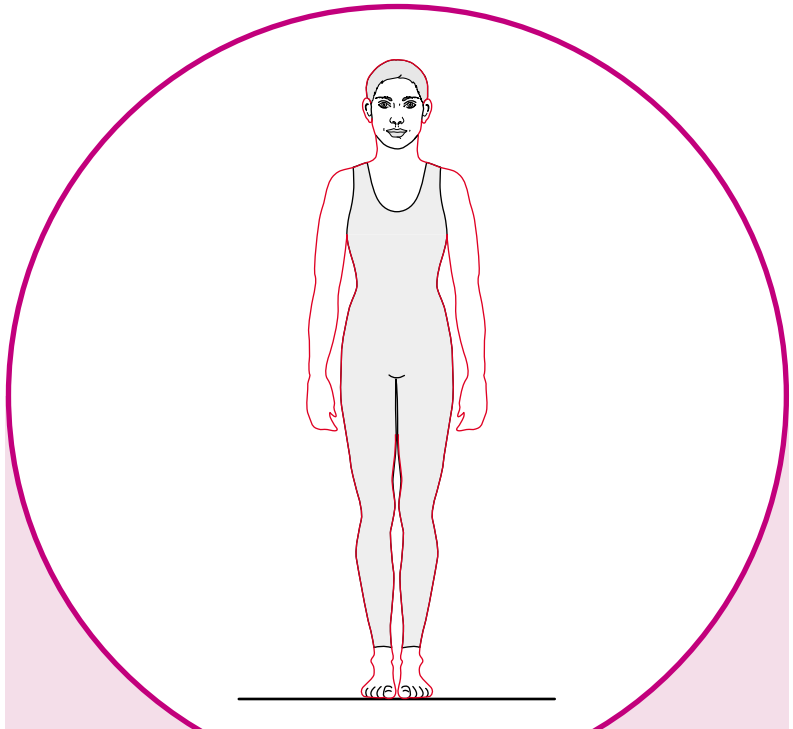
Strength

Whole body

Body Mass

Percentile	Kg
1	53.6
5	57.2
10	58.8
15	60.4
20	61.8
25	62.6
30	63.1
35	64.4
40	66.0
45	66.8
50	67.7
55	68.6
60	69.4
65	70.5
70	71.4
75	73.0
80	74.1
85	75.7
90	78.8
95	82.5
99	93.2

	Kg
Maximum	100.7
Minimum	51.9
Range	48.8
Mean value	68.4
Standard deviation	8.1
SE (Mean)	0.5
Coefficient of variation =	11.8%
No subjects =	314



Subject to stand on the weighing scales upright, still and looking straight ahead.

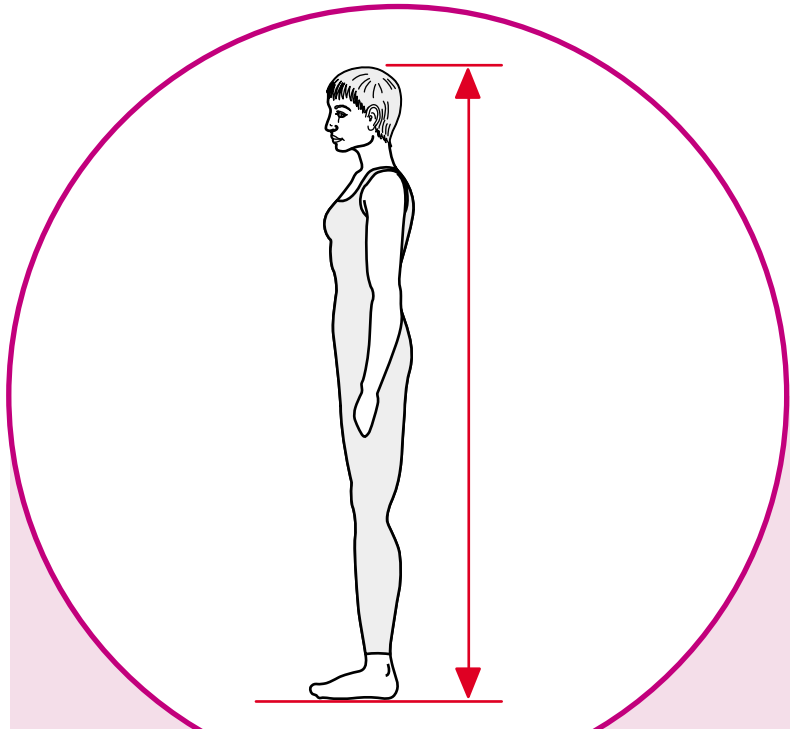
1

Whole body

Stature

Percentile	mm
1	1557.1
5	1581.3
10	1608.0
15	1622.0
20	1634.0
25	1642.0
30	1650.4
35	1659.0
40	1667.0
45	1671.0
50	1675.0
55	1685.0
60	1690.0
65	1699.0
70	1704.0
75	1714.8
80	1720.4
85	1736.5
90	1752.0
95	1770.3
99	1816.5

	mm
Maximum	1868.0
Minimum	1519.0
Range	349.0
Mean value	1679.3
Standard deviation	57.1
SE (Mean)	3.2
Coefficient of variation =	3.4%
No subjects =	315



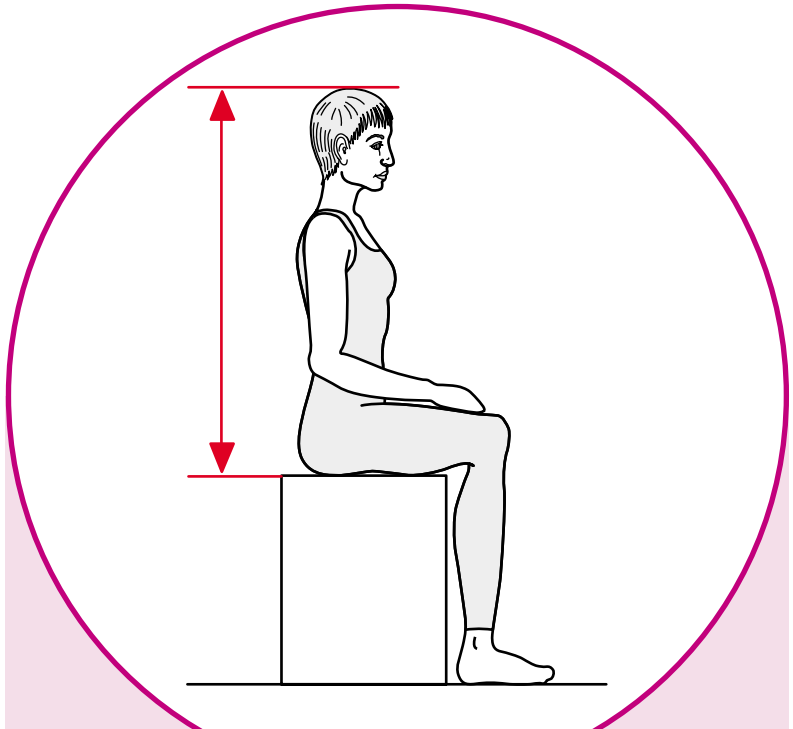
Measured vertically from the floor to the top of the head (vertex). The person stands erect, looking ahead, the arms hanging loosely at the sides.

Whole body

Sitting Height

Percentile	mm
1	825.1
5	836.5
10	854.0
15	863.0
20	867.2
25	873.0
30	877.0
35	882.0
40	887.8
45	891.0
50	896.0
55	898.0
60	903.0
65	905.0
70	908.0
75	911.0
80	916.4
85	923.0
90	929.8
95	938.9
99	964.0

	mm
Maximum	976.0
Minimum	817.0
Range	159.0
Mean value	892.7
Standard deviation	30.1
SE (Mean)	1.7
Coefficient of variation =	3.4%
No subjects =	311



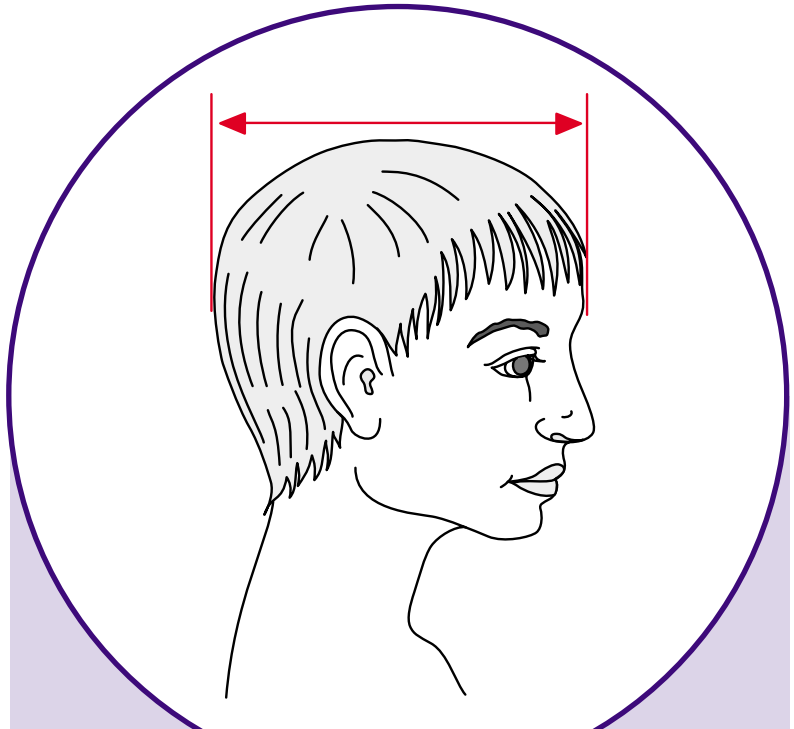
Measured vertically from the seat surface to the top of the head (vertex), compressing the hair. Subject sits erect, looking straight ahead, hands in lap. Ensure thighs are horizontal.

Head & Neck

Head Length – front to back

Percentile	mm
1	177.2
5	183.0
10	184.0
15	187.0
20	188.0
25	189.0
30	189.0
35	190.0
40	191.0
45	192.0
50	193.0
55	194.0
60	194.0
65	195.0
70	196.0
75	197.0
80	198.0
85	199.3
90	201.0
95	203.0
99	208.0

	mm
Maximum	209.0
Minimum	172.0
Range	37.0
Mean value	192.8
Standard deviation	6.3
SE (Mean)	0.4
Coefficient of variation =	3.3%
No subjects =	316



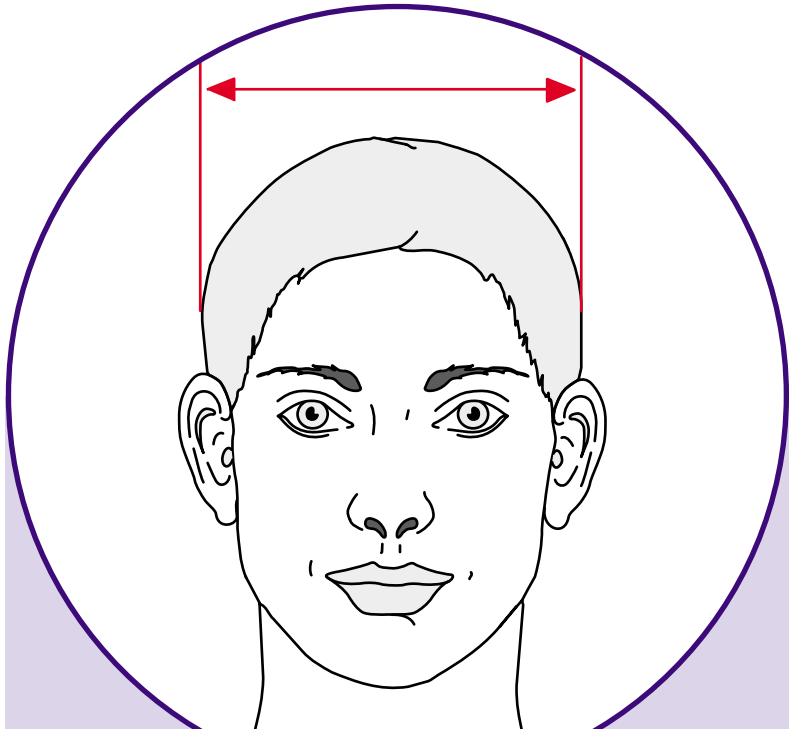
The length measured from the brow ridge (glabella) to the prominence at the back of the head (occiput).

Head & Neck

Head Breadth

Percentile	mm
1	136.0
5	140.0
10	143.0
15	144.0
20	145.0
25	146.0
30	146.0
35	147.0
40	148.0
45	149.0
50	150.0
55	150.0
60	151.0
65	152.0
70	152.0
75	153.0
80	154.0
85	155.0
90	156.0
95	158.0
99	159.2

	mm
Maximum	165.0
Minimum	133.0
Range	32.0
Mean value	149.4
Standard deviation	5.3
SE (Mean)	0.3
Coefficient of variation =	3.6%
No subjects =	316



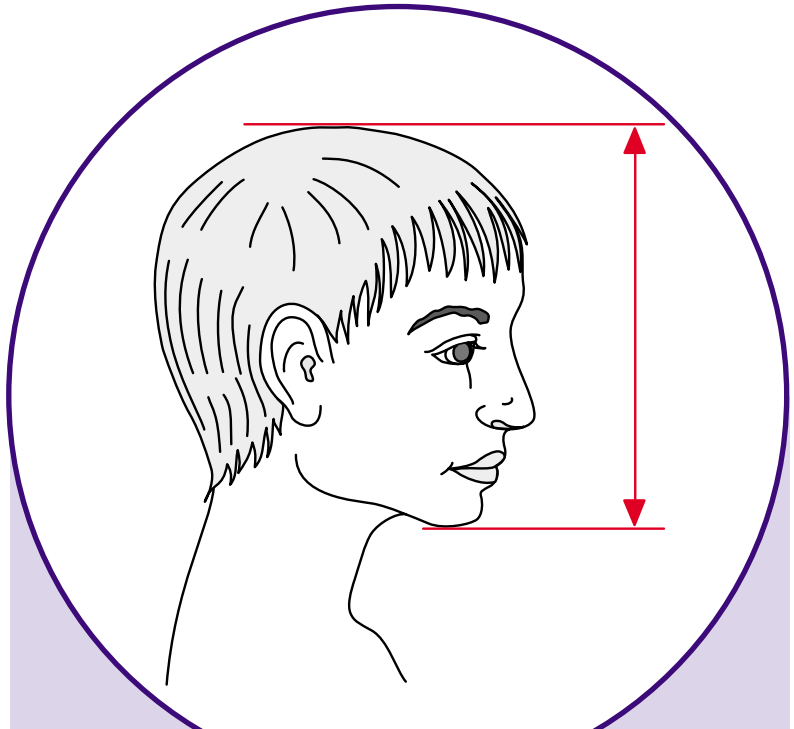
Measured horizontally across the head, above and behind the ears, where the head is broadest. Hair is compressed.

Head & Neck

Head Height

Percentile	mm
1	195.2
5	203.0
10	205.0
15	207.0
20	210.0
25	211.0
30	212.7
35	215.0
40	216.0
45	217.0
50	218.0
55	219.0
60	220.0
65	222.0
70	223.7
75	225.0
80	226.0
85	228.0
90	230.3
95	233.0
99	241.0

	mm
Maximum	247
Minimum	191
Range	56
Mean value	217.6
Standard deviation	9.6
SE (Mean)	0.5
Coefficient of variation =	4.4%
No subjects =	316



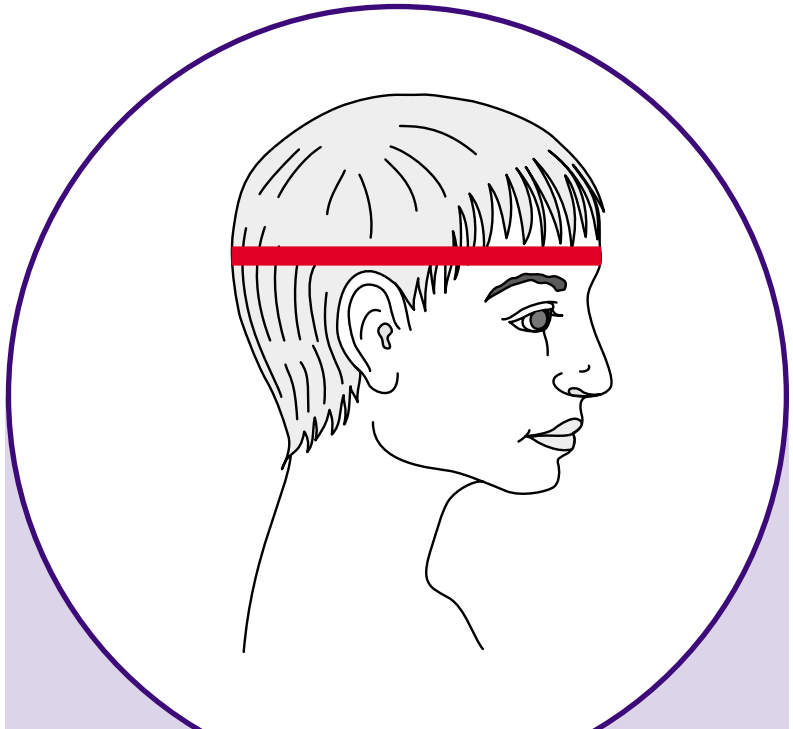
Measured vertically from the bony tip of the chin (menton) to the top of the head (vertex).

Head & Neck

Head Circumference

Percentile	mm
1	527.1
5	537.3
10	545.0
15	546.0
20	549.0
25	550.3
30	552.0
35	555.0
40	557.0
45	558.0
50	560.0
55	561.0
60	563.0
65	565.0
70	568.0
75	570.0
80	572.0
85	575.0
90	579.0
95	583.5
99	591.1

	mm
Maximum	602
Minimum	522
Range	80
Mean value	560.3
Standard deviation	14.1
SE (Mean)	0.8
Coefficient of variation =	2.5%
No subjects =	315



Measured around the maximum circumference of the head, just above the brow ridges at the front and the most protruding portion of the back of the head (occiput). Hair should be compressed.

Head & Neck

Bitagion Arc Length

Percentile	mm
1	309.0
5	316.0
10	320.0
15	323.0
20	325.6
25	327.8
30	329.0
35	332.0
40	333.0
45	335.0
50	336.0
55	338.6
60	340.0
65	342.0
70	343.0
75	346.0
80	348.0
85	351.0
90	353.6
95	358.0
99	368.0

	mm
Maximum	372
Minimum	304
Range	68
Mean value	336.6
Standard deviation	13.0
SE (Mean)	0.7
Coefficient of variation =	3.9%
No subjects =	313

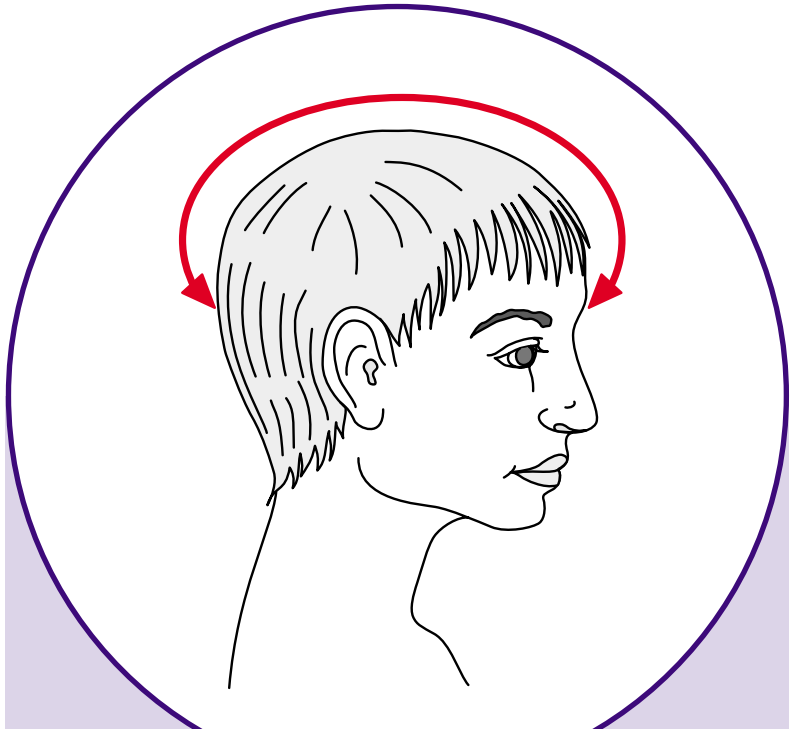
Measured from the tragion of one ear vertically over the top of the head to the tragion of the other ear with sufficient tape tension to flatten the hair.

Head & Neck

Sagital Arc Length - front to back

Percentile	mm
1	309.0
5	319.0
10	323.0
15	327.5
20	329.0
25	330.0
30	332.0
35	333.0
40	334.0
45	338.0
50	340.0
55	342.0
60	342.6
65	345.0
70	346.3
75	349.0
80	352.0
85	355.0
90	359.0
95	363.0
99	370.1

	mm
Maximum	374.0
Minimum	304.0
Range	70.0
Mean value	340.3
Standard deviation	13.9
SE (Mean)	0.8
Coefficient of variation =	4.1%
No subjects =	314



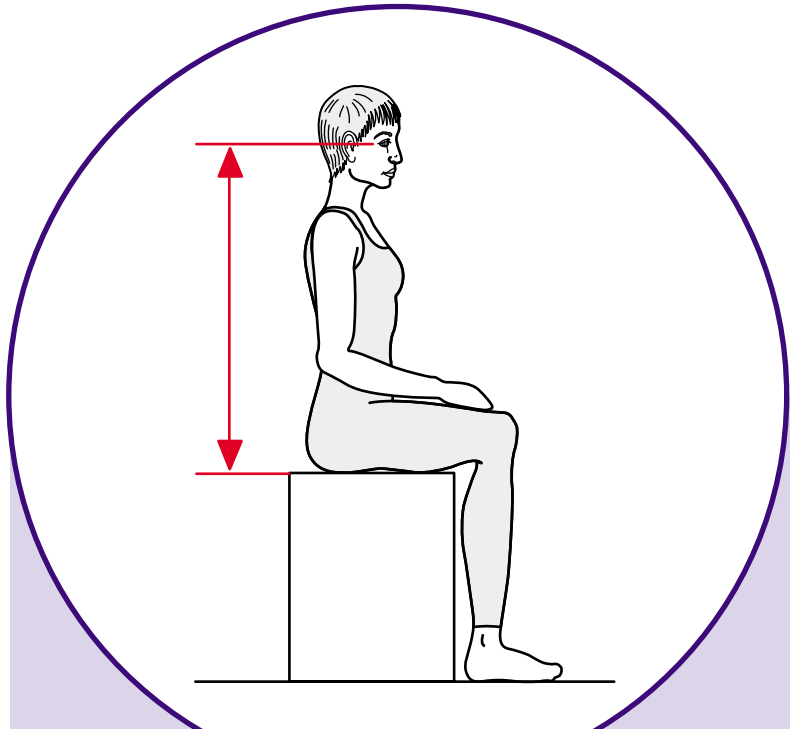
Measured along the surface from the brow ridge (glabella) to the prominence at the back of the head (occiput).

Head & Neck

Eye Height Sitting

Percentile	mm
1	718.0
5	725.4
10	741.0
15	748.9
20	756.0
25	759.0
30	762.0
35	766.7
40	771.0
45	775.0
50	779.5
55	784.0
60	787.2
65	790.4
70	794.0
75	798.0
80	803.0
85	808.2
90	814.0
95	826.5
99	841.2

	mm
Maximum	875.0
Minimum	689.0
Range	186.0
Mean value	778.3
Standard deviation	29.4
SE (Mean)	1.7
Coefficient of variation =	3.8%
No subjects =	310



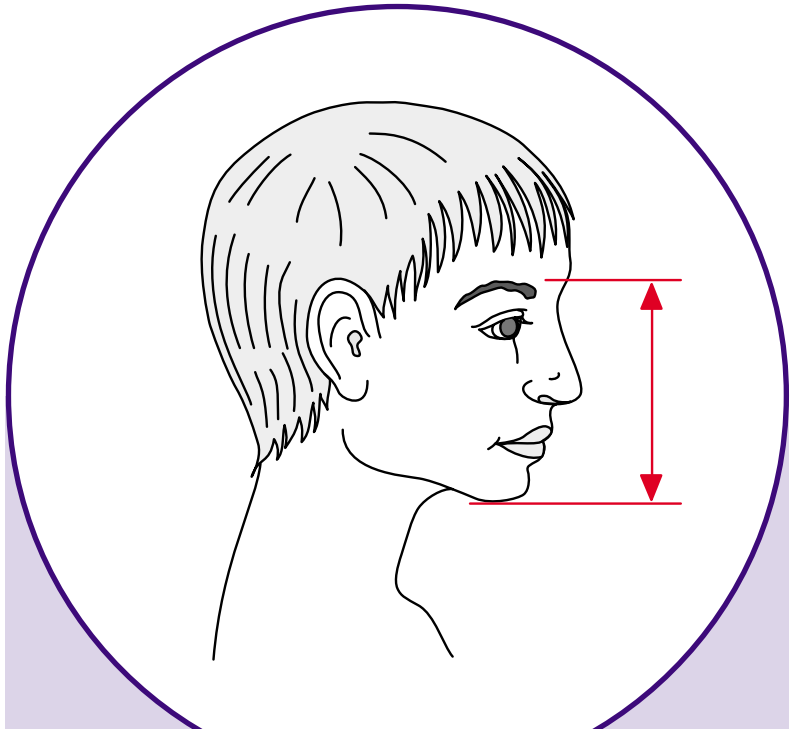
Measured vertically from the seat surface to the outer border of the eye socket (ectocanthus). Subject sits erect, looking straight ahead, hands in lap. Ensure thighs are horizontal.

Face Length – menton to brow ridge

Measured vertically from the bony tip of the chin (menton) to the brow ridge (glabella).

Percentile	mm
1	113.0
5	114.0
10	116.0
15	117.1
20	119.0
25	120.0
30	121.0
35	122.0
40	123.0
45	124.0
50	124.0
55	125.0
60	126.0
65	127.0
70	127.0
75	128.0
80	129.0
85	131.0
90	133.0
95	136.0
99	139.0

	mm
Maximum	146
Minimum	104
Range	42
Mean value	124.4
Standard deviation	6.5
SE (Mean)	0.4
Coefficient of variation =	5.2%
No subjects =	310

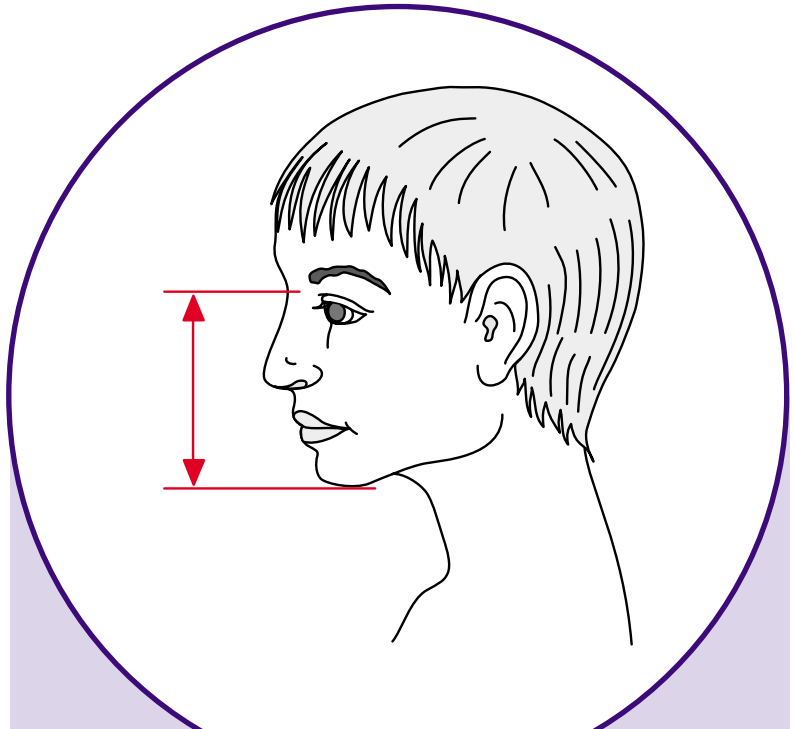


Head & Neck

Face Length – menton to naison

Percentile	mm
1	96.0
5	98.0
10	100.0
15	101.0
20	102.0
25	103.0
30	104.0
35	106.0
40	107.0
45	108.0
50	109.0
55	110.0
60	110.0
65	112.0
70	112.0
75	114.0
80	115.0
85	118.0
90	119.0
95	122.0
99	126.2

	mm
Maximum	135.0
Minimum	94.0
Range	41.0
Mean value	109.0
Standard deviation	7.6
SE (Mean)	0.4
Coefficient of variation =	6.9%
No subjects =	310



Measured vertically from the bony tip of the chin (menton) to the depression at the top of the nose (naison).

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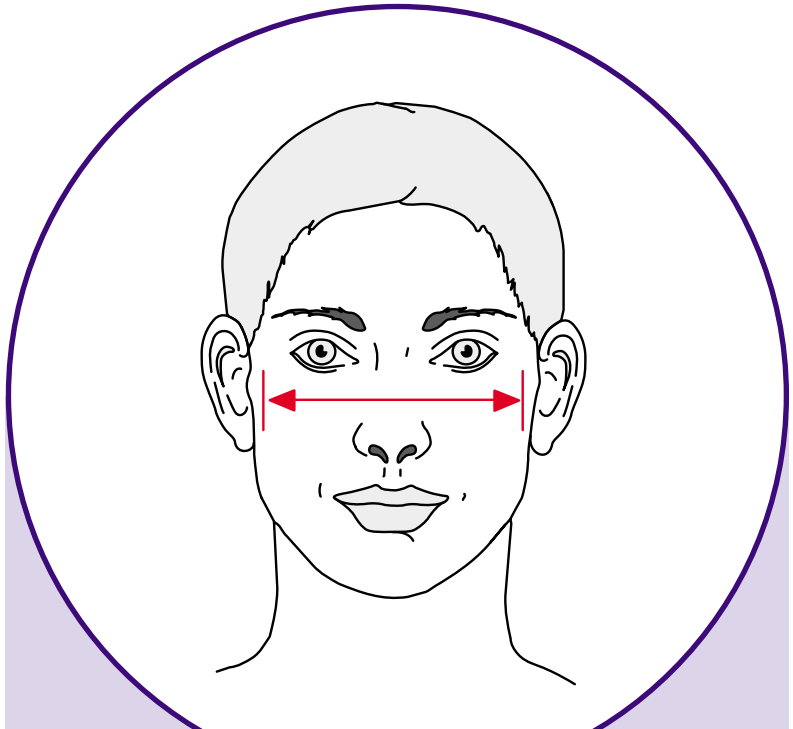
Head & Neck

Face Breadth

Measured horizontally between the broadest portion of the cheekbones, between the eyes and ears.

Percentile	mm
1	126.0
5	129.0
10	131.0
15	132.0
20	133.0
25	134.0
30	134.9
35	135.0
40	136.0
45	137.0
50	137.0
55	138.0
60	138.0
65	139.0
70	139.0
75	140.0
80	140.0
85	141.0
90	142.0
95	145.0
99	147.1

	mm
Maximum	149
Minimum	123
Range	26
Mean value	136.8
Standard deviation	4.7
SE (Mean)	0.3
Coefficient of variation =	3.4
No subjects =	309

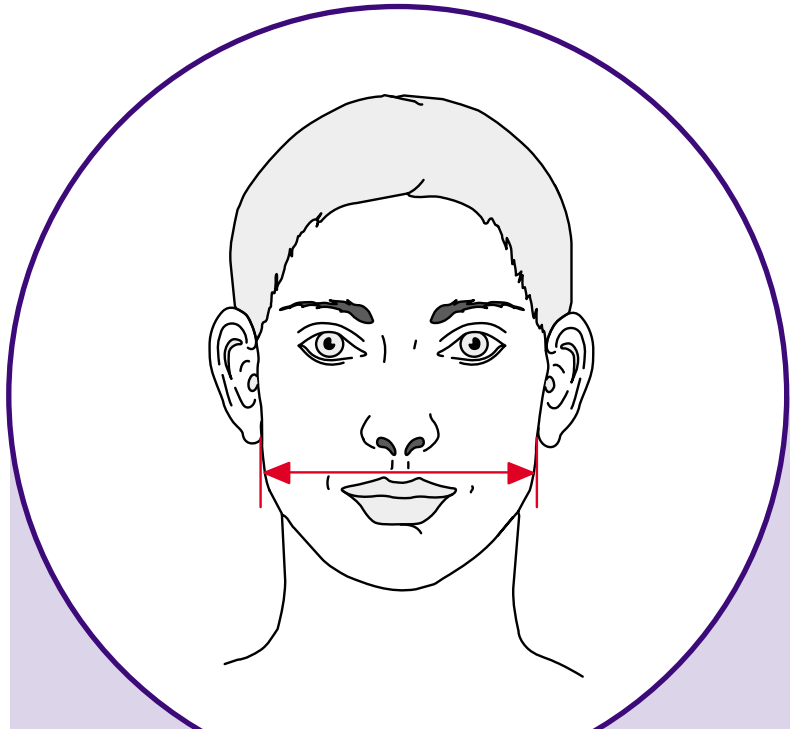


Head & Neck

Jaw Width

Percentile	mm
1	104.0
5	107.0
10	110.0
15	111.9
20	113.0
25	114.0
30	115.0
35	115.0
40	116.4
45	118.0
50	118.0
55	119.0
60	119.0
65	120.0
70	121.0
75	122.0
80	123.0
85	125.0
90	127.0
95	128.0
99	131.1

	mm
Maximum	135.0
Minimum	103.0
Range	32.0
Mean value	117.9
Standard deviation	6.2
SE (Mean)	0.4
Coefficient of variation =	5.3%
No subjects =	310



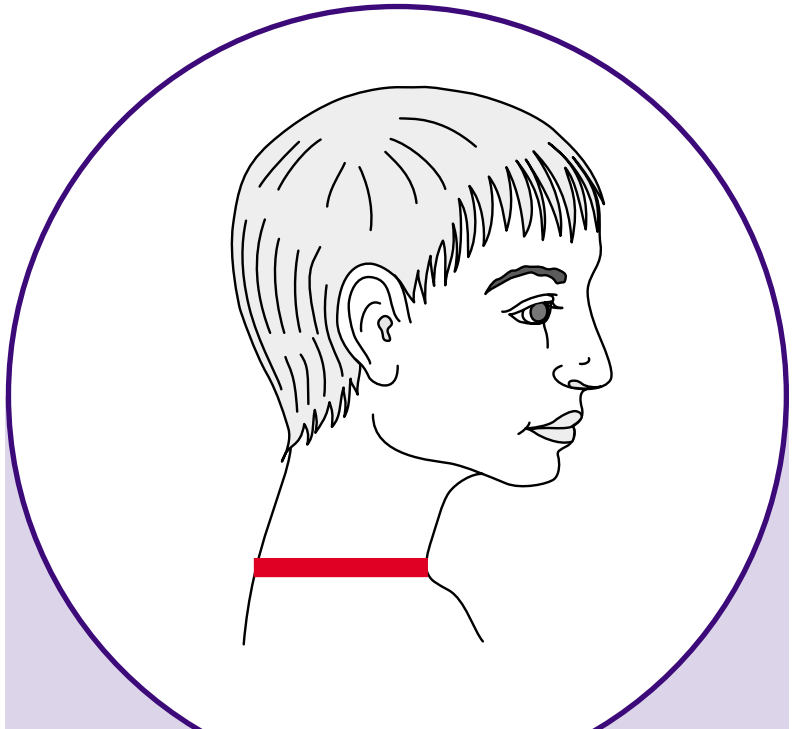
Measured horizontally between the outer angles of the jawbone.

Neck Circumference

Measured around the neck, halfway between the Adam's apple and the top of the breastbone (sternum). The tape should pass over the prominent neck vertebra (C7) at the back. Pressure on the tape should be minimal to avoid discomfort.

Percentile	mm
1	321.0
5	329.0
10	333.0
15	336.8
20	340.0
25	342.5
30	345.0
35	347.8
40	349.0
45	351.0
50	352.0
55	354.0
60	357.0
65	358.3
70	360.0
75	362.0
80	364.0
85	369.0
90	371.0
95	378.0
99	391.3

	mm
Maximum	412.0
Minimum	304.0
Range	108.0
Mean value	353.1
Standard deviation	15.9
SE (Mean)	0.9
Coefficient of variation =	4.5%
No subjects =	316

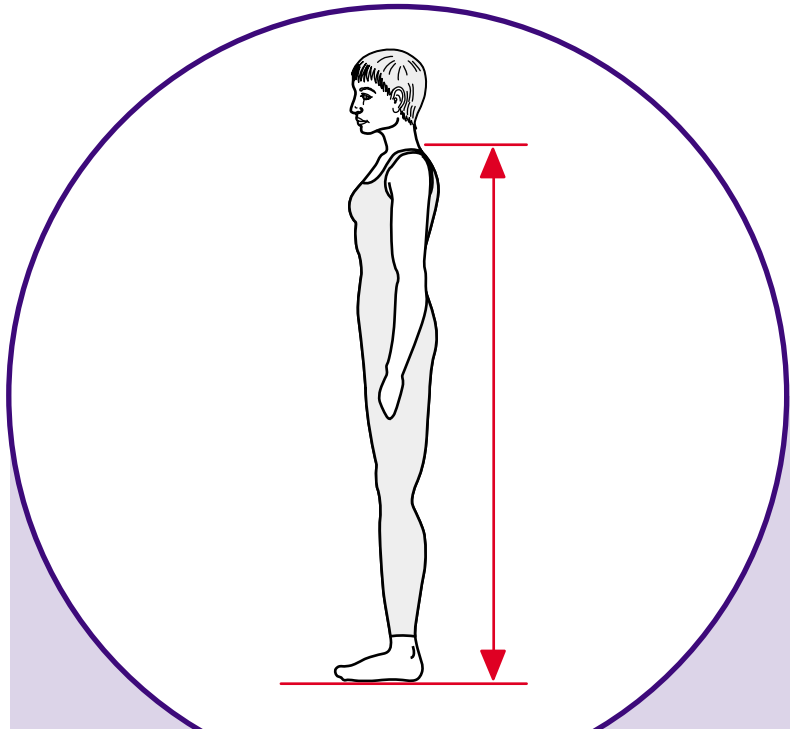


Head & Neck

Cervicale Height Standing

Percentile	mm
1	1289.2
5	1317.5
10	1333.6
15	1352.1
20	1361.0
25	1371.3
30	1380.0
35	1385.1
40	1394.8
45	1405.5
50	1411.0
55	1420.0
60	1424.8
65	1432.0
70	1439.2
75	1449.3
80	1460.2
85	1472.1
90	1484.6
95	1507.5
99	1538.5

	mm
Maximum	1579
Minimum	1248
Range	331
Mean value	1411.0
Standard deviation	58.1
SE (Mean)	3.3
Coefficient of variation =	4.1
No subjects =	311



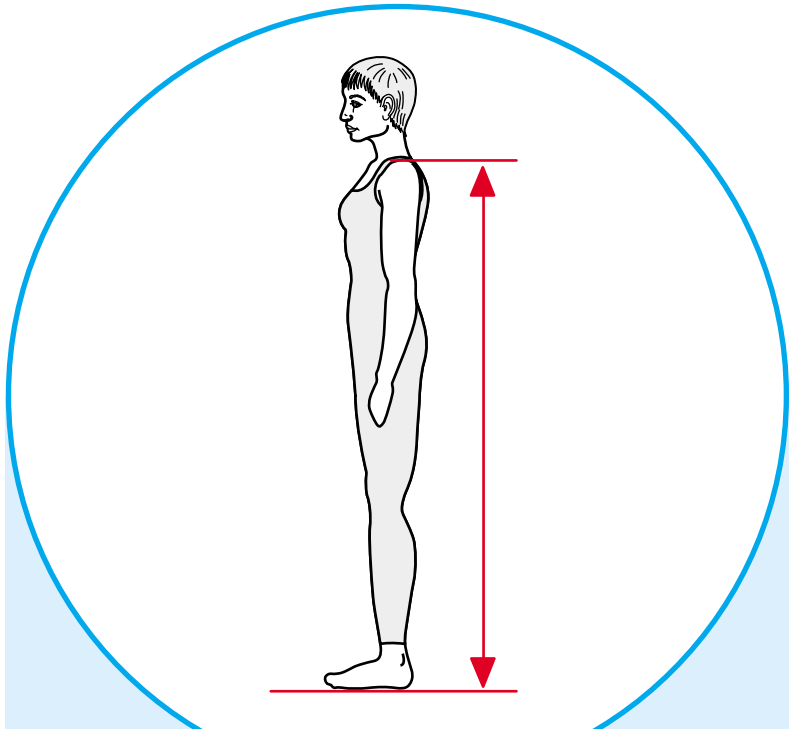
Measured vertically from the floor to the level of the prominent bone at the base of the neck (cervicale or C7). The person stands erect, looking ahead, the arms hanging loosely at the sides.

Shoulder Height Standing

Measured vertically from the floor to the bony tip of the shoulder (acromion). The subject stands erect with the arms hanging loosely at the side.

Percentile	mm
1	1273.7
5	1306.4
10	1320.0
15	1331.8
20	1341.0
25	1354.0
30	1361.0
35	1365.7
40	1374.0
45	1377.0
50	1384.0
55	1390.9
60	1398.2
65	1406.4
70	1412.0
75	1420.0
80	1426.0
85	1443.2
90	1455.9
95	1472.0
99	1515.8

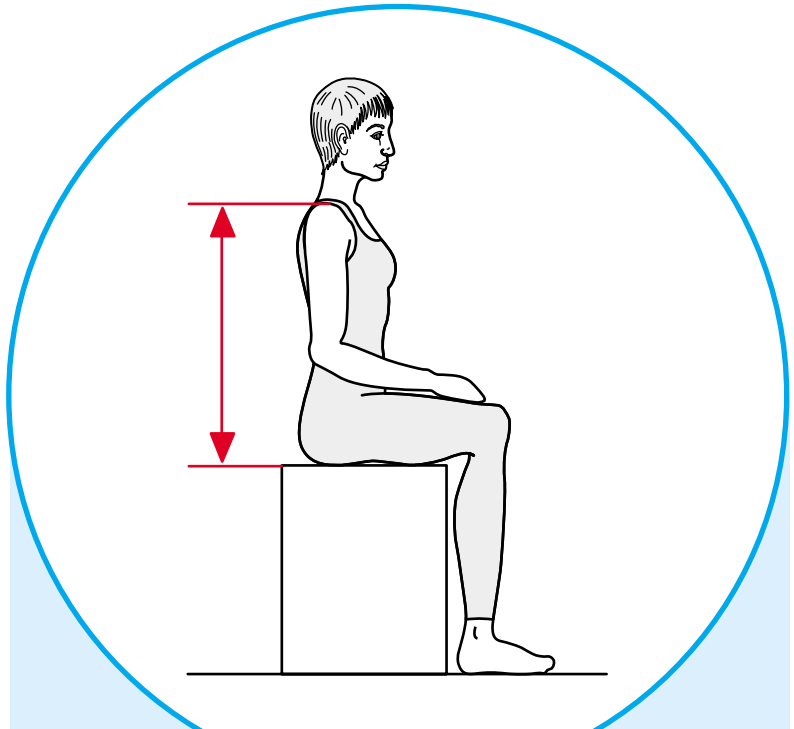
	mm
Maximum	1563.0
Minimum	1229.0
Range	334.0
Mean value	1387.0
Standard deviation	52.8
SE (Mean)	3.0
Coefficient of variation =	3.8%
No subjects =	310



Shoulder Height Sitting

Percentile	mm
1	540.1
5	553.0
10	559.0
15	565.0
20	571.0
25	577.8
30	580.6
35	584.0
40	587.0
45	591.0
50	594.0
55	598.0
60	602.6
65	606.0
70	608.8
75	612.0
80	615.6
85	622.0
90	628.0
95	636.0
99	662.2

	mm
Maximum	677
Minimum	526
Range	151
Mean value	593.9
Standard deviation	26.4
SE (Mean)	1.5
Coefficient of variation =	4.5
No subjects =	309



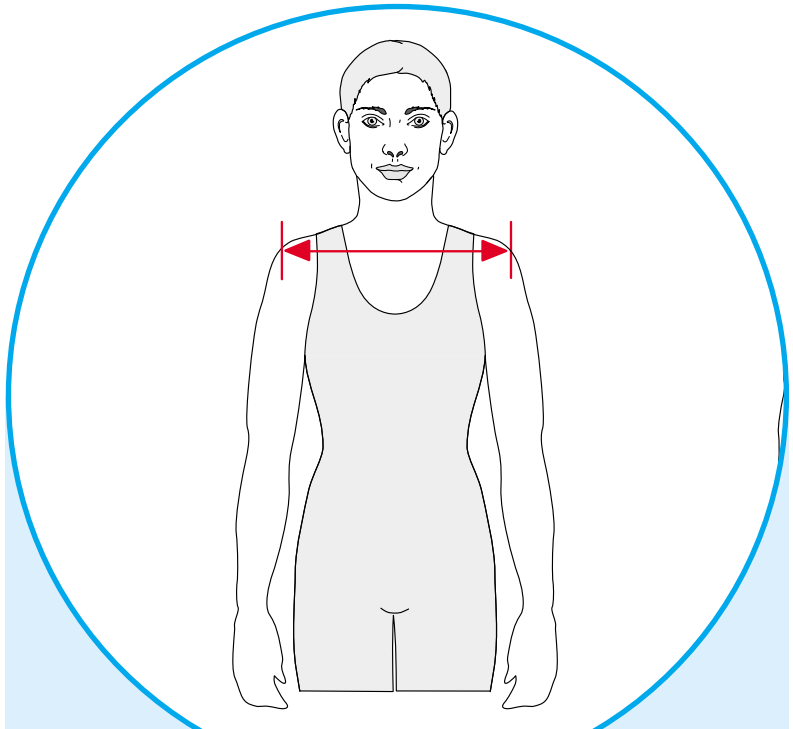
Measured vertically from the seat surface to the bony tip of the shoulder (acromion). Subject sits erect, looking straight ahead, hands in lap. Ensure thighs are horizontal.

Bi-acromial Width

Measured horizontally between the bony tips of the shoulders (acromial processes). The person stands erect with the arms at the sides. The shoulders should be relaxed.

Percentile	mm
1	310.0
5	320.4
10	326.0
15	331.0
20	335.0
25	339.0
30	342.0
35	345.7
40	349.0
45	353.0
50	357.0
55	360.0
60	363.8
65	368.0
70	372.0
75	375.3
80	380.2
85	384.0
90	393.8
95	404.5
99	417.4

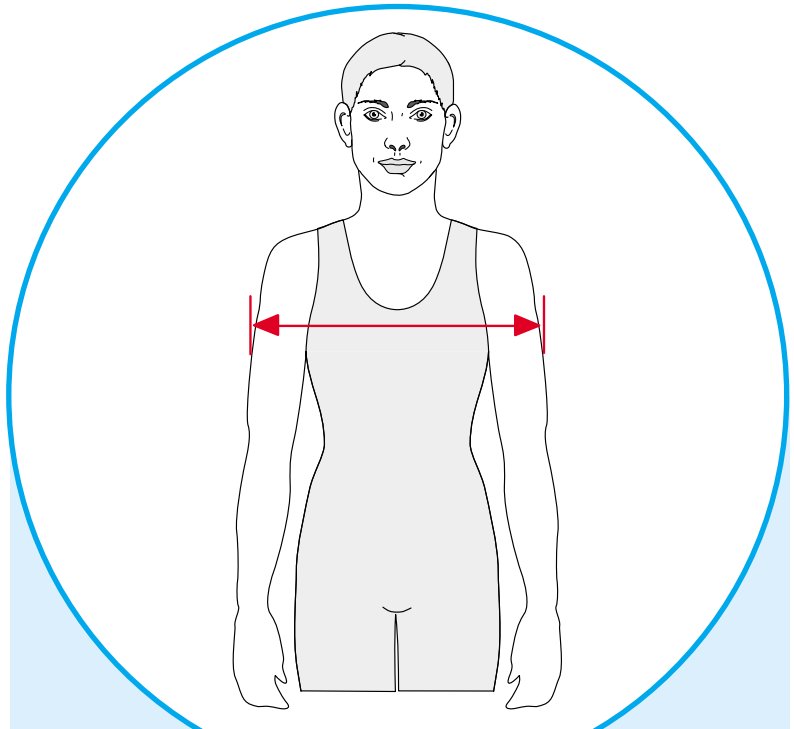
	mm
Maximum	427.0
Minimum	305.0
Range	122.0
Mean value	358.6
Standard deviation	25.8
SE (Mean)	1.5
Coefficient of variation =	7.2%
No subjects =	310



Bi-deltoid Width

Percentile	mm
1	403.3
5	419.7
10	425.0
15	429.7
20	433.0
25	436.0
30	438.4
35	441.0
40	445.0
45	447.3
50	451.0
55	454.0
60	457.0
65	459.7
70	464.0
75	467.3
80	473.0
85	477.0
90	481.0
95	492.3
99	519.4

	mm
Maximum	547.0
Minimum	382.0
Range	165.0
Mean value	452.1
Standard deviation	23.7
SE (Mean)	1.3
Coefficient of variation =	5.2%
No subjects =	315



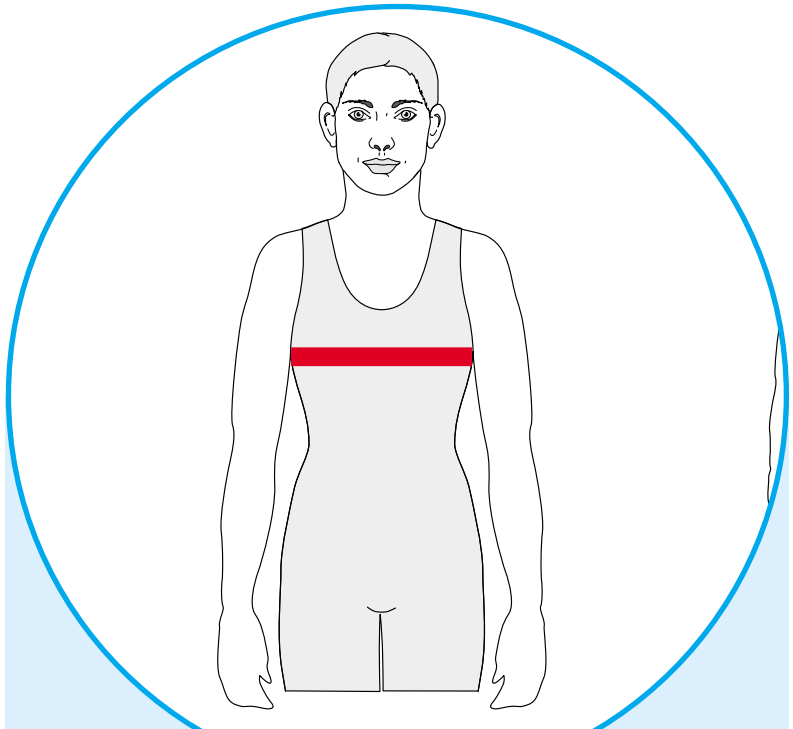
Measured horizontally between points of maximum protrusion of the deltoid muscles on the upper, outer border of the arm and shoulder. The person stands erect with the arms at the side.

Chest Circumference

The maximum circumference, measured horizontally around the chest at the level of the nipples (or widest point). The person stands erect, looking forwards, with the shoulders relaxed and breathing normally. Measurement is taken at the midpoint of respiration.

Percentile	mm
1	825.6
5	843.3
10	870.0
15	881.7
20	892.0
25	900.3
30	910.0
35	920.0
40	923.0
45	930.0
50	936.0
55	943.7
60	951.0
65	960.7
70	970.0
75	979.3
80	990.0
85	1005.0
90	1020.8
95	1062.0
99	1086.0

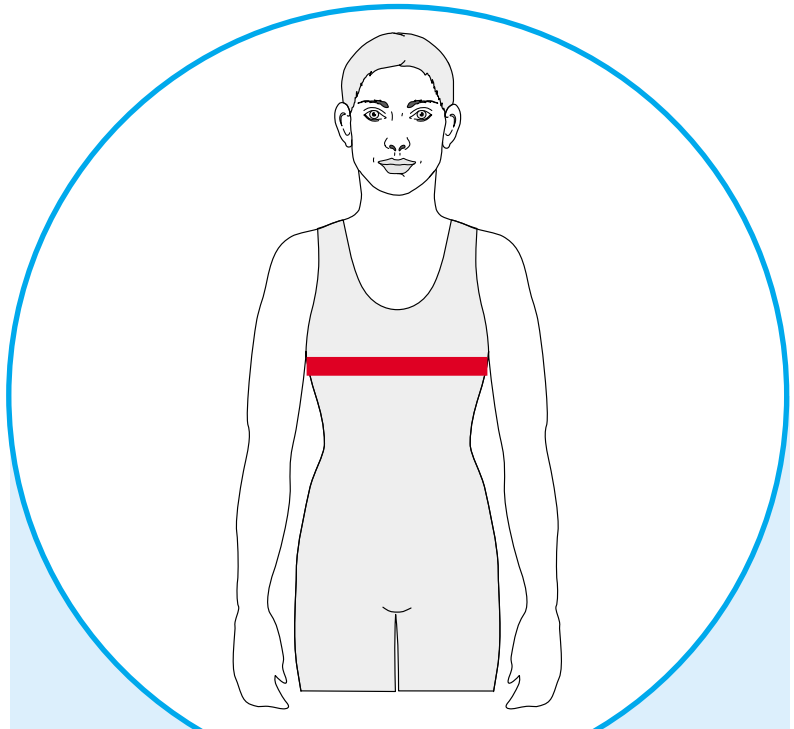
	mm
Maximum	1190
Minimum	810
Range	380
Mean value	943.9
Standard deviation	61.8
SE (Mean)	3.5
Coefficient of variation =	6.5
No subjects =	315



Chest Circumference - max

Percentile	mm
1	855.8
5	889.7
10	905.8
15	918.0
20	929.0
25	940.0
30	945.4
35	950.0
40	959.4
45	965.0
50	971.0
55	979.7
60	985.0
65	990.7
70	1004.0
75	1010.0
80	1026.0
85	1034.5
90	1052.8
95	1095.8
99	1114.1

	mm
Maximum	1215.0
Minimum	843.0
Range	372.0
Mean value	978.1
Standard deviation	60.3
SE (Mean)	3.4
Coefficient of variation =	6.2%
No subjects =	315



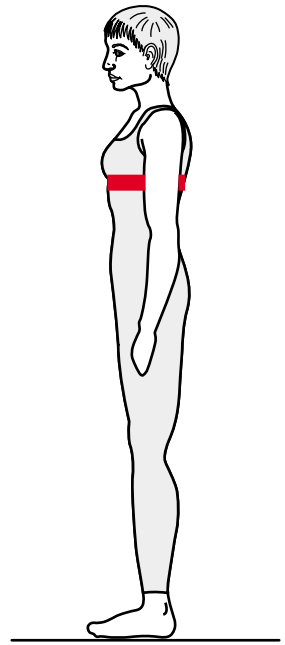
Measured as chest circumference, but with the person expanding the chest as much as possible through both maximal inhalation and muscle flexion.

Female Underbust Circumference

Measured around the chest below the breasts. The subject stands erect with the arms hanging loosely at the side. The measurement is taken at the midpoint of respiration.

Percentile	mm
1	723.6
5	745.4
10	756.0
15	767.8
20	777.0
25	786.0
30	792.0
35	800.0
40	806.0
45	812.0
50	818.0
55	820.9
60	828.2
65	833.4
70	840.0
75	850.0
80	861.4
85	878.4
90	892.9
95	924.5
99	982.3

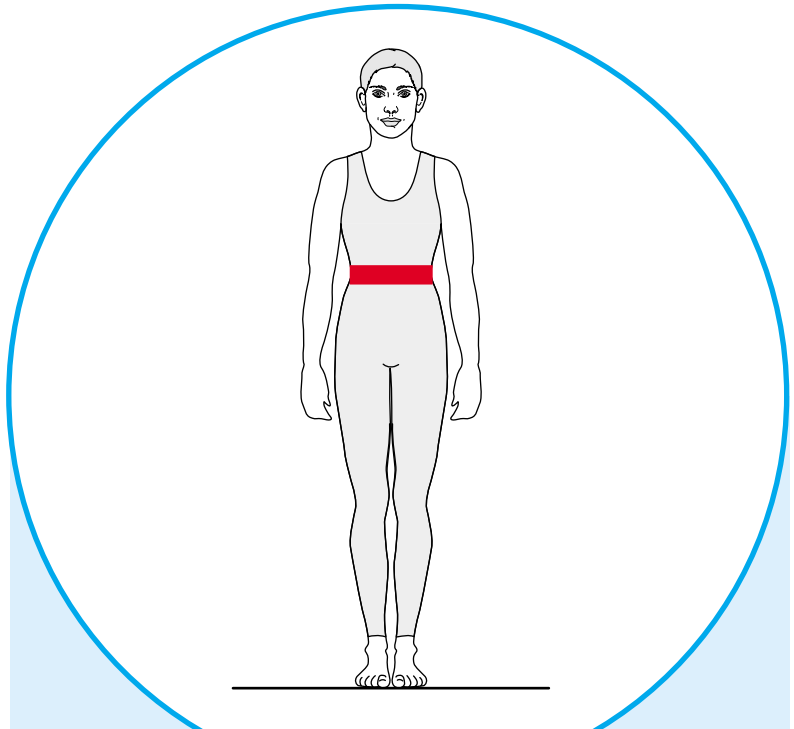
	mm
Maximum	1100
Minimum	688
Range	412
Mean value	823.5
Standard deviation	56.0
SE (Mean)	3.2
Coefficient of variation =	6.8
No subjects =	310



Waist Circumference

Percentile	mm
1	671.3
5	679.0
10	690.4
15	705.5
20	719.0
25	732.0
30	737.0
35	744.1
40	754.0
45	762.0
50	770.0
55	780.0
60	789.0
65	794.0
70	804.0
75	813.0
80	828.0
85	842.2
90	862.0
95	927.6
99	1019.4

	mm
Maximum	1080.0
Minimum	649.0
Range	431.0
Mean value	779.1
Standard deviation	72.3
SE (Mean)	4.1
Coefficient of variation =	9.3%
No subjects =	314



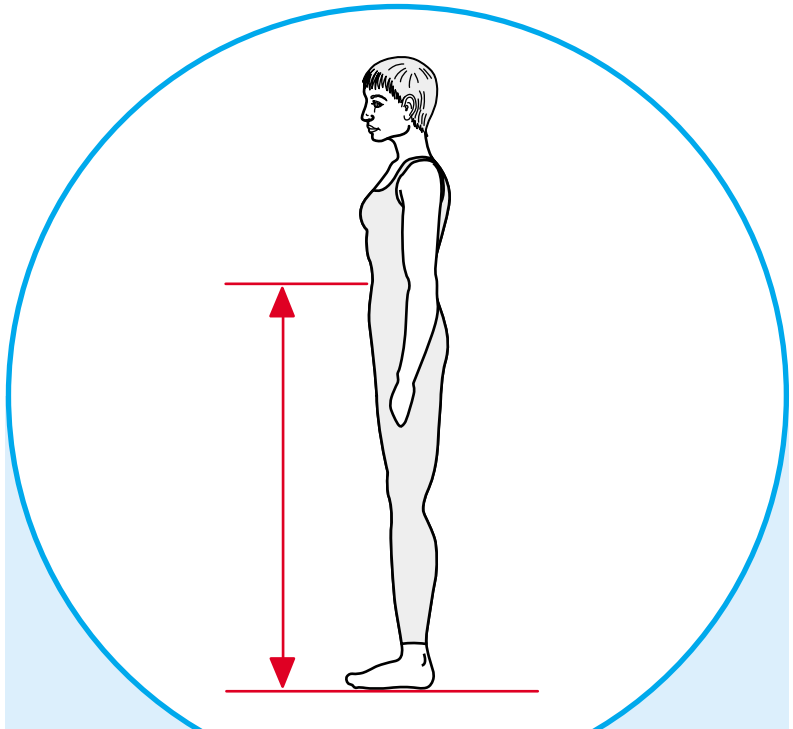
Measured at the natural indentation of the waist.

Waist Height

Measured vertically from the floor to the level of the natural waist.
The person stands erect, heels together, weight evenly balanced.

Percentile	mm
1	946.0
5	958.5
10	979.6
15	989.8
20	999.2
25	1010.0
30	1015.0
35	1025.0
40	1035.0
45	1043.0
50	1050.0
55	1054.0
60	1060.0
65	1065.3
70	1072.0
75	1079.0
80	1086.2
85	1093.3
90	1104.0
95	1118.0
99	1158.2

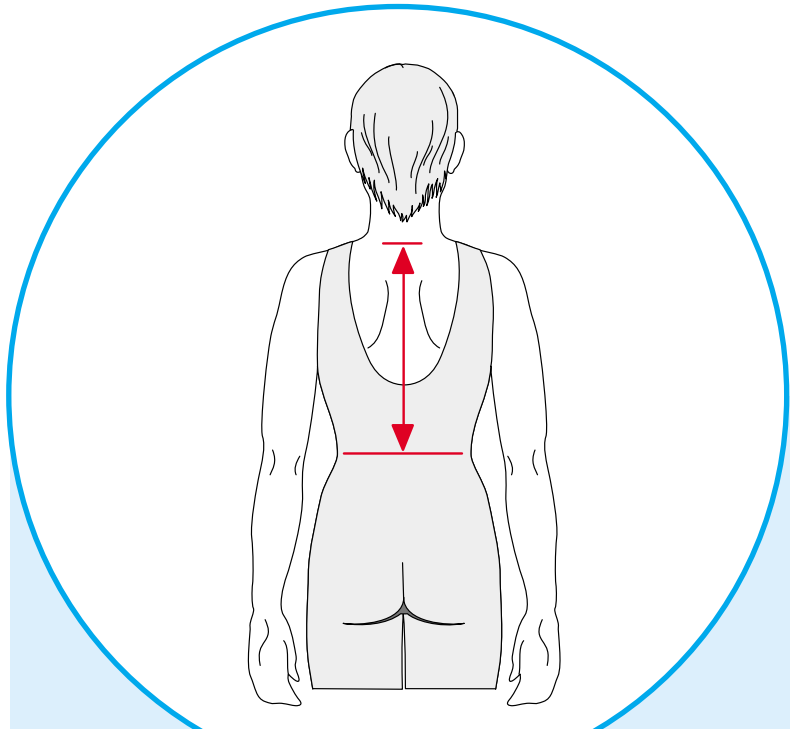
	mm
Maximum	1196
Minimum	901
Range	295
Mean value	1045.4
Standard deviation	49.7
SE (Mean)	2.8
Coefficient of variation =	4.8
No subjects =	316



Waist-Back Height

Percentile	mm
1	322.3
5	335.7
10	341.0
15	346.7
20	350.0
25	354.0
30	355.4
35	359.0
40	361.0
45	363.0
50	364.0
55	366.0
60	369.0
65	371.0
70	372.0
75	377.0
80	378.0
85	382.0
90	386.6
95	395.0
99	409.2

	mm
Maximum	421
Minimum	317
Range	104
Mean value	364.3
Standard deviation	17.7
SE (Mean)	1.0
Coefficient of variation =	4.9
No subjects =	315



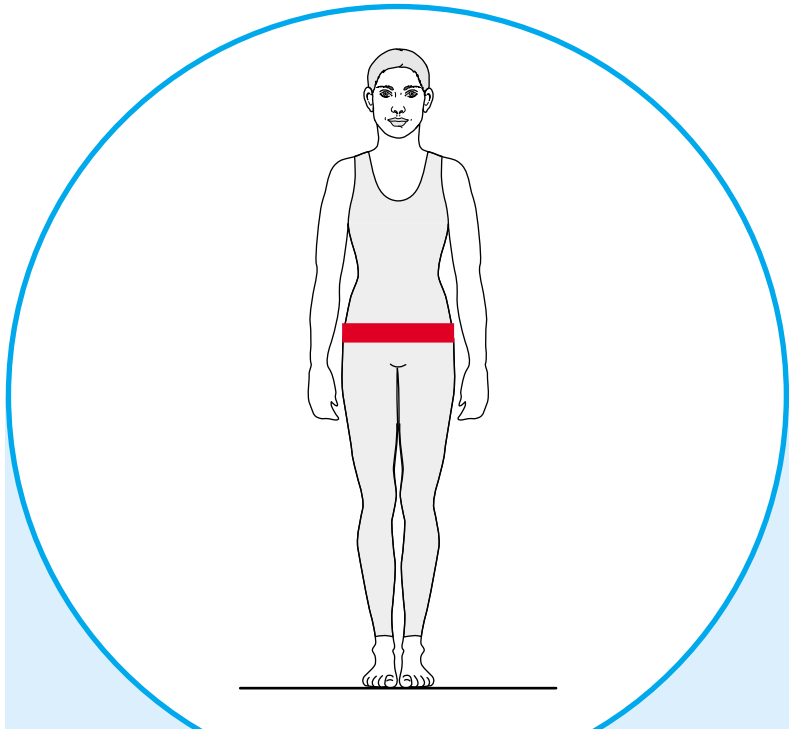
Measured from the prominent bone at the base of the neck (cervicale or C7) to the level of the natural waist. The person stands erect.

Hip Circumference

Measured horizontally around the hips and buttocks at the point of maximum protrusion. The person stands erect, feet together, arms held away from the sides.

Percentile	mm
1	896.4
5	934.7
10	954.2
15	965.0
20	971.0
25	980.5
30	992.4
35	998.0
40	1008.4
45	1015.0
50	1027.0
55	1036.0
60	1041.0
65	1049.0
70	1054.0
75	1065.0
80	1071.4
85	1085.9
90	1108.8
95	1135.5
99	1208.2

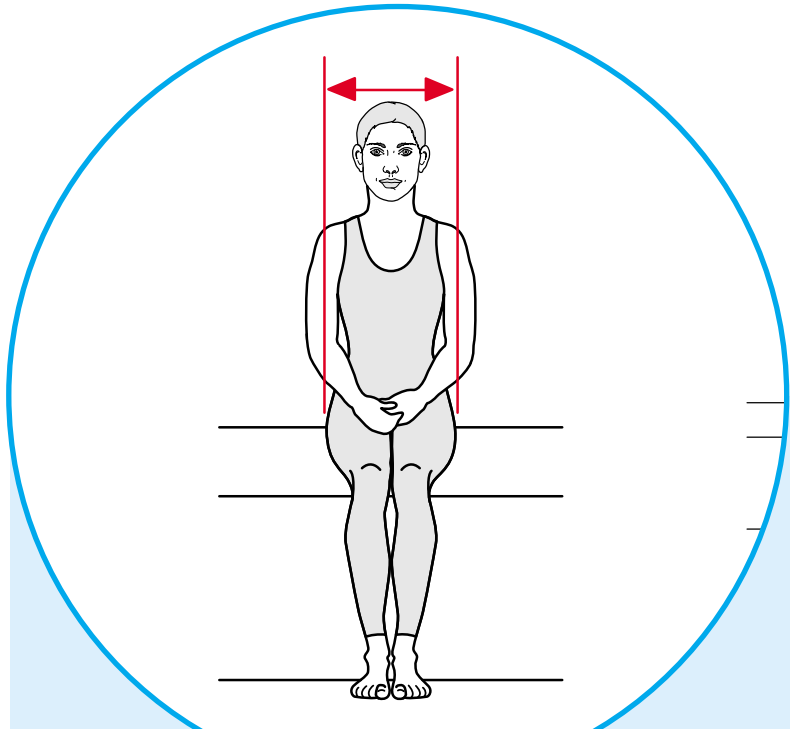
	mm
Maximum	1244.0
Minimum	886.0
Range	358.0
Mean value	1028.5
Standard deviation	62.8
SE (Mean)	3.5
Coefficient of variation =	6.1%
No subjects =	315



Hip Breadth - sitting (max)

Percentile	mm
1	357.1
5	371.9
10	379.0
15	385.0
20	391.0
25	396.0
30	400.0
35	402.0
40	405.8
45	408.0
50	411.0
55	415.0
60	419.0
65	422.0
70	427.0
75	429.3
80	437.0
85	444.0
90	448.0
95	461.5
99	479.4

	mm
Maximum	489
Minimum	351
Range	138
Mean value	413.1
Standard deviation	26.8
SE (Mean)	1.5
Coefficient of variation =	6.5
No subjects =	311



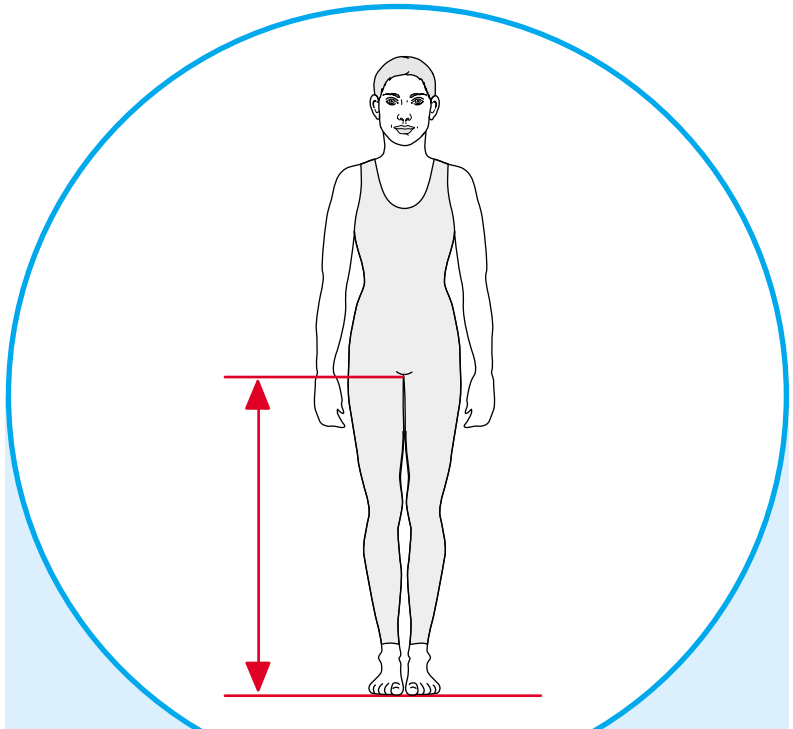
Measured horizontally across the widest part of the hips. The subject sits erect with the legs and feet together.

Crotch Height

Measured vertically from the floor to the crotch. Subject stands erect, legs very slightly apart. Subject holds end of device to just make contact with soft tissue. The subject's feet should then be brought together.

Percentile	mm
1	675.4
5	704.0
10	714.1
15	724.0
20	731.8
25	738.0
30	744.1
35	749.0
40	754.0
45	759.0
50	764.0
55	769.0
60	774.0
65	778.0
70	783.0
75	788.5
80	796.6
85	805.6
90	821.5
95	832.3
99	853.1

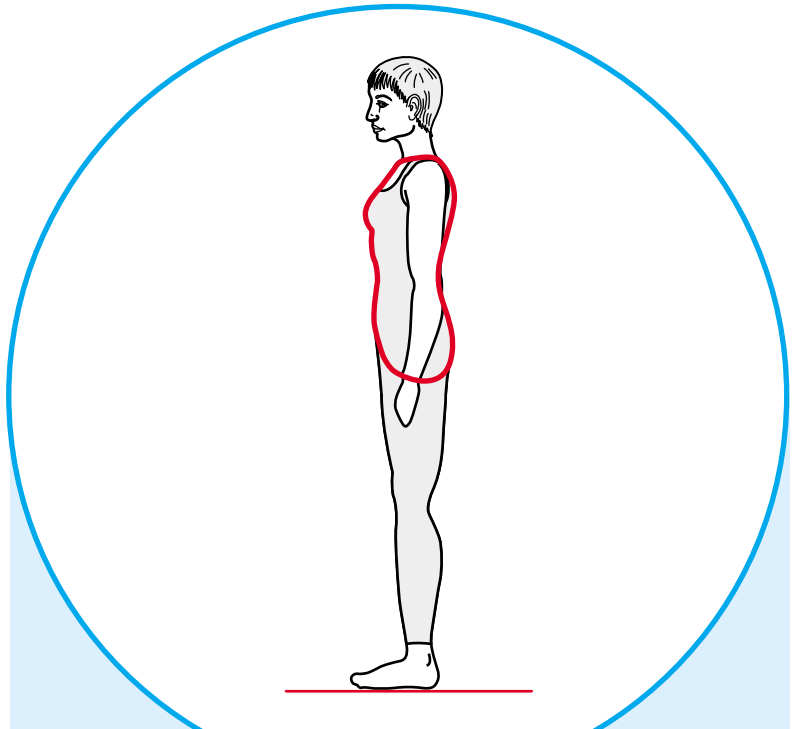
	mm
Maximum	872
Minimum	644
Range	228
Mean value	765.3
Standard deviation	39.3
SE (Mean)	2.2
Coefficient of variation =	5.1
No subjects =	314



Vertical Trunk Circumference

Percentile	mm
1	1498.2
5	1527.3
10	1548.0
15	1568.0
20	1578.0
25	1588.0
30	1595.0
35	1602.0
40	1609.0
45	1615.1
50	1621.5
55	1628.0
60	1635.0
65	1650.0
70	1659.1
75	1668.0
80	1680.0
85	1699.0
90	1715.1
95	1737.6
99	1800.4

	mm
Maximum	1809.0
Minimum	1490.0
Range	319.0
Mean value	1627.5
Standard deviation	63.3
SE (Mean)	3.6
Coefficient of variation =	3.9%
No subjects =	308



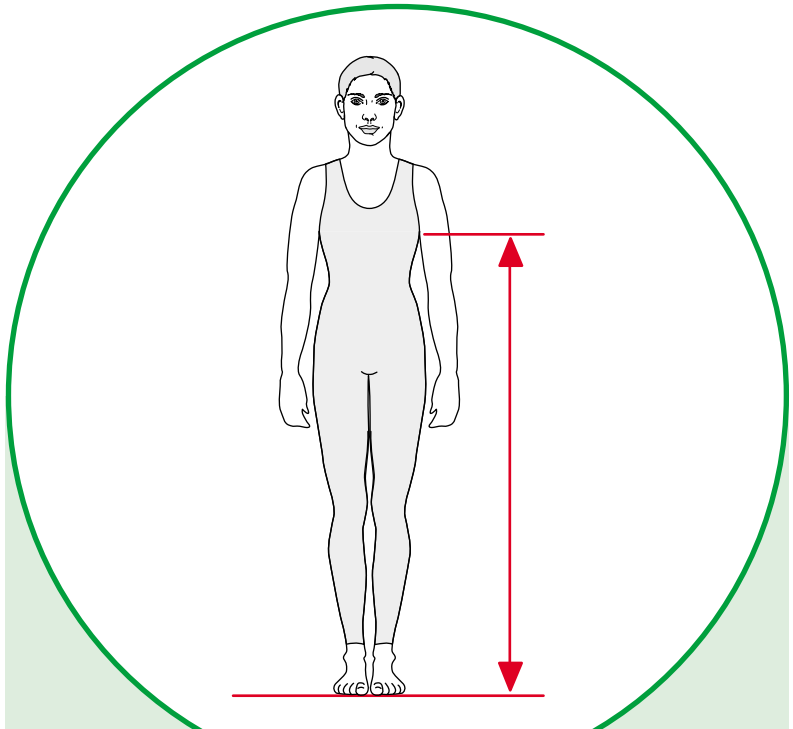
Measured along the surface from the mid-shoulder, down over the nipple, under the crotch, up over the buttock protrusion and back to the shoulder. The subject stands erect, legs slightly apart, weight balanced.

Axilla (armpit) Height Standing

Measured vertically from the floor to just under the muscle that borders the front of the armpit (axilla). The subject stands erect, looking ahead with the arms relaxed at the side and the weight evenly balanced

Percentile	mm
1	1132.2
5	1161.4
10	1174.0
15	1184.9
20	1196.0
25	1204.0
30	1214.0
35	1224.4
40	1230.0
45	1235.0
50	1240.0
55	1246.0
60	1254.0
65	1261.0
70	1268.0
75	1276.0
80	1282.8
85	1293.2
90	1307.9
95	1327.0
99	1371.3

	mm
Maximum	1401.0
Minimum	1101.0
Range	300.0
Mean value	1242.4
Standard deviation	51.9
SE (Mean)	2.9
Coefficient of variation =	4.2%
No subjects =	310

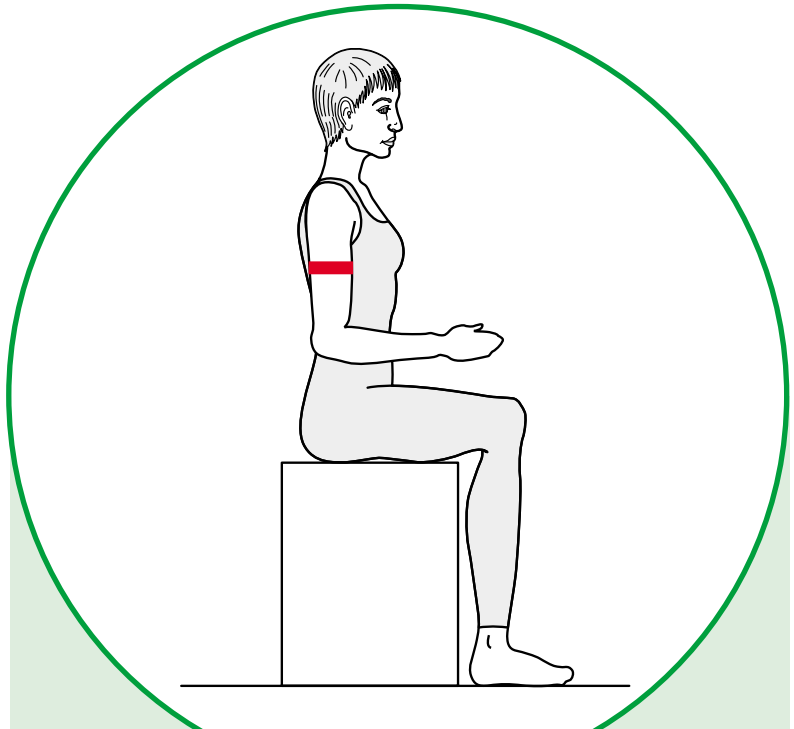


Arms

Arm Circumference

Percentile	mm
1	285.2
5	278.0
10	285.6
15	290.0
20	294.0
25	300.0
30	302.6
35	308.0
40	310.0
45	312.0
50	315.0
55	317.4
60	320.0
65	322.0
70	325.0
75	329.0
80	332.0
85	337.0
90	343.0
95	351.4
99	379.2

	mm
Maximum	393.0
Minimum	219.0
Range	174.0
Mean value	314.2
Standard deviation	24.2
SE (Mean)	1.4
Coefficient of variation =	7.7%
No subjects =	309



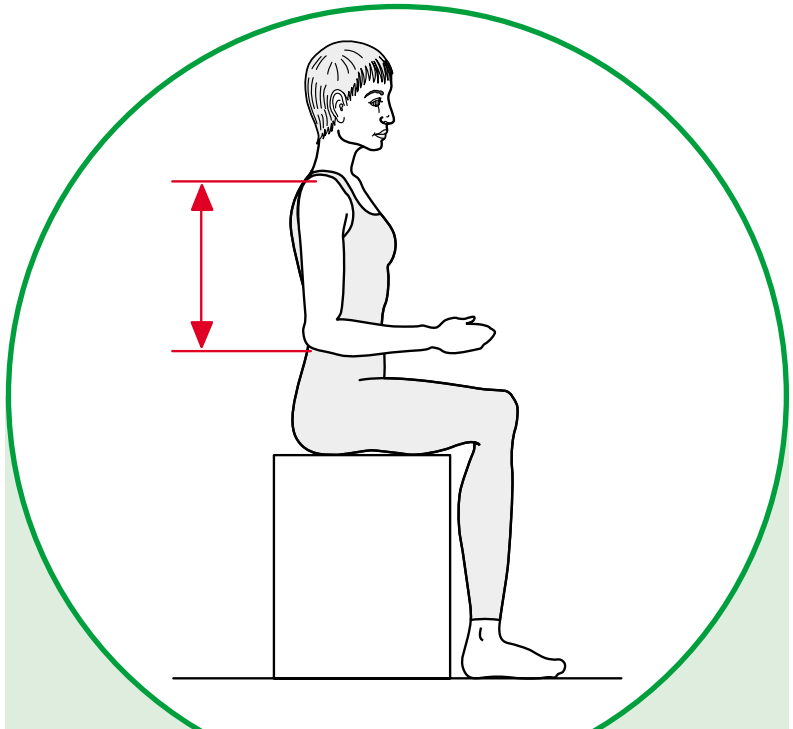
Measured around the midpoint of the upper arm with the elbow bent at 90 degrees and the bicep flexed.

Arms

Shoulder – Elbow Length

Percentile	mm
1	321.3
5	332.7
10	339.2
15	342.0
20	346.0
25	348.0
30	350.0
35	353.0
40	355.0
45	357.0
50	358.0
55	360.0
60	362.0
65	364.7
70	366.0
75	368.0
80	370.8
85	374.0
90	379.0
95	386.0
99	400.0

	mm
Maximum	418.0
Minimum	293.0
Range	125.0
Mean value	358.6
Standard deviation	16.8
SE (Mean)	0.9
Coefficient of variation =	4.7%
No subjects =	315



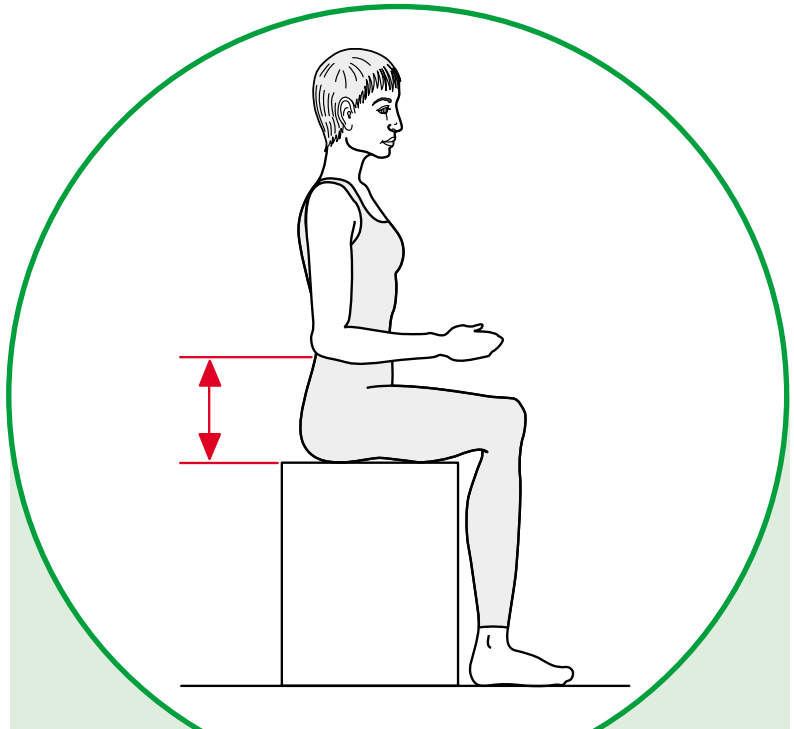
Measured vertically from the bony tip of the shoulder (acromion) to the underside of the elbow. The subject sits with the upper arm vertical, the elbow flexed to 90 degrees, and the palm facing the centre of the body.

Arms

Elbow Rest Height

Percentile	mm
1	192.2
5	211.0
10	219.0
15	223.0
20	229.0
25	233.0
30	237.0
35	240.0
40	243.4
45	246.0
50	251.0
55	253.0
60	256.2
65	259.4
70	265.0
75	268.0
80	272.0
85	276.2
90	282.9
95	292.0
99	309.1

	mm
Maximum	321.0
Minimum	177.0
Range	144.0
Mean value	249.7
Standard deviation	25.2
SE (Mean)	1.4
Coefficient of variation =	10.1%
No subjects =	310



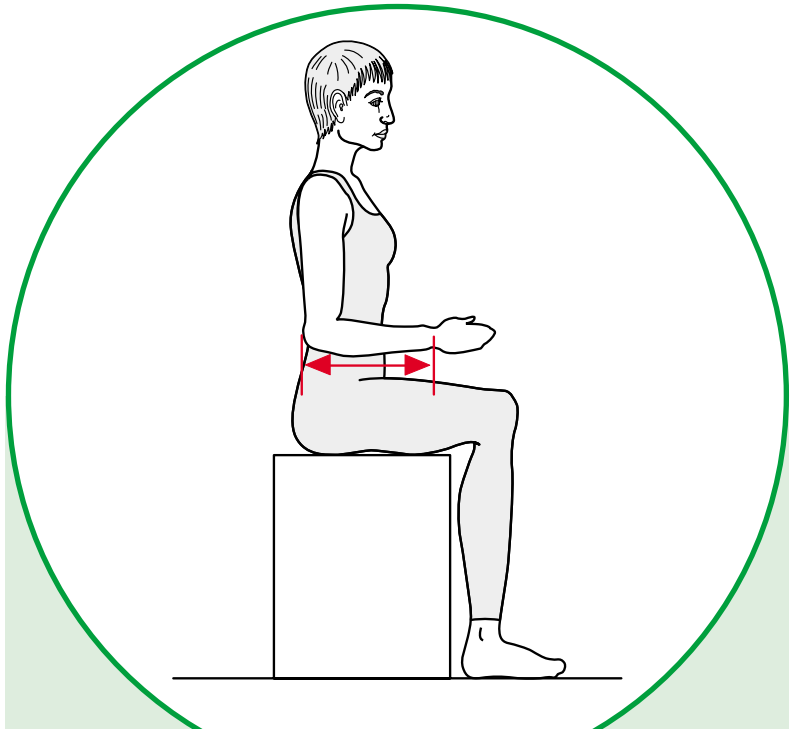
Measured vertically from the seat surface to the underside of the elbow. Subject sits erect, looking straight ahead, the elbow flexed at 90 degrees. Ensure thighs are horizontal.

Elbow – Wrist Length

Measured from the back of the elbow to the bony protrusion on the outside of the wrist (radial styloid process). The subject sits with the upper arm vertical, the elbow flexed to 90 degrees and the palm facing the centre of the body.

Percentile	mm
1	232.2
5	239.0
10	244.0
15	246.8
20	248.2
25	251.0
30	253.0
35	256.0
40	257.0
45	259.0
50	260.0
55	262.0
60	263.0
65	265.0
70	266.0
75	268.0
80	270.0
85	272.0
90	275.0
95	285.0
99	291.1

	mm
Maximum	297.0
Minimum	226.0
Range	71.0
Mean value	260.2
Standard deviation	12.9
SE (Mean)	0.7
Coefficient of variation =	4.9%
No subjects =	316

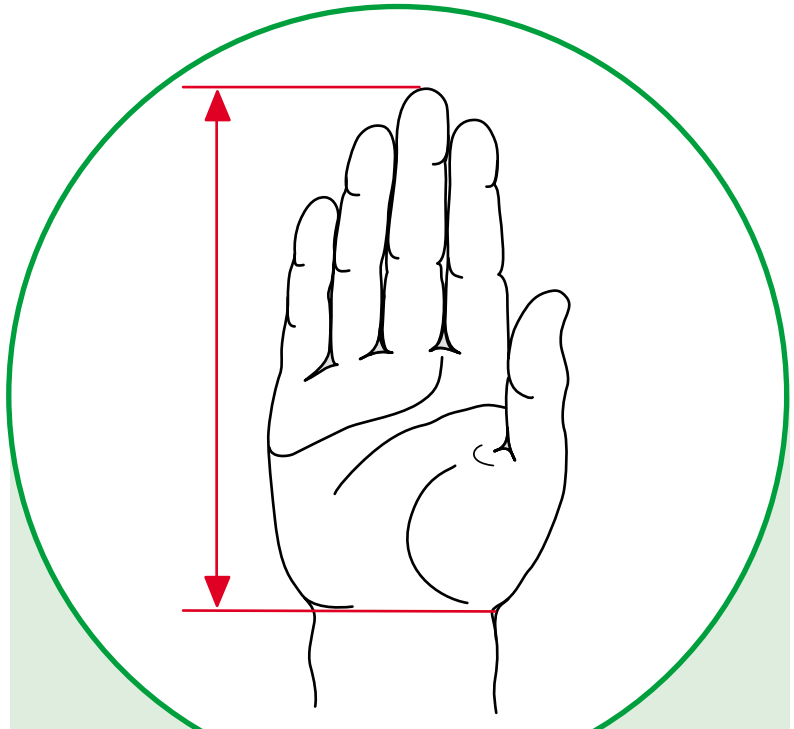


Arms

Hand Length

Percentile	mm
1	161.2
5	166.0
10	169.3
15	171.0
20	174.0
25	175.0
30	176.0
35	177.0
40	178.0
45	179.7
50	180.0
55	182.0
60	182.8
65	183.0
70	184.0
75	185.0
80	187.0
85	188.3
90	191.0
95	193.2
99	200.1

	mm
Maximum	211.0
Minimum	153.0
Range	58.0
Mean value	180.2
Standard deviation	8.5
SE (Mean)	0.5
Coefficient of variation =	4.7%
No subjects =	316



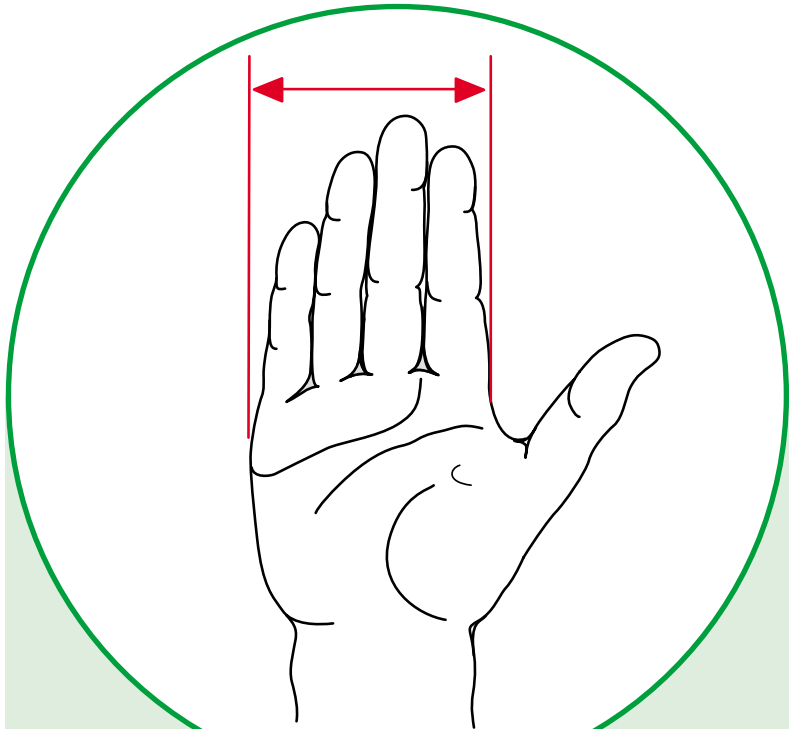
Measured from the wrist crease directly below the pad of the muscle at the base of the thumb (thenar eminence) to the tip of the middle finger. The hand and fingers should be held straight and flat, palm uppermost.

Palm Breadth

Measured at the widest aspect between metacarpal-phalangeal joints II (index finger) and V (little finger). Hand and fingers held straight and the thumb held away (abducted) from the palm.

Percentile	mm
1	74.0
5	77.0
10	79.0
15	80.0
20	80.0
25	81.0
30	81.0
35	82.0
40	82.0
45	83.0
50	83.0
55	84.0
60	84.0
65	85.0
70	85.7
75	86.0
80	86.0
85	87.0
90	88.0
95	89.2
99	92.1

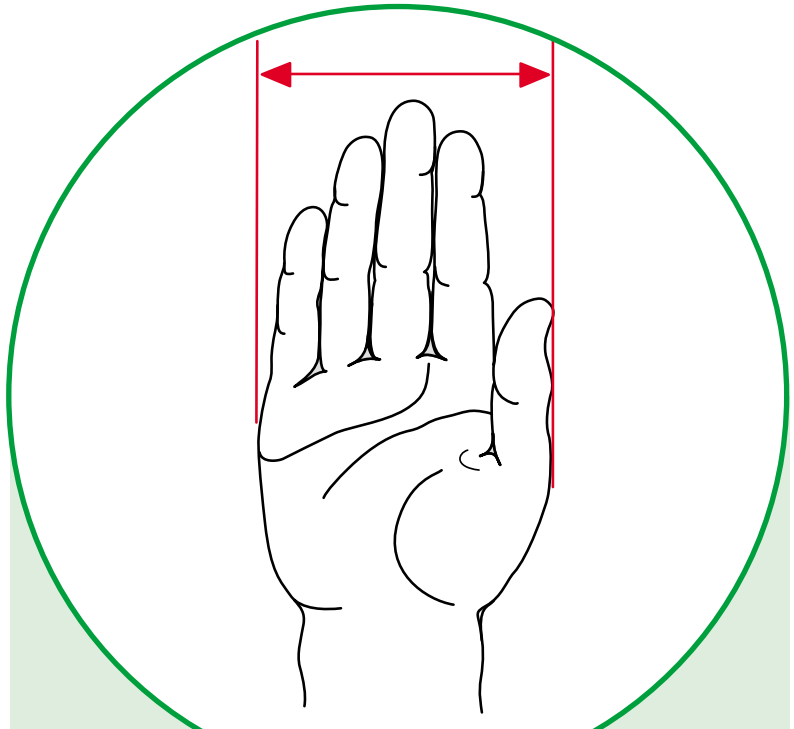
	mm
Maximum	94.0
Minimum	72.0
Range	22.0
Mean value	83.3
Standard deviation	3.9
SE (Mean)	0.2
Coefficient of variation =	4.6%
No subjects =	316



Palm Breadth - max

Percentile	mm
1	85.0
5	87.0
10	90.0
15	90.0
20	91.0
25	91.0
30	92.0
35	93.0
40	93.0
45	94.0
50	95.0
55	95.0
60	96.0
65	96.0
70	97.0
75	98.0
80	98.2
85	99.0
90	101.0
95	102.0
99	105.1

	mm
Maximum	107.0
Minimum	84.0
Range	23.0
Mean value	94.6
Standard deviation	4.5
SE (Mean)	0.3
Coefficient of variation =	4.7%
No subjects =	316



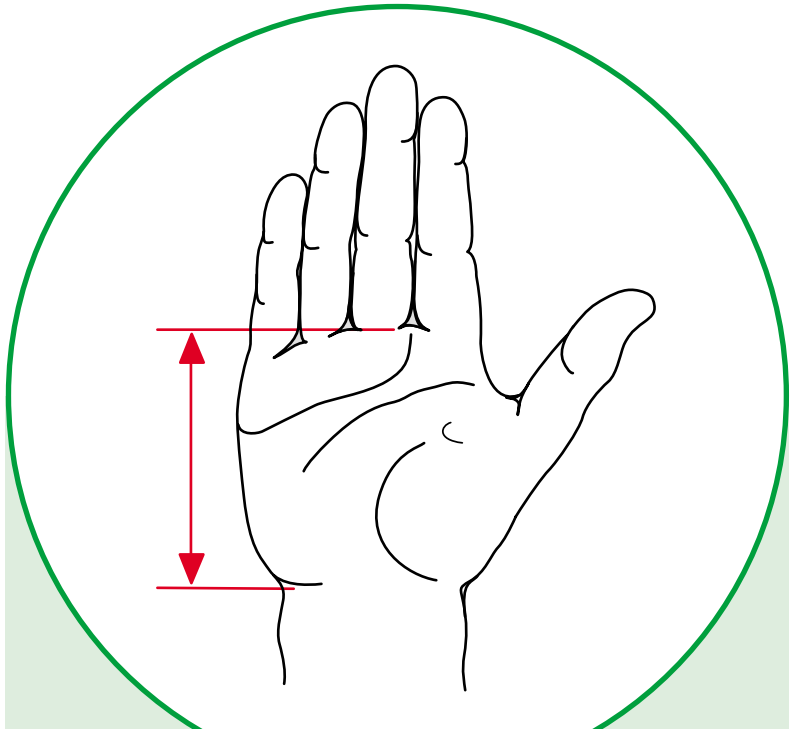
Measured across the palm of the hand at the level of the base of the thumb, including the joint at the base of the thumb.

Palm Length

Measured from the baseline (wrist crease) to the crease between the middle finger and the palm. Hand and fingers held straight and flat. The thumb held away (abducted) from the palm.

Percentile	mm
1	90.2
5	94.0
10	95.0
15	96.8
20	98.0
25	99.0
30	100.0
35	100.0
40	101.0
45	101.0
50	102.0
55	102.0
60	103.0
65	104.0
70	104.0
75	105.0
80	106.0
85	107.0
90	108.3
95	110.0
99	115.0

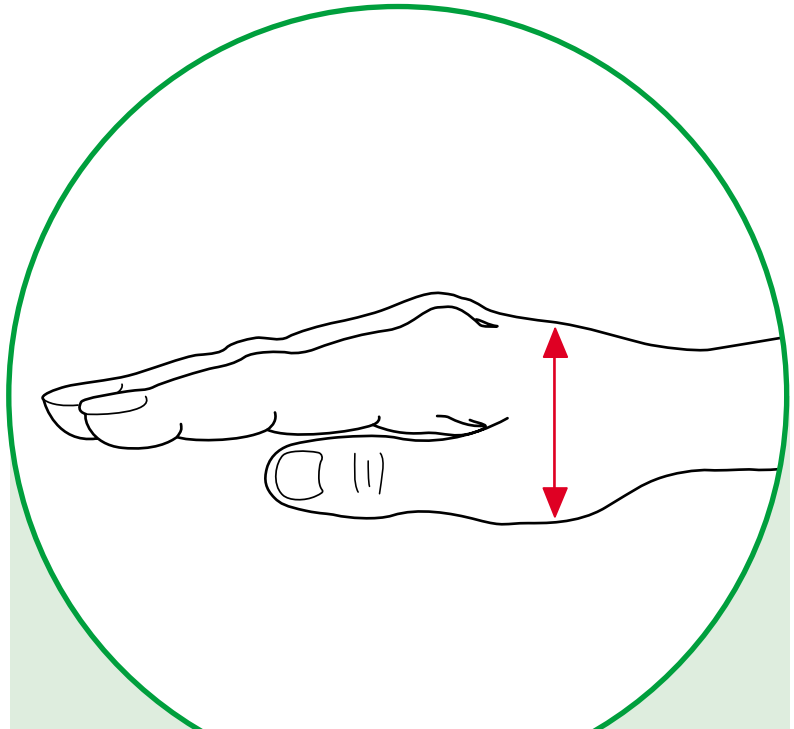
	mm
Maximum	119.0
Minimum	87.0
Range	32.0
Mean value	101.9
Standard deviation	5.1
SE (Mean)	0.3
Coefficient of variation =	5.0%
No subjects =	316



Hand Thickness - max

Percentile	mm
1	40.0
5	43.0
10	45.0
15	45.0
20	47.0
25	48.0
30	48.7
35	49.0
40	50.0
45	50.0
50	51.0
55	51.0
60	52.0
65	52.0
70	52.0
75	53.0
80	54.0
85	54.0
90	56.0
95	56.0
99	59.1

	mm
Maximum	63.0
Minimum	35.0
Range	28.0
Mean value	50.1
Standard deviation	4.2
SE (Mean)	0.2
Coefficient of variation =	8.4%
No subjects =	316



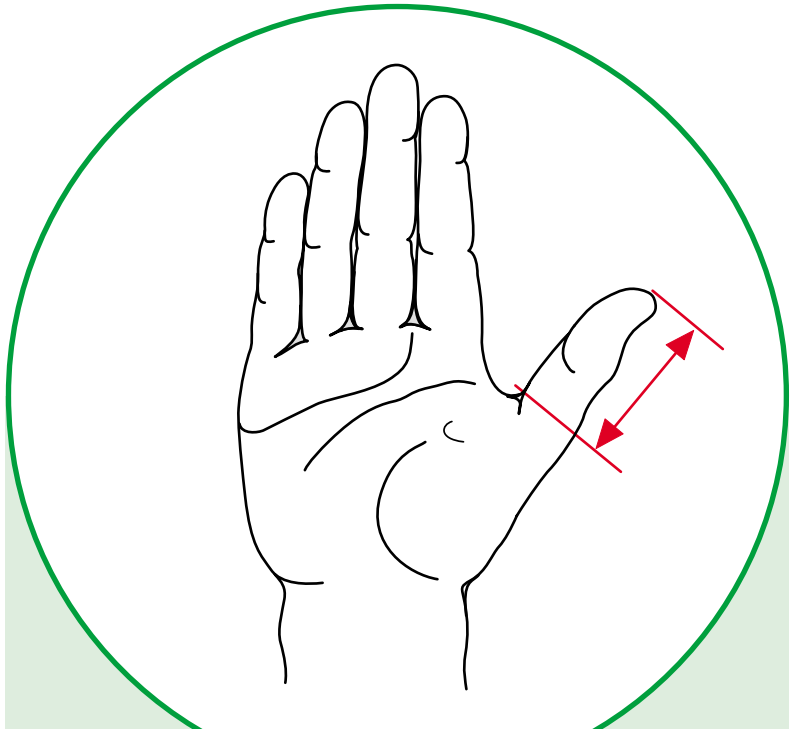
Measured from the pad of muscle at the base of the thumb to the back of the hand. Hand and fingers held straight, with the thumb aligned along the side of the palm. (A maximum measure of flat hand thickness).

Thumb Length

Measured from the tip of the thumb to the base of the thumb at the level of the skin web between it and the index finger. Thumb held straight out from palm.

Percentile	mm
1	46.0
5	48.0
10	50.0
15	51.0
20	51.0
25	52.0
30	52.0
35	53.0
40	54.0
45	54.0
50	55.0
55	55.0
60	56.0
65	56.0
70	56.0
75	57.0
80	58.0
85	59.0
90	60.0
95	61.2
99	63.1

	mm
Maximum	65
Minimum	44
Range	21
Mean value	54.8
Standard deviation	3.9
SE (Mean)	0.2
Coefficient of variation =	7.2%
No subjects =	316

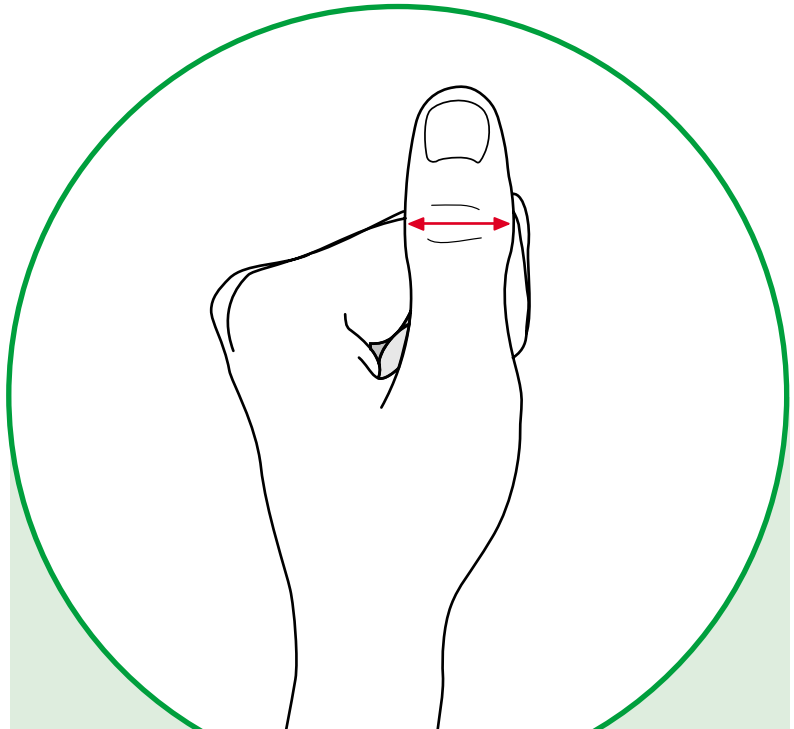


Arms

Thumb Width

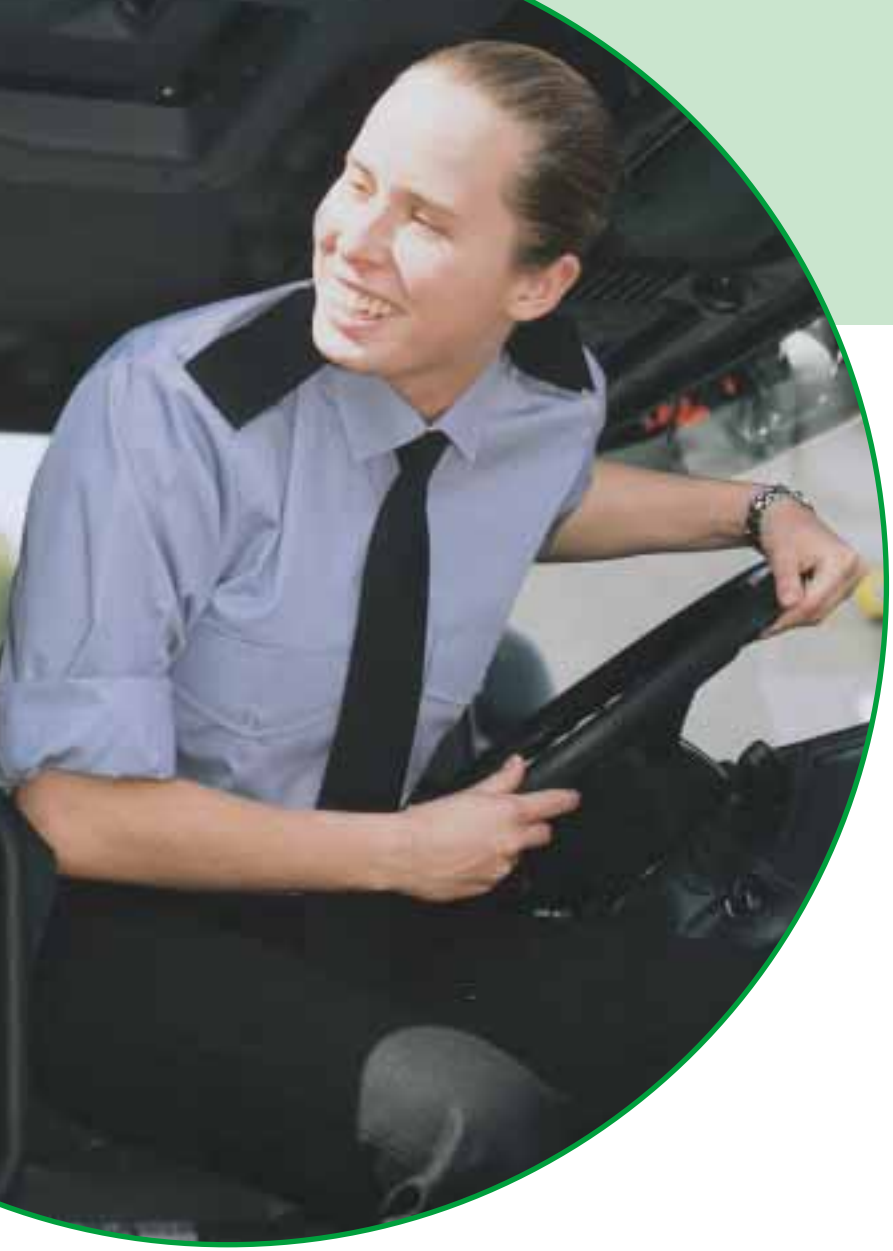
Percentile	mm
1	18.0
5	19.0
10	19.2
15	20.0
20	20.0
25	20.0
30	20.0
35	20.0
40	20.0
45	20.0
50	21.0
55	21.0
60	21.0
65	21.0
70	21.0
75	21.0
80	22.0
85	22.0
90	22.0
95	22.3
99	23.0

	mm
Maximum	25.0
Minimum	17.0
Range	8.0
Mean value	20.6
Standard deviation	1.1
SE (Mean)	0.06
Coefficient of variation =	5.3%
No subjects =	315



Measured across the broadest part of the thumb joint. Thumb held straight.

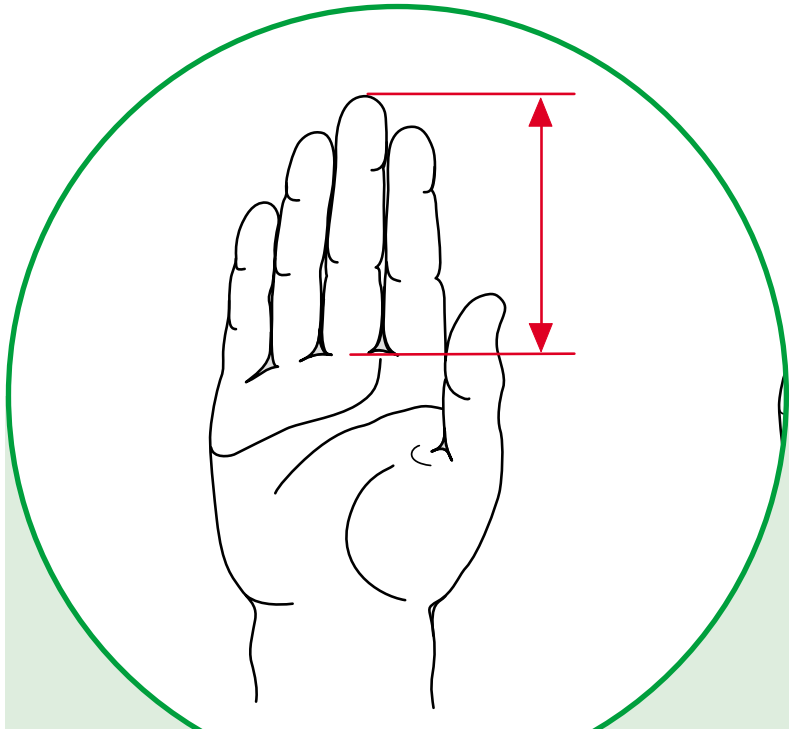
Finger Length – Middle Finger



Measured from the tip of the middle finger to the skin crease at the base of the finger, parallel to its long axis. The hands and fingers should be held straight and flat, palm uppermost.

Percentile	mm
1	67.0
5	71.0
10	73.0
15	74.0
20	75.0
25	76.0
30	76.0
35	76.0
40	77.0
45	78.0
50	78.0
55	79.0
60	79.0
65	80.0
70	80.0
75	81.0
80	81.0
85	82.0
90	84.0
95	85.0
99	89.1

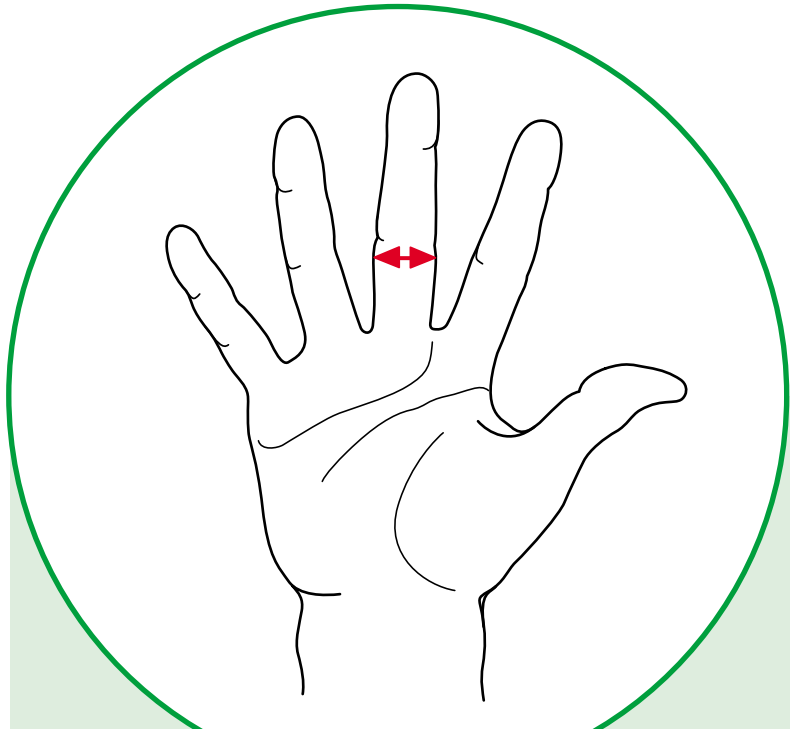
	mm
Maximum	94.0
Minimum	65.0
Range	29.0
Mean value	78.1
Standard deviation	4.3
SE (Mean)	0.2
Coefficient of variation =	5.5%
No subjects =	315



FInger Width – Middle Finger

Percentile	mm
1	17.0
5	17.0
10	18.0
15	18.0
20	18.0
25	18.0
30	18.0
35	19.0
40	19.0
45	19.0
50	19.0
55	19.0
60	19.0
65	19.0
70	20.0
75	20.0
80	20.0
85	20.0
90	20.0
95	21.0
99	21.0

	mm
Maximum	22.0
Minimum	16.0
Range	6.0
Mean value	19.0
Standard deviation	1.0
SE (Mean)	0.05
Coefficient of variation =	5.4%
No subjects =	315



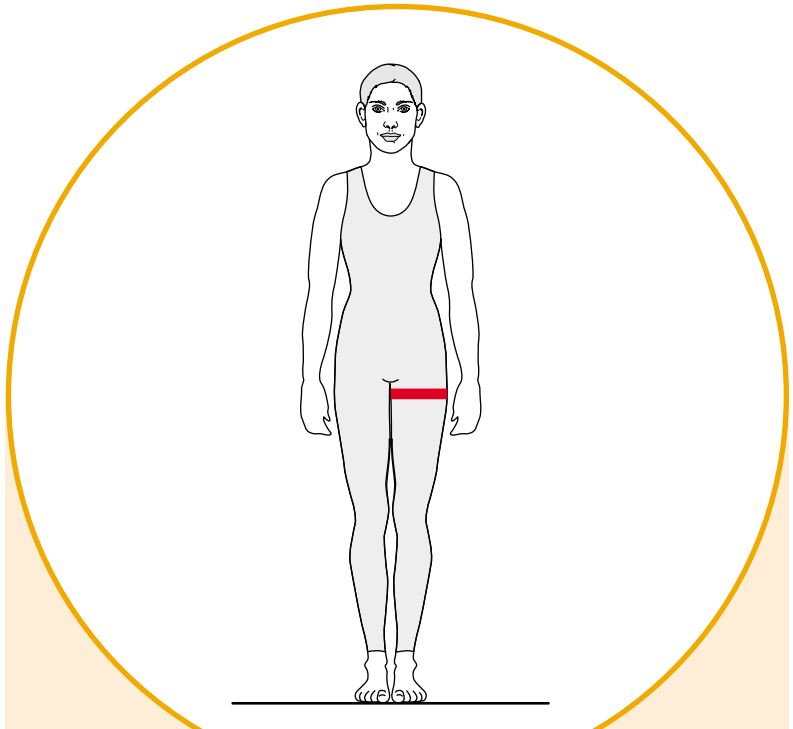
Measured across the broadest part of the middle joint (proximal joint) of the middle finger. Finger held straight.

Thigh Circumference

Measured horizontally around the thigh immediately below the fold of the buttock. The person stands erect, legs slightly apart, weight evenly balanced.

Percentile	mm
1	470.1
5	512.7
10	530.2
15	544.7
20	553.0
25	561.0
30	570.0
35	574.5
40	582.0
45	586.3
50	592.0
55	597.0
60	602.2
65	610.0
70	618.0
75	624.3
80	635.4
85	642.5
90	658.4
95	676.5
99	717.1

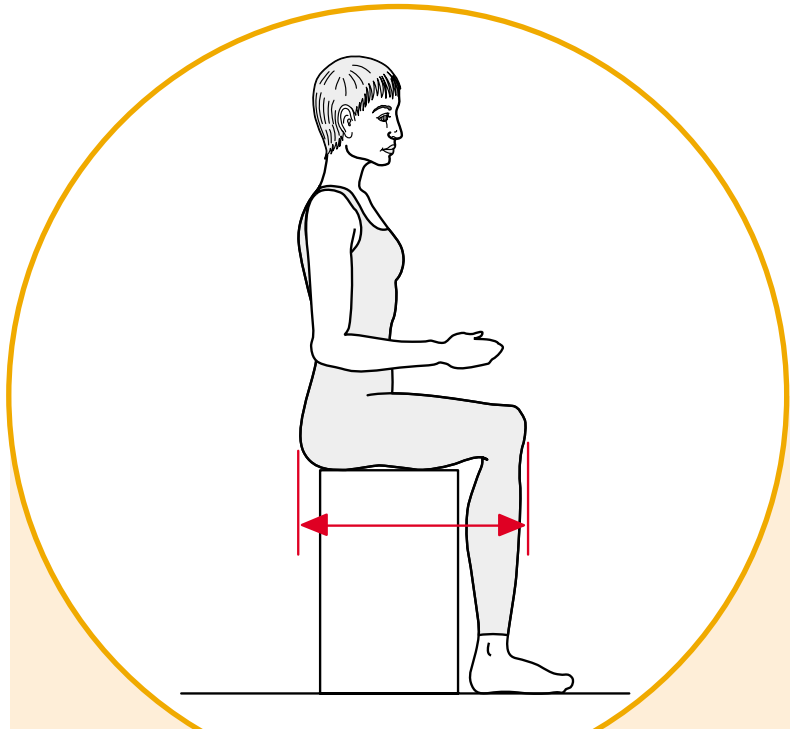
	mm
Maximum	736.0
Minimum	418.0
Range	318.0
Mean value	592.7
Standard deviation	50.2
SE (Mean)	2.8
Coefficient of variation =	8.5%
No subjects =	315



Buttock to Front of Knee

Percentile	mm
1	548.2
5	563.0
10	568.0
15	572.0
20	574.0
25	580.0
30	584.0
35	586.0
40	588.0
45	592.0
50	594.0
55	597.0
60	601.0
65	606.0
70	609.0
75	613.3
80	617.0
85	623.0
90	632.6
95	640.5
99	654.1

	mm
Maximum	666.0
Minimum	534.0
Range	132.0
Mean value	597.4
Standard deviation	24.5
SE (Mean)	1.4
Coefficient of variation =	4.1%
No subjects =	310



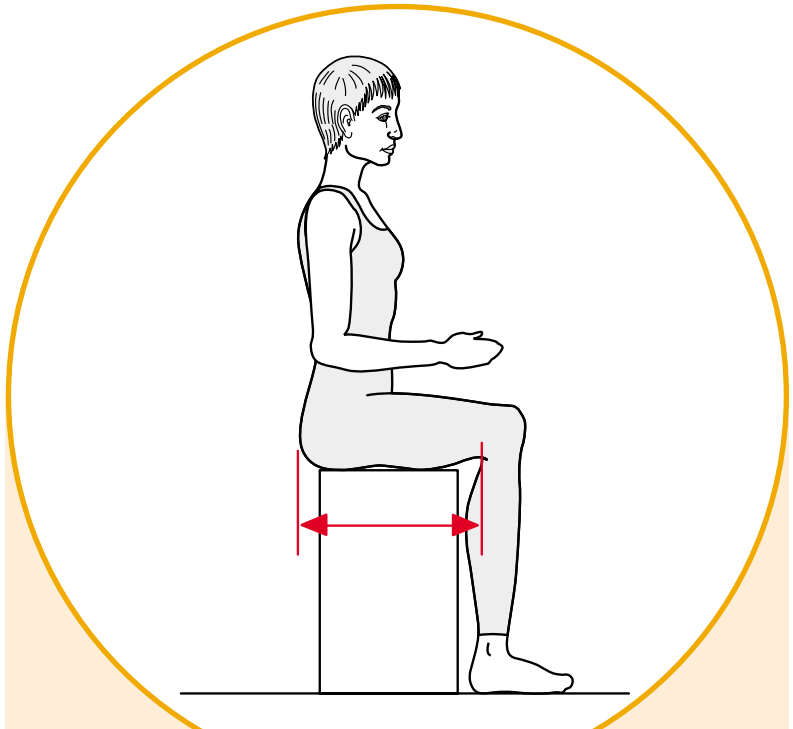
Measured horizontally from the most posterior part of the buttock to the front of the knee (patella). The seat should be adjusted so that the person can sit with the lower legs vertical, thighs horizontal and feet flat.

Legs

Buttock to Back of Knee

Percentile	mm
1	446.1
5	459.0
10	466.7
15	472.0
20	475.0
25	479.0
30	481.0
35	485.0
40	487.0
45	489.0
50	492.0
55	495.0
60	498.0
65	501.0
70	505.2
75	510.0
80	514.2
85	520.1
90	529.0
95	536.5
99	547.3

	mm
Maximum	562.0
Minimum	438.0
Range	124.0
Mean value	494.5
Standard deviation	23.1
SE (Mean)	1.3
Coefficient of variation =	4.7%
No subjects =	310



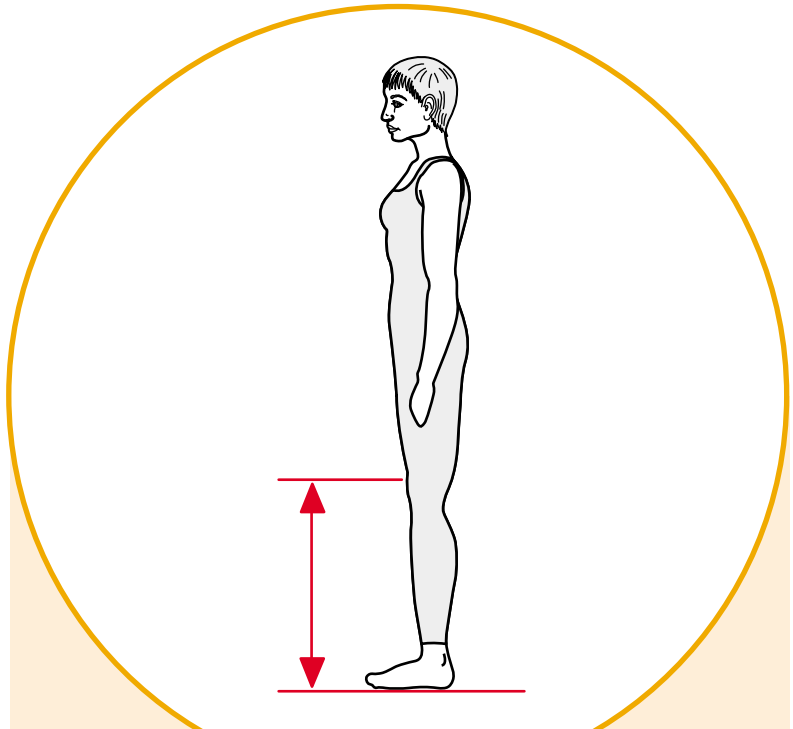
Measured horizontally from the most posterior part of the buttock to the back of the knee (popliteal fossa). The seat should be adjusted so that the person can sit with the lower legs vertical, thighs horizontal and feet flat.

Legs

Knee Height

Percentile	mm
1	436.0
5	445.6
10	455.0
15	462.0
20	465.0
25	468.0
30	472.0
35	477.0
40	478.4
45	481.0
50	484.0
55	486.0
60	490.0
65	492.0
70	495.0
75	500.0
80	504.0
85	507.0
90	513.4
95	521.0
99	542.6

	mm
Maximum	554.0
Minimum	427.0
Range	127.0
Mean value	484.8
Standard deviation	23.5
SE (Mean)	1.3
Coefficient of variation =	4.8%
No subjects =	313



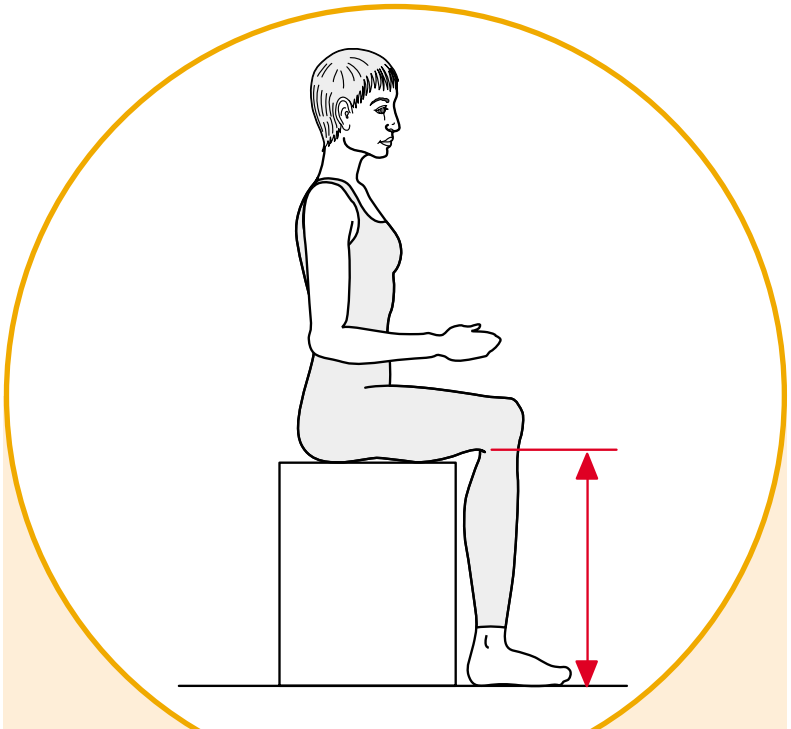
Measured vertically from the floor to the upper border of the knee-cap (patella). The person stands erect with the legs together.

Back of Knee Height Sitting

Measured vertically from the floor to the popliteal tendon, which extends back from the knee along the lower, outer part of the thigh. Ensure thighs are horizontal.

Percentile	mm
1	349.0
5	362.0
10	367.7
15	371.0
20	377.0
25	380.0
30	381.0
35	384.0
40	385.0
45	388.0
50	391.0
55	392.9
60	396.0
65	398.0
70	400.5
75	403.5
80	408.0
85	411.0
90	414.0
95	418.0
99	434.1

	mm
Maximum	436.0
Minimum	331.0
Range	105.0
Mean value	390.9
Standard deviation	18.5
SE (Mean)	1.0
Coefficient of variation =	4.7%
No subjects =	310

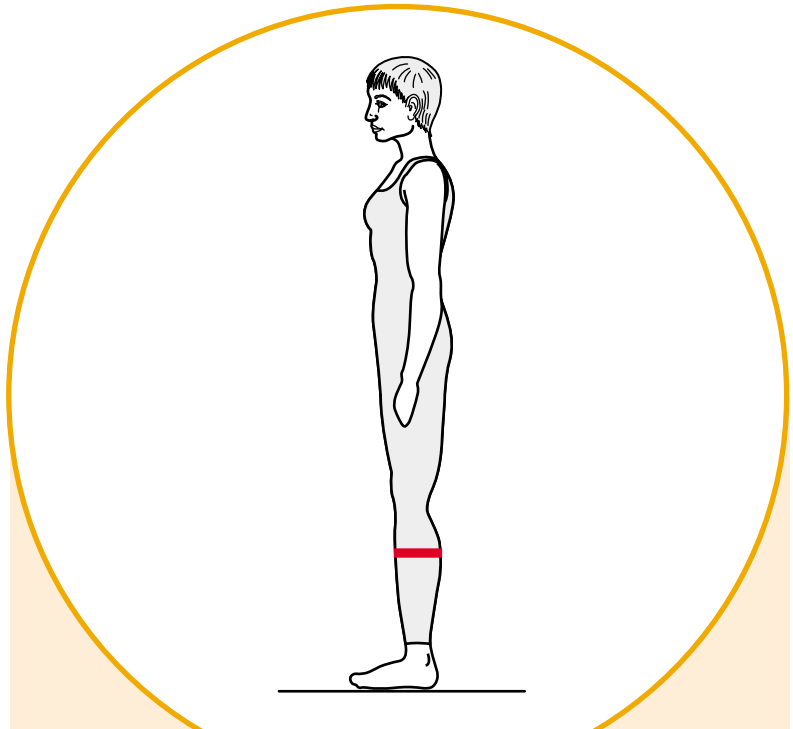


Legs

Calf Circumference

Percentile	mm
1	325.0
5	334.0
10	340.0
15	343.4
20	349.0
25	352.0
30	355.0
35	360.0
40	362.0
45	365.0
50	368.0
55	370.0
60	371.0
65	375.0
70	379.6
75	382.0
80	387.0
85	391.0
90	398.0
95	411.0
99	426.7

	mm
Maximum	455.0
Minimum	308.0
Range	147.0
Mean value	368.8
Standard deviation	23.3
SE (Mean)	1.3
Coefficient of variation =	6.3%
No subjects =	313



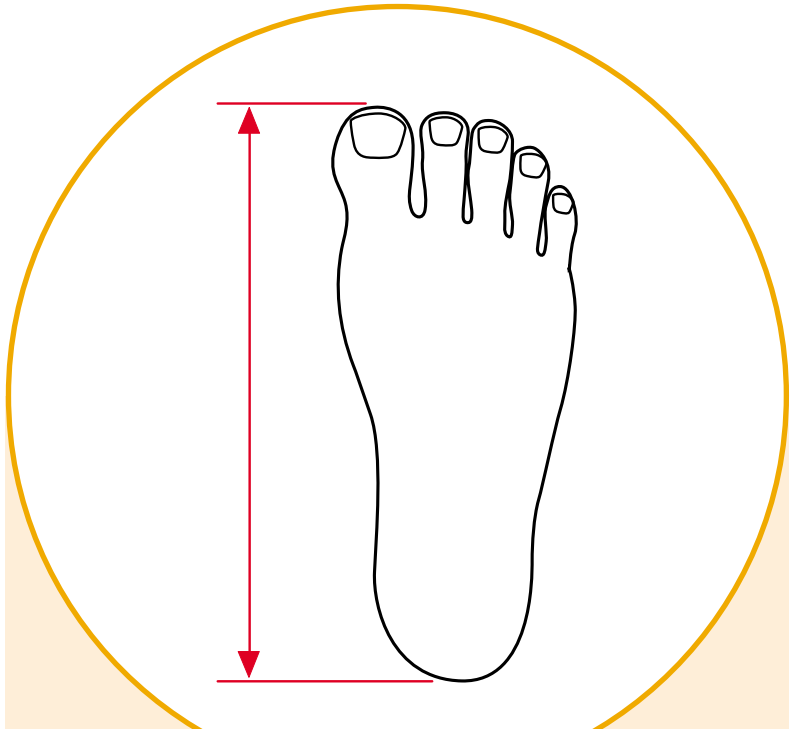
Measured around the point of maximum calf circumference in a plane perpendicular to the long axis of the leg. The person stands with the weight evenly distributed between both legs.

Legs

Foot Length

Percentile	mm
1	218.5
5	228.0
10	231.0
15	234.0
20	236.0
25	239.0
30	240.0
35	242.0
40	243.0
45	245.0
50	246.0
55	248.0
60	249.0
65	251.0
70	252.0
75	253.0
80	256.0
85	259.0
90	261.0
95	266.0
99	279.0

	mm
Maximum	281.0
Minimum	211.0
Range	70.0
Mean value	246.3
Standard deviation	11.9
SE (Mean)	0.7
Coefficient of variation =	4.8%
No subjects =	316



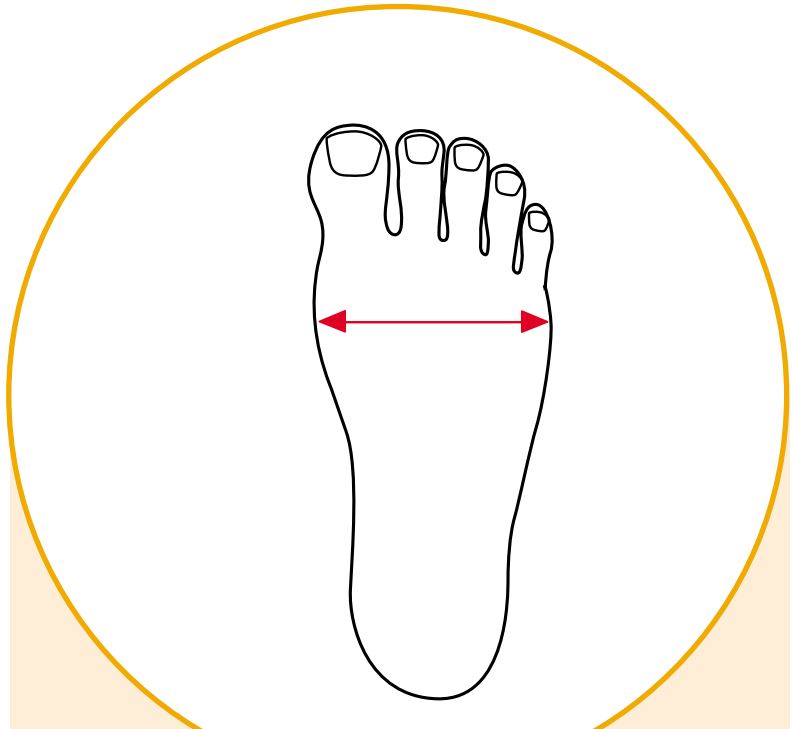
Measured horizontally from the tip of the longest toe to the back of the heel. The person stands erect with their weight evenly balanced on both feet, which are placed approximately 100mm apart.

Legs

Foot Breadth

Percentile	mm
1	85.0
5	87.0
10	89.0
15	90.0
20	90.0
25	91.0
30	92.0
35	92.0
40	93.0
45	94.0
50	94.0
55	94.2
60	95.0
65	96.0
70	97.0
75	98.0
80	99.0
85	100.0
90	101.0
95	103.0
99	108.0

	mm
Maximum	111
Minimum	84
Range	27
Mean value	94.5
Standard deviation	5.0
SE (Mean)	0.3
Coefficient of variation =	5.3%
No subjects =	316



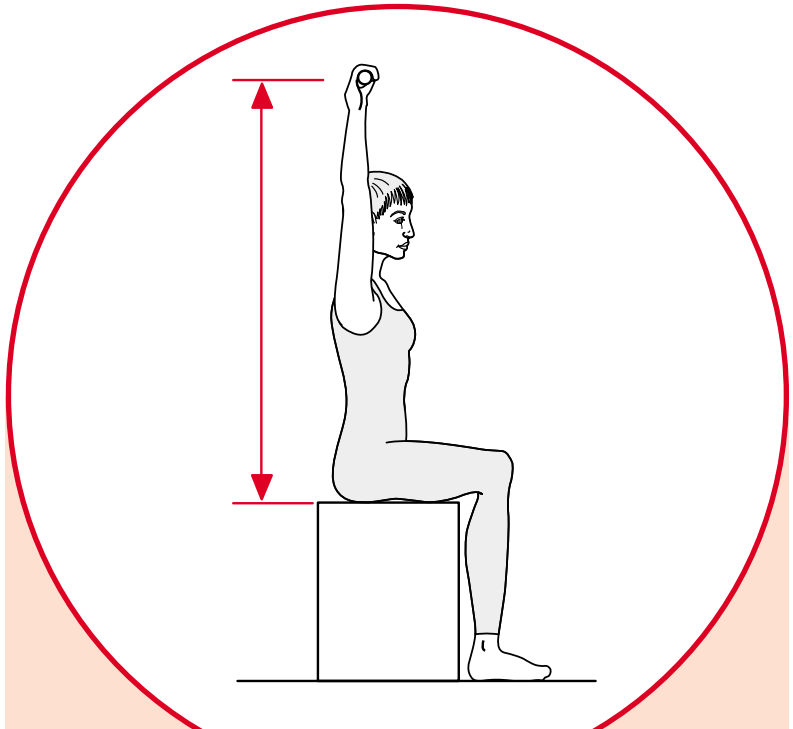
Measured horizontally across widest part of the foot, perpendicular to the length of the foot. This is usually at the medial point of the metatarsal-phalangeal joint (where the toes begin). Subject stands with feet approximately 100mm apart.

Functional Anthropometry

Overhead Grip Reach Sitting

Percentile	mm
1	1116.0
5	1137.9
10	1155.8
15	1170.1
20	1180.0
25	1185.3
30	1195.0
35	1202.0
40	1208.8
45	1215.0
50	1219.0
55	1225.0
60	1230.8
65	1237.1
70	1245.2
75	1251.0
80	1259.2
85	1270.1
90	1286.0
95	1308.9
99	1340.4

	mm
Maximum	1419.0
Minimum	1075.0
Range	344.0
Mean value	1221.0
Standard deviation	51.3
SE (Mean)	2.9
Coefficient of variation =	4.2%
No subjects =	311



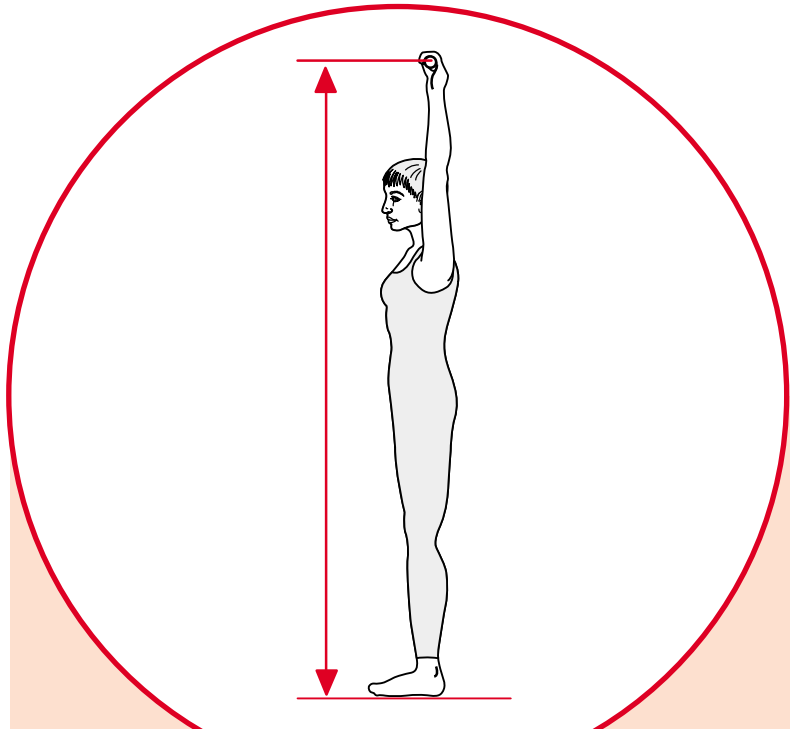
Measured vertically from the seat surface to the centre of a rod gripped horizontally in the hands. The person sits erect, looking ahead, with the arms extended straight above the head.

Functional Anthropometry

Overhead Grip Reach Standing

Percentile	mm
1	1864.2
5	1891.4
10	1919.2
15	1941.8
20	1957.8
25	1971.0
30	1982.0
35	1992.0
40	2000.4
45	2010.0
50	2022.0
55	2032.0
60	2042.0
65	2050.0
70	2059.0
75	2070.5
80	2079.4
85	2096.2
90	2127.7
95	2170.0
99	2233.0

	mm
Maximum	2294.0
Minimum	1750.0
Range	544.0
Mean value	2023.9
Standard deviation	82.2
SE (Mean)	4.7
Coefficient of variation =	4.1%
No subjects =	309



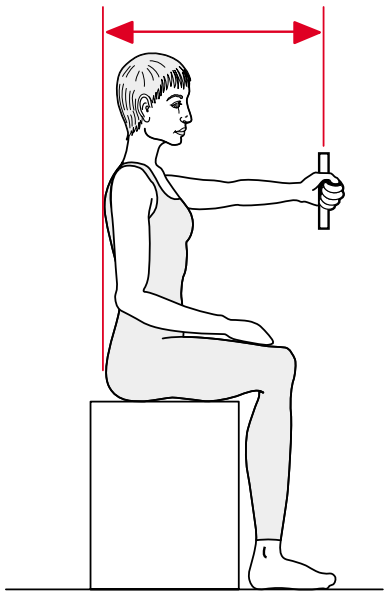
Measured vertically from the floor to the centre of a rod gripped horizontally in the hands. The person stands erect, weight evenly balanced, with the arms extended vertically above the head.

Functional Anthropometry

Forward Grip Reach

Percentile	mm
1	626.6
5	647.4
10	660.6
15	669.8
20	679.8
25	687.0
30	691.6
35	696.4
40	699.0
45	703.0
50	708.0
55	713.0
60	716.6
65	722.0
70	729.0
75	732.0
80	739.0
85	747.0
90	756.0
95	770.0
99	790.1

	mm
Maximum	812
Minimum	613
Range	199
Mean value	708.9
Standard deviation	36.5
SE (Mean)	2.1
Coefficient of variation =	5.1%
No subjects =	309



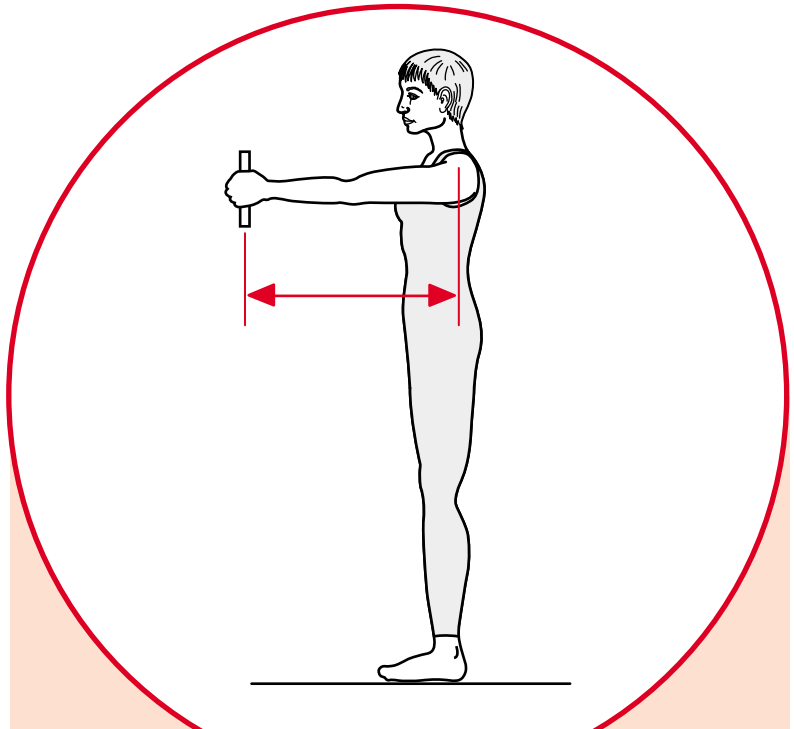
Measured horizontally from the wall to the centre of a rod gripped vertically in the hand. The subject stands or sits erect, the arm stretched horizontally in front of them.

Functional Anthropometry

Acromion to Grip Length

Percentile	mm
1	574.3
5	591.4
10	600.6
15	608.8
20	615.8
25	620.8
30	624.0
35	626.0
40	628.0
45	629.6
50	633.0
55	635.4
60	638.0
65	643.0
70	648.0
75	650.0
80	657.0
85	663.0
90	671.0
95	680.2
99	695.6

	mm
Maximum	718
Minimum	566
Range	152
Mean value	635.2
Standard deviation	26.7
SE (Mean)	1.5
Coefficient of variation =	4.2%
No subjects =	309



Measured from the bony tip of the shoulder (acromion) to the tip of the centre of a rod gripped vertically in the hand. The arm should be straight.

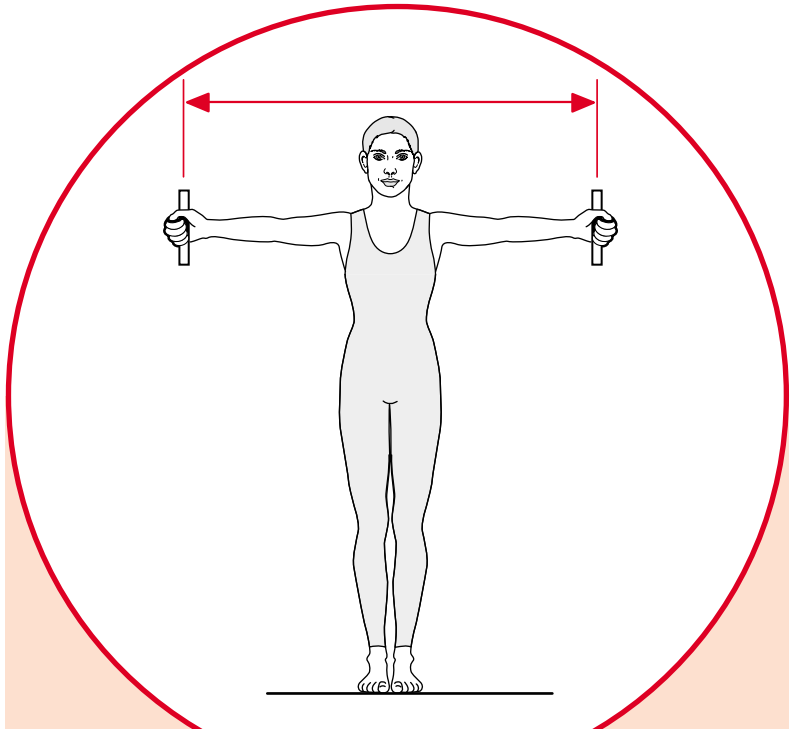
Functional Anthropometry

Functional Arm Span

Measured horizontally from the centre of a rod gripped vertically in one hand to the centre of a rod gripped in the other hand. The person stands erect, feet together and the arms and hands stretched out on either side in line with the shoulders.

Percentile	mm
1	1297.0
5	1345.1
10	1377.8
15	1393.0
20	1403.0
25	1412.0
30	1423.0
35	1432.7
40	1445.0
45	1451.0
50	1459.0
55	1465.0
60	1476.6
65	1483.5
70	1492.8
75	1502.8
80	1512.6
85	1527.4
90	1544.0
95	1576.0
99	1645.0

	mm
Maximum	1673
Minimum	1252
Range	421
Mean value	1460.4
Standard deviation	70.1
SE (Mean)	4.0
Coefficient of variation =	4.8%
No subjects =	309

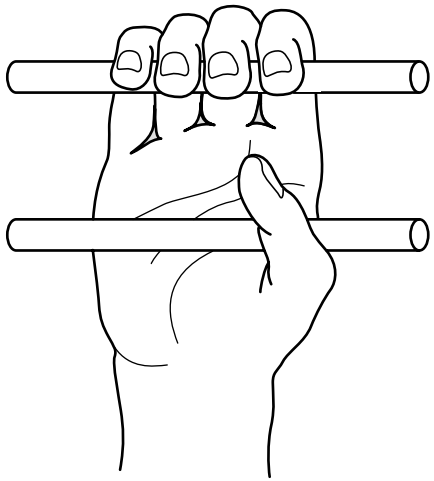


Strength

Handgrip Strength

Right hand	N	Left hand	N
Maximum	49.3	Maximum	48.2
Minimum	21.7	Minimum	24.2
Range	27.7	Range	24.0
Mean value	38.8	Mean value	36.8
Standard deviation	4.7	Standard deviation	4.4
SE (Mean)	0.3	SE (Mean)	0.3
Coefficient of variation =	12.2%	Coefficient of variation =	12.0%
No subjects =	308	No subjects =	308

Dominant hand	N	Non-dominant hand	N
Maximum	49.3	Maximum	48.2
Minimum	21.7	Minimum	24.2
Range	27.7	Range	24.0
Mean value	38.7	Mean value	36.9
Standard deviation	4.8	Standard deviation	4.3
SE (Mean)	0.3	SE (Mean)	0.2
Coefficient of variation =	12.5%	Coefficient of variation =	11.7%
No subjects =	308	No subjects =	308



Maximum static gripping force (Newtons) exerted by squeezing a handle held between the middle joints of the thumb and all four fingers. The subject stands, holding the measuring instrument with a straight arm at the side of the body (taking care not to make contact with the body). Wrist position is self-selected to allow for maximum gripping.

5. Scatter Diagrams

Whole Body

Head & Neck

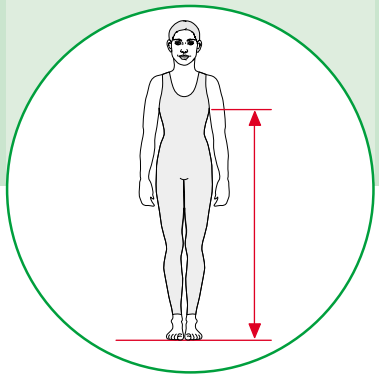
Torso

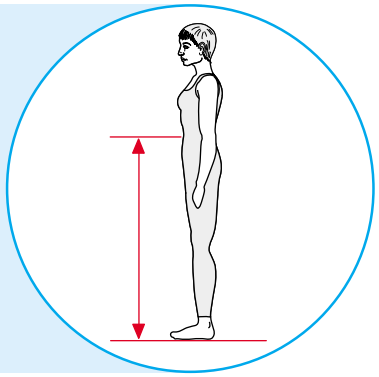
Arms

Legs

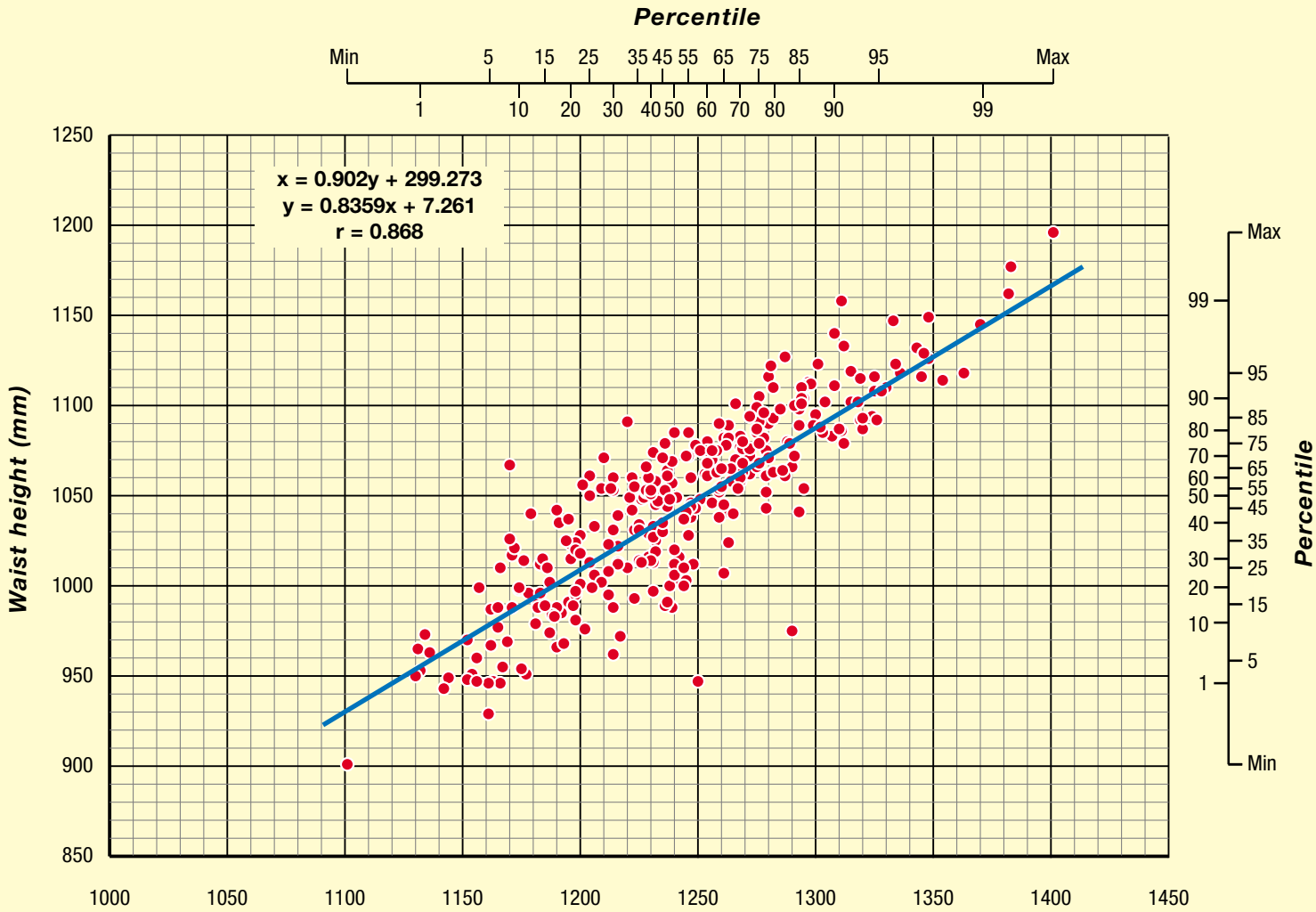
Functional Anthropometry

Strength

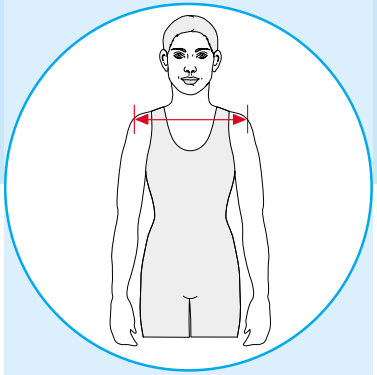


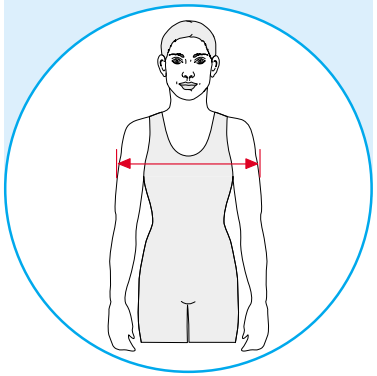


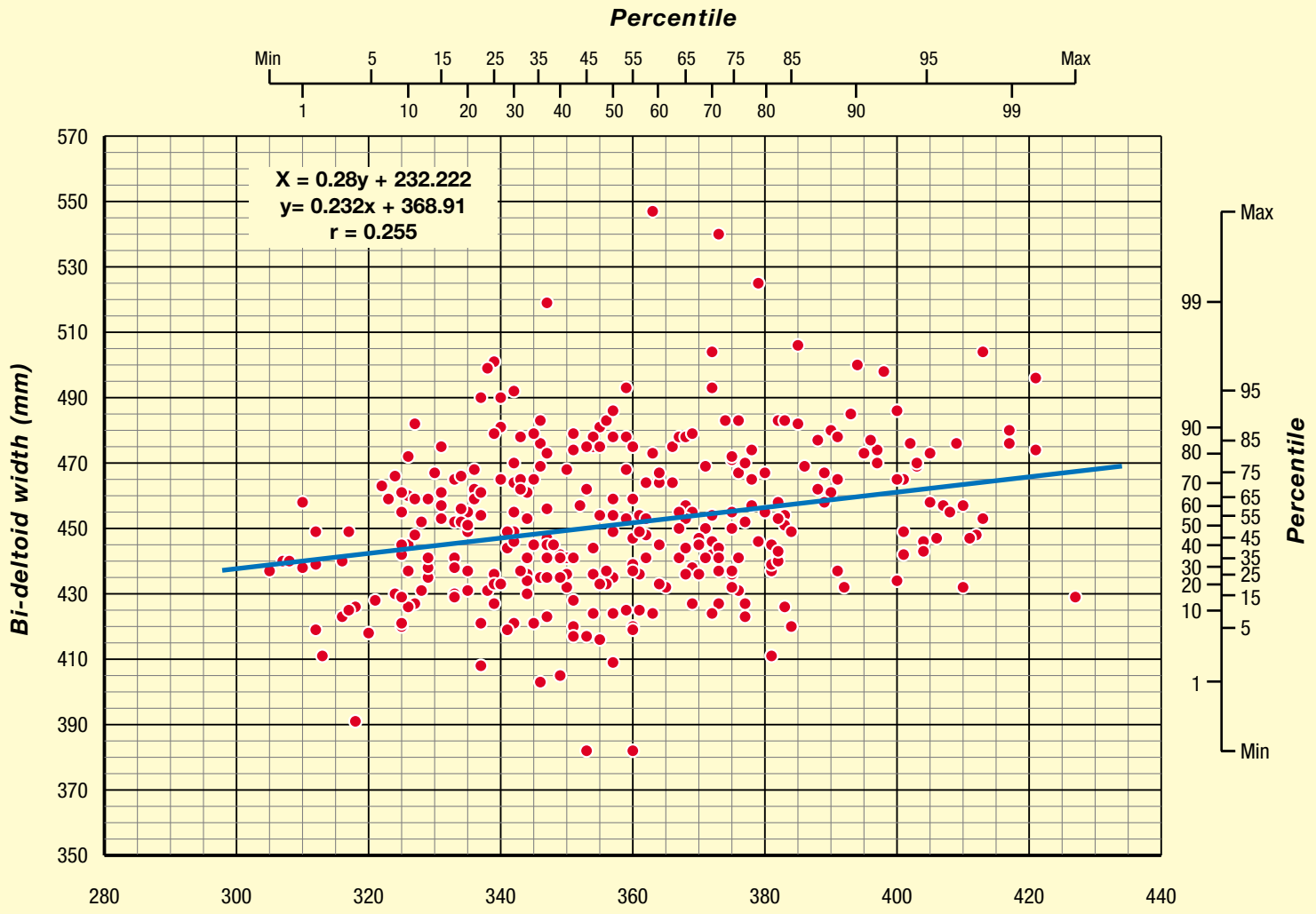
Axilla Height Standing
Waist Height

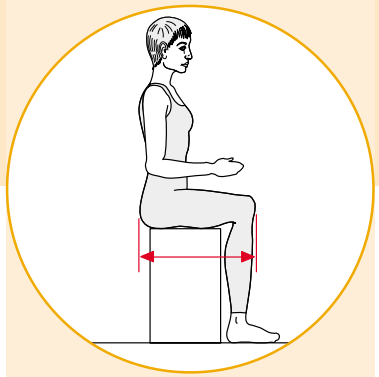


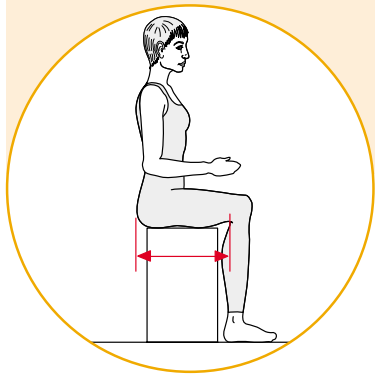
Bi-acromial Width
Bi-deltoid Width



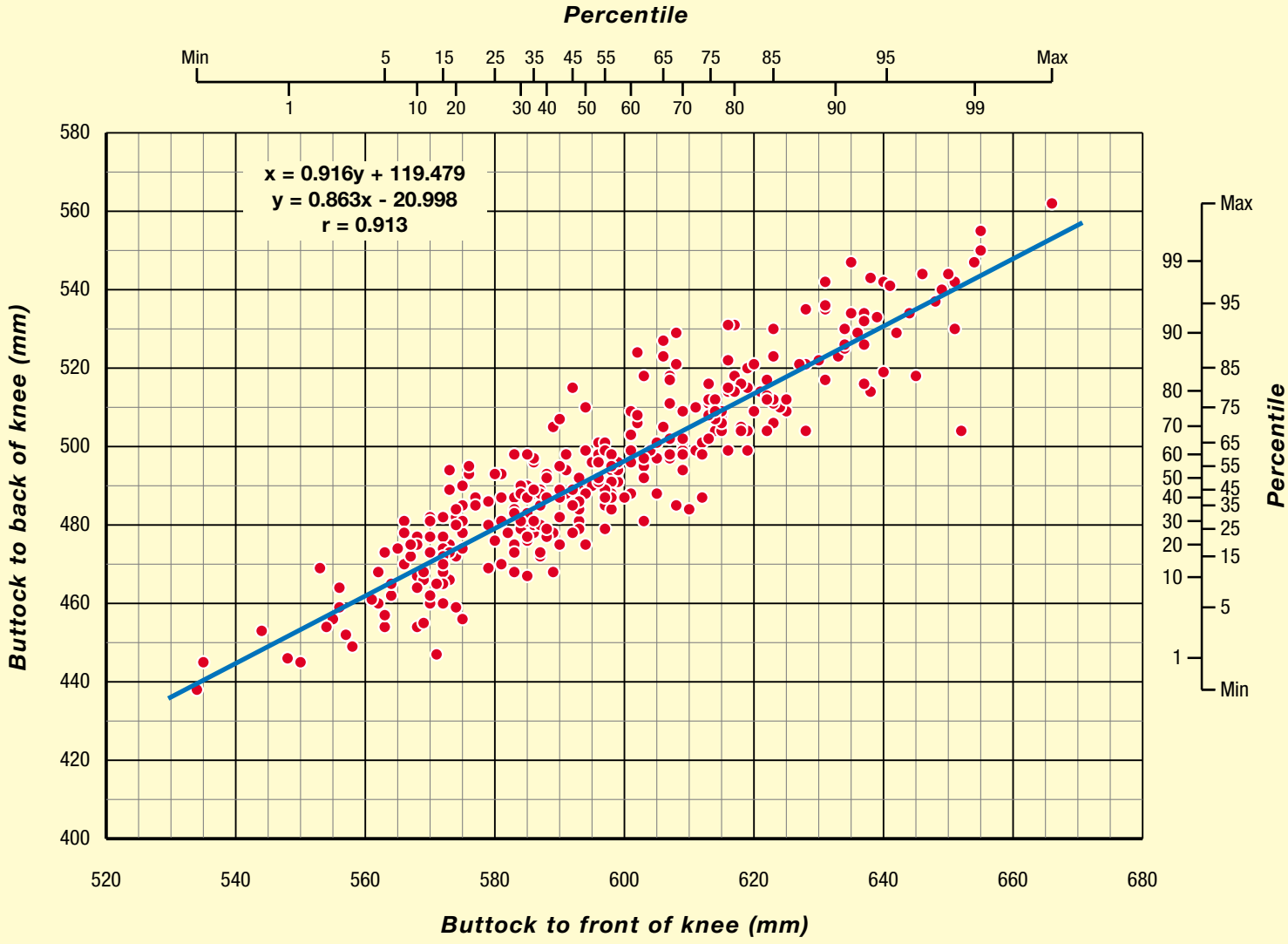




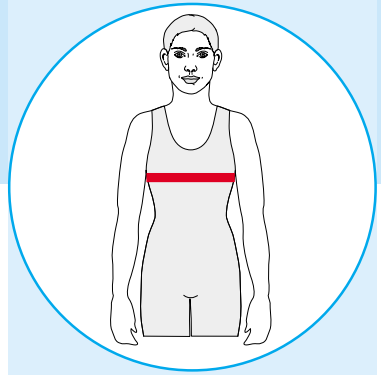


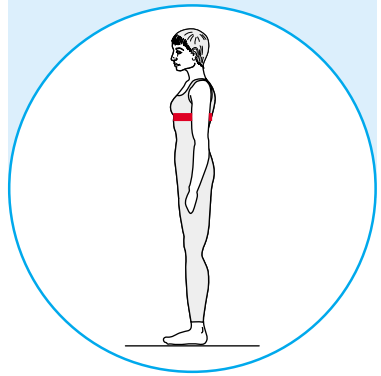


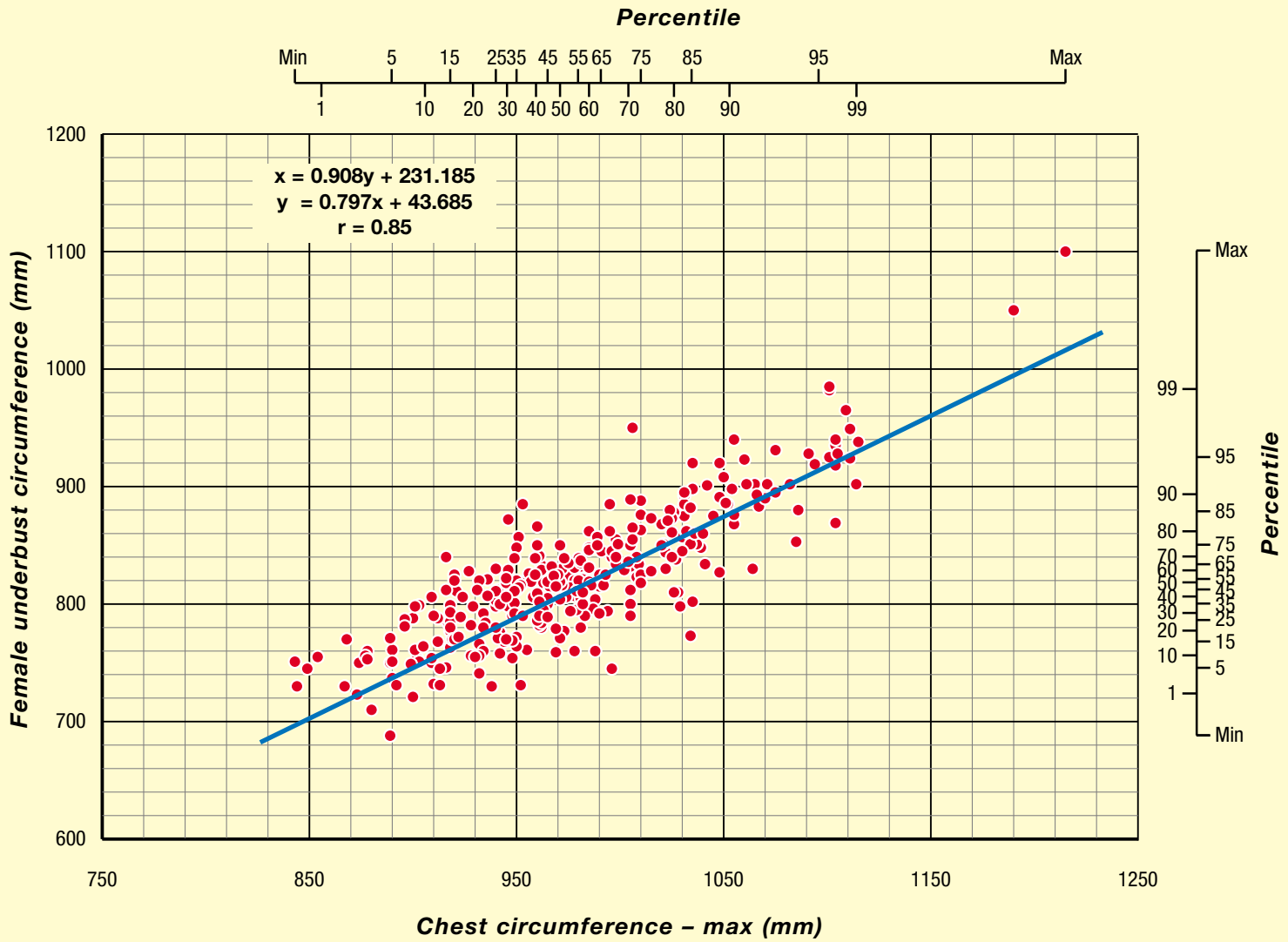
Buttock to Front of Knee
Buttock to Back of Knee

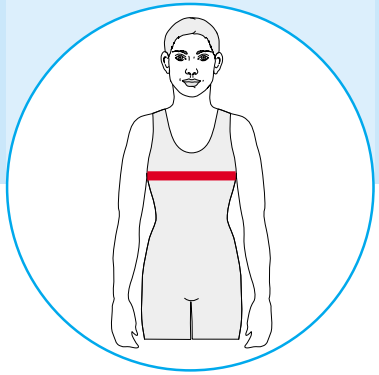


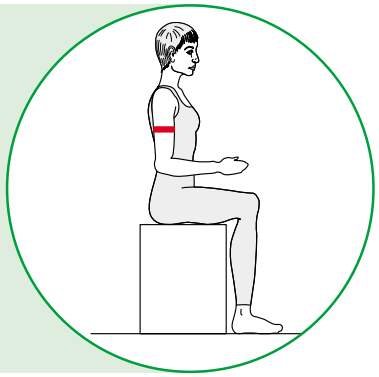
Chest Circumference – max
Female Underbust Circumference



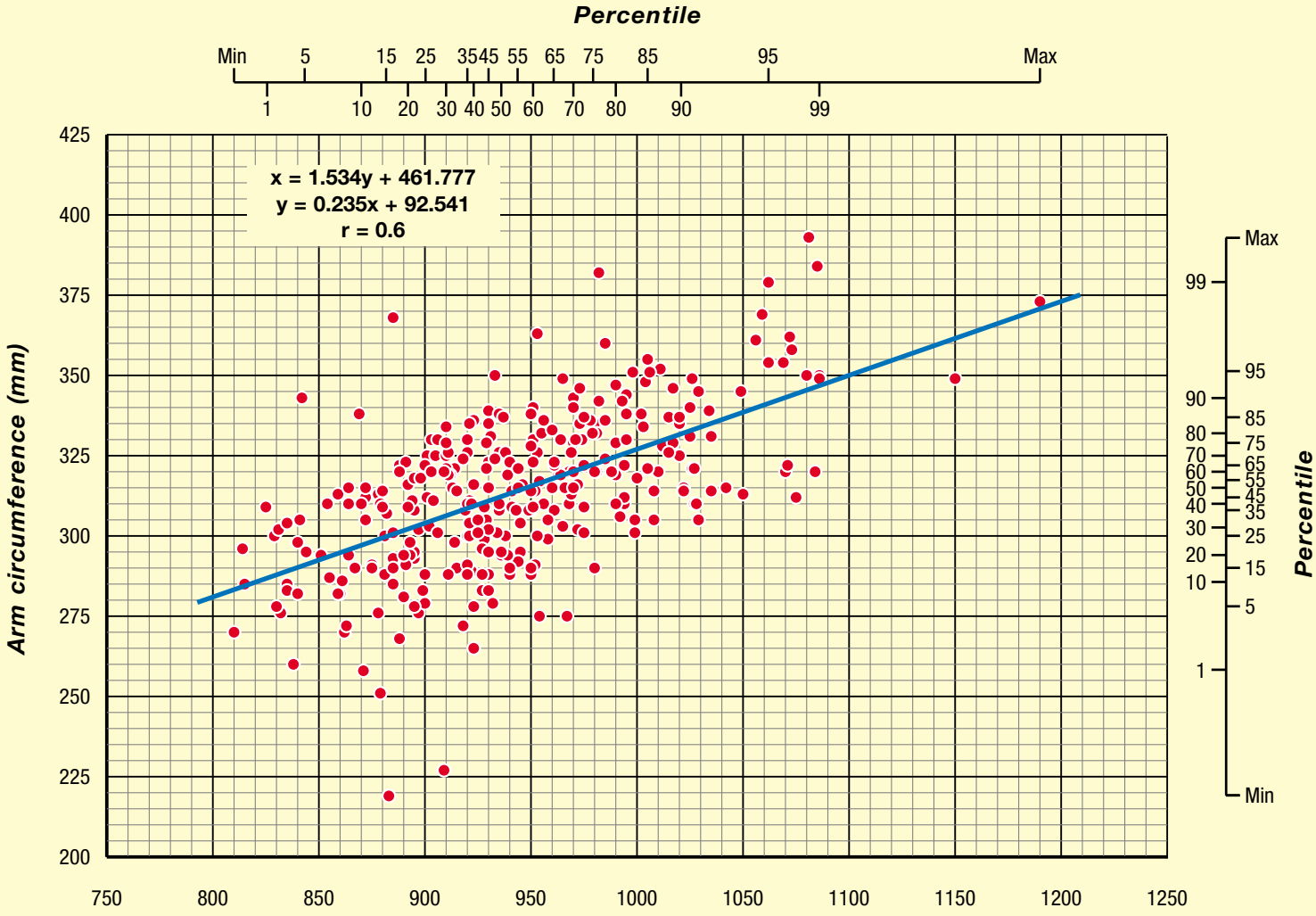




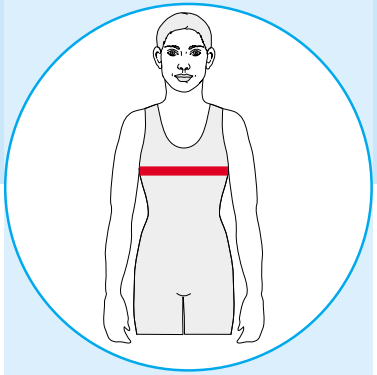


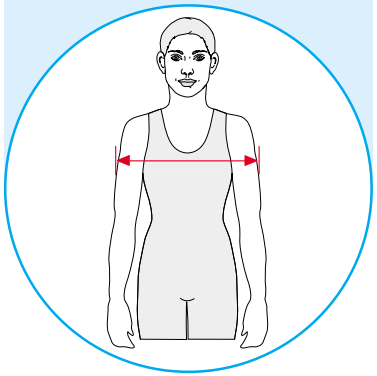


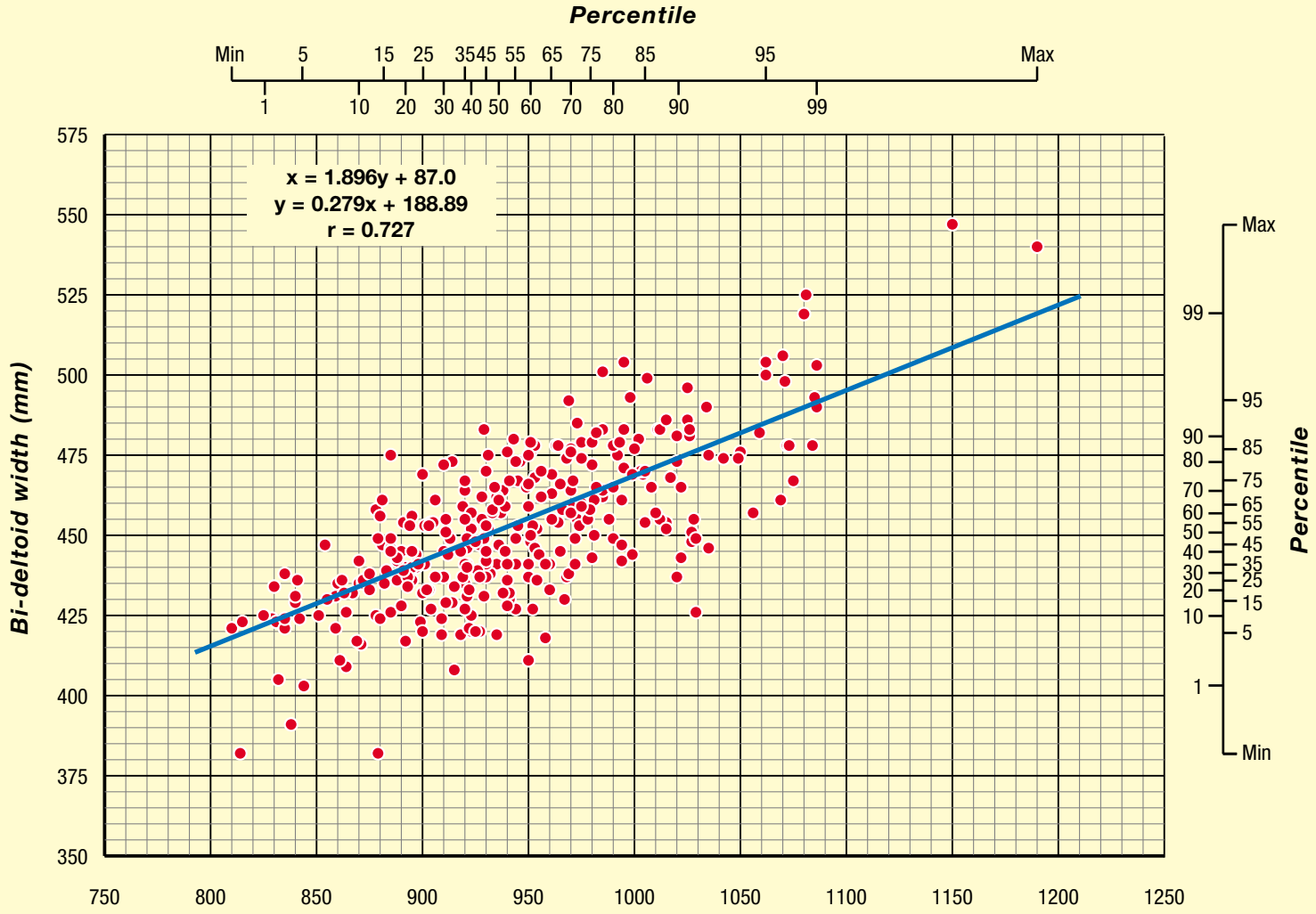
Chest Circumference
Arm Circumference

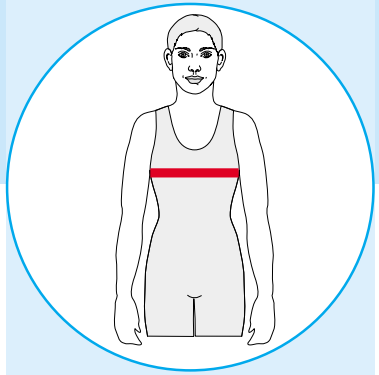


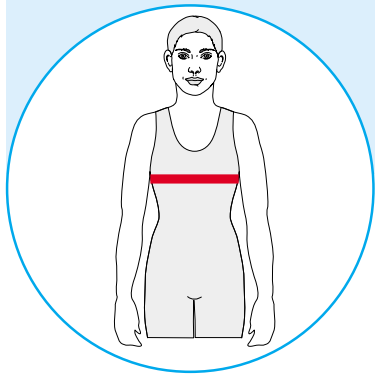
Chest Circumference
Bi-deltoid Width



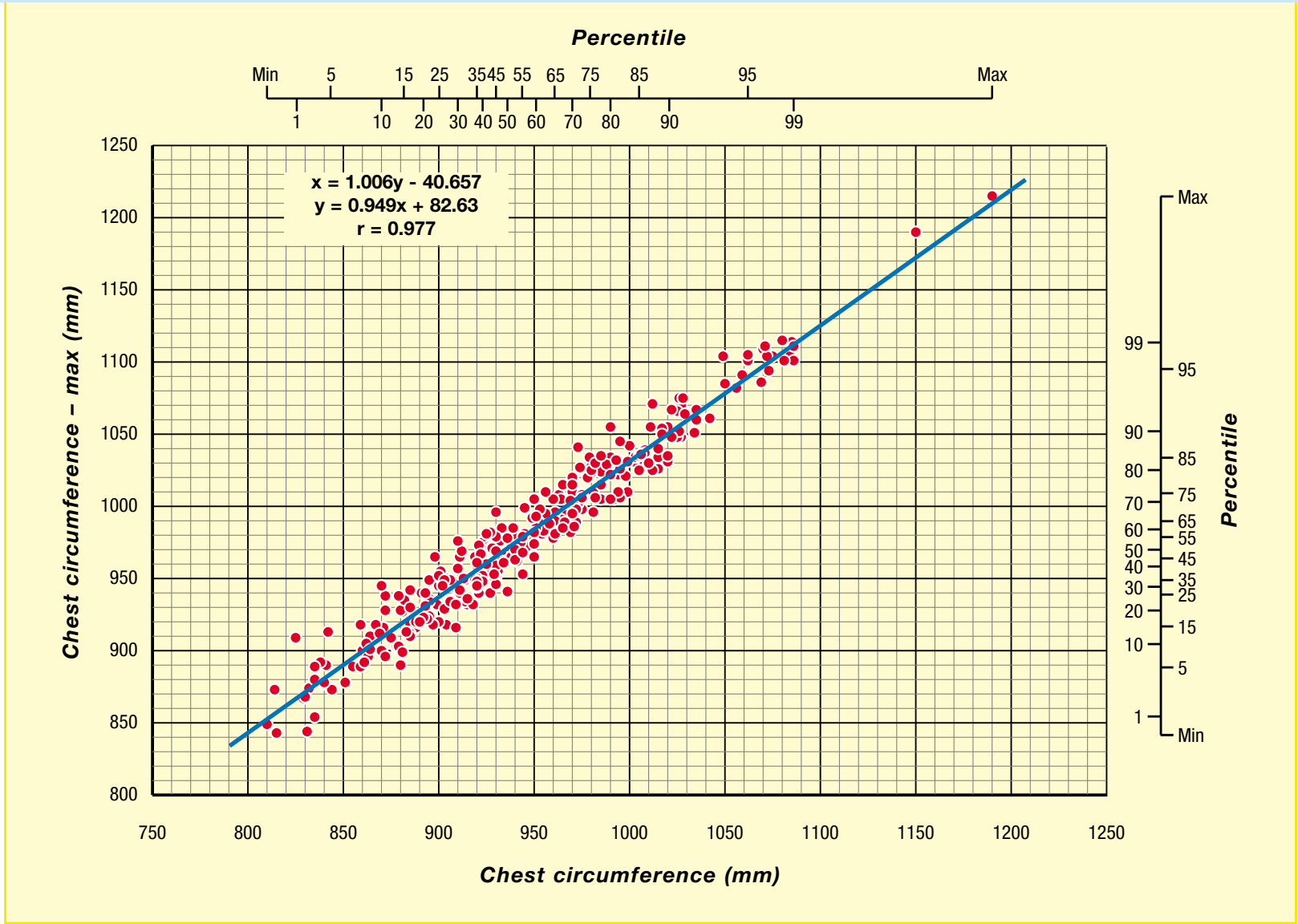




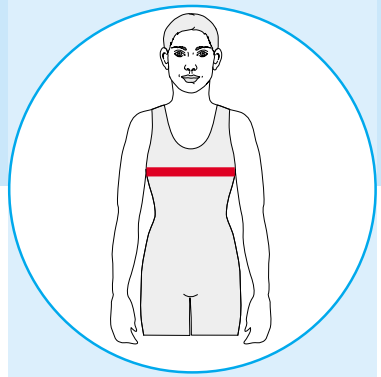


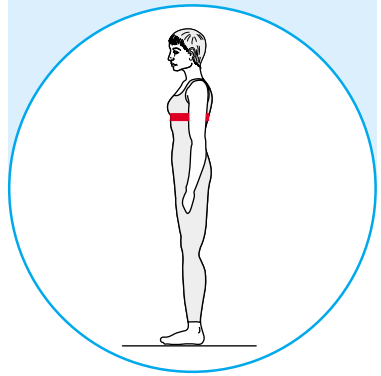


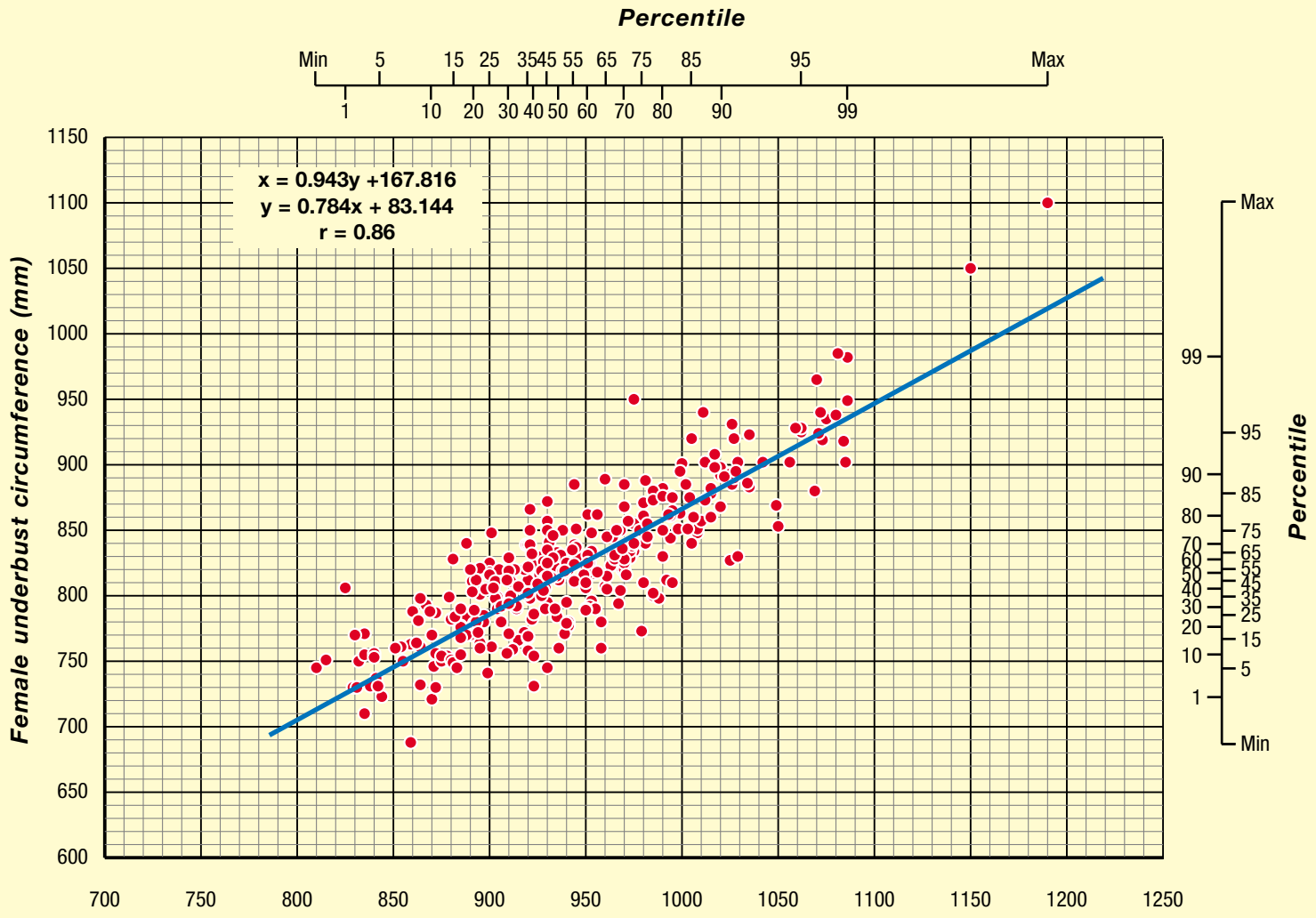
Chest Circumference
Chest Circumference – max

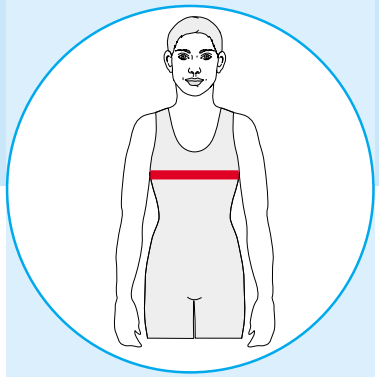


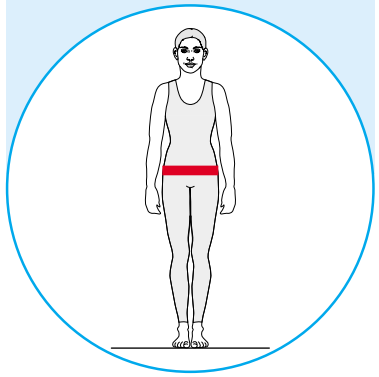
Chest Circumference
Female Underbust Circumference



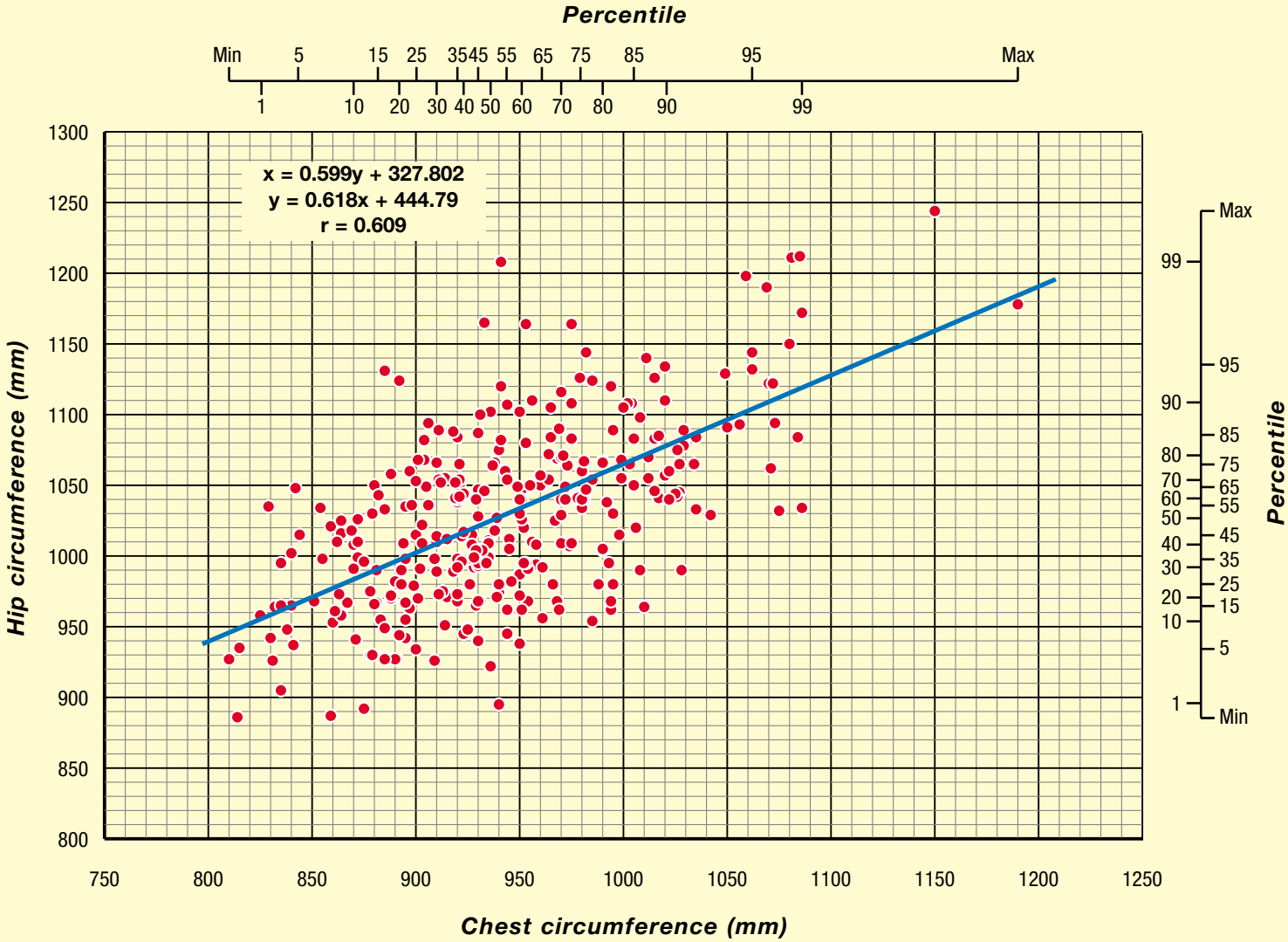




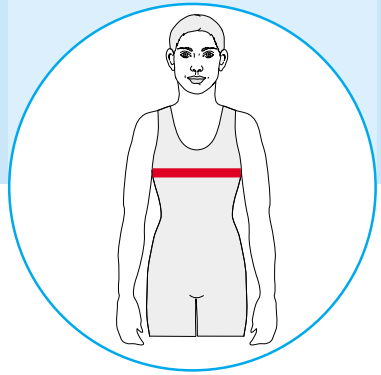


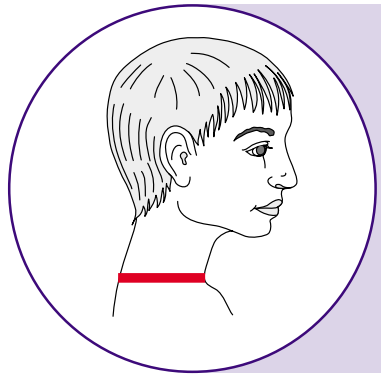


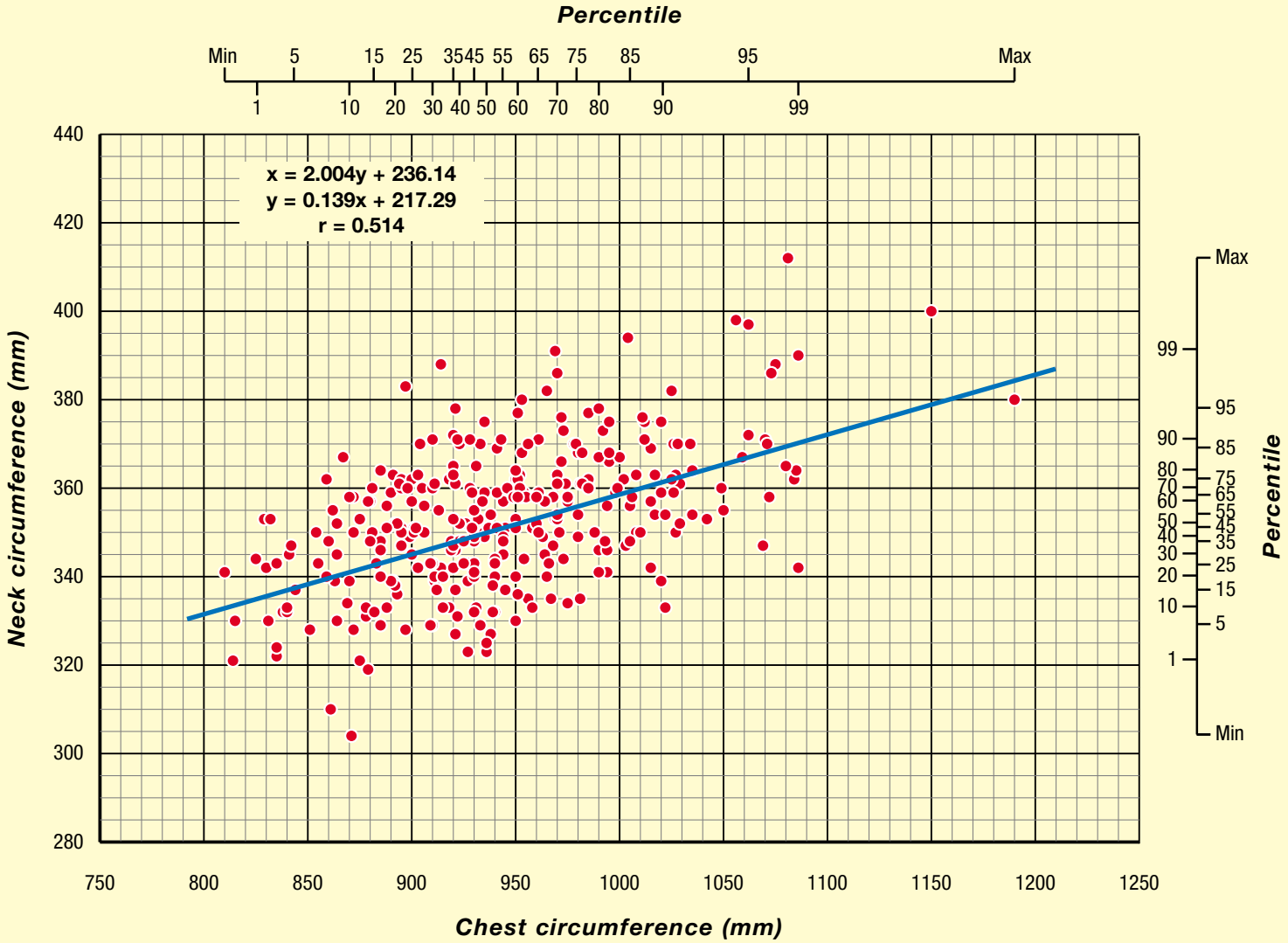
Chest Circumference
Hip Circumference

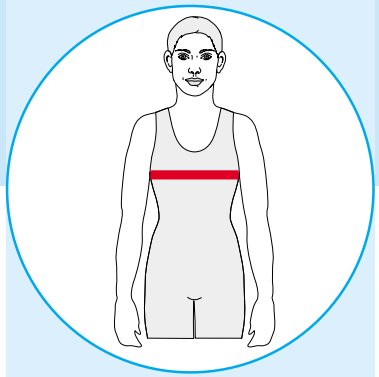


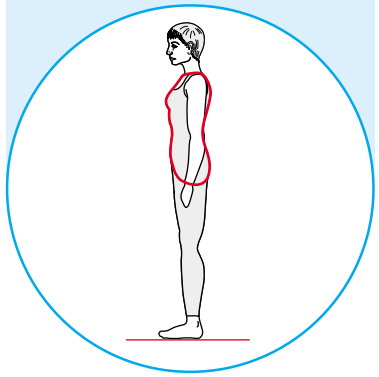
Chest Circumference
Neck Circumference



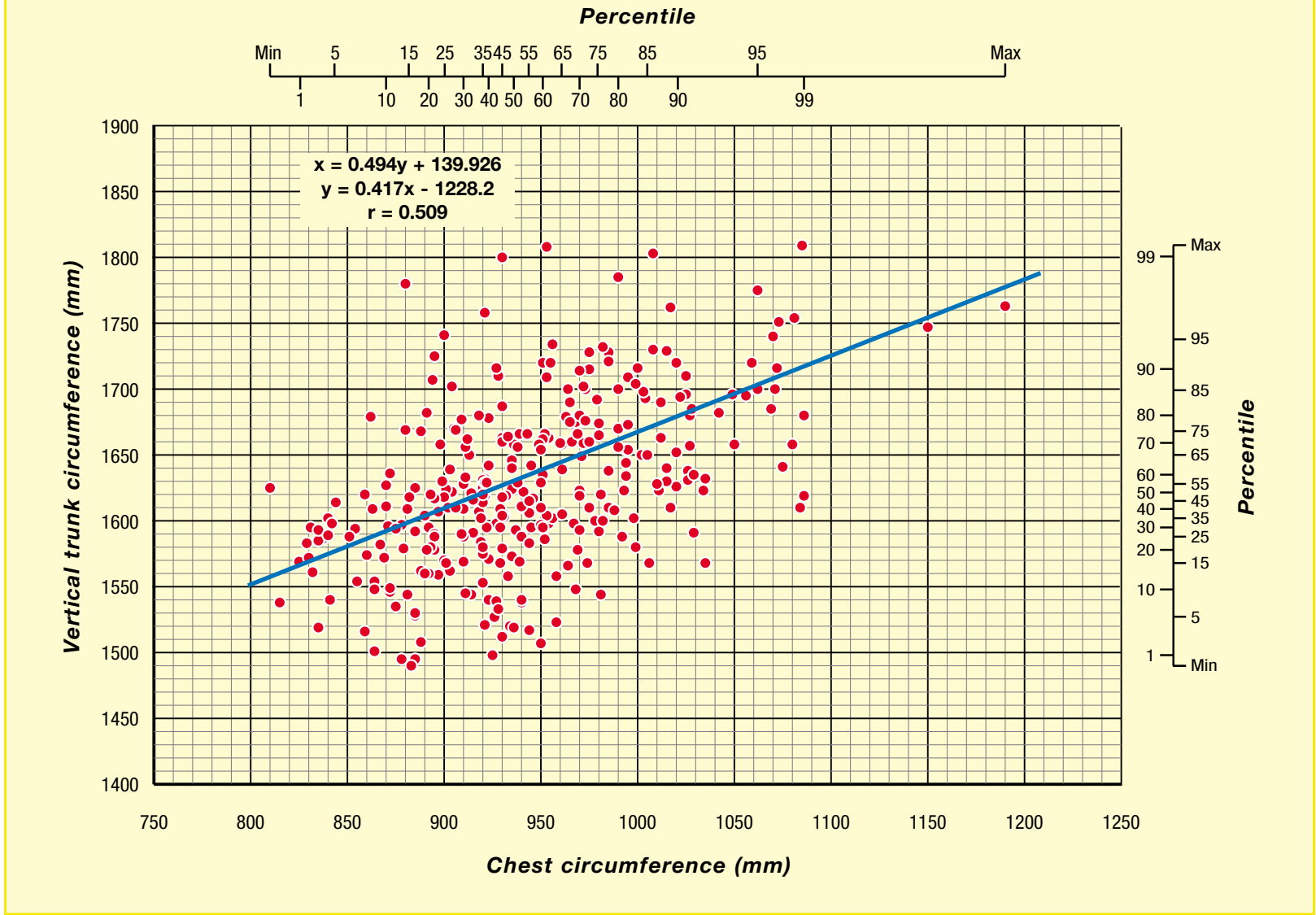




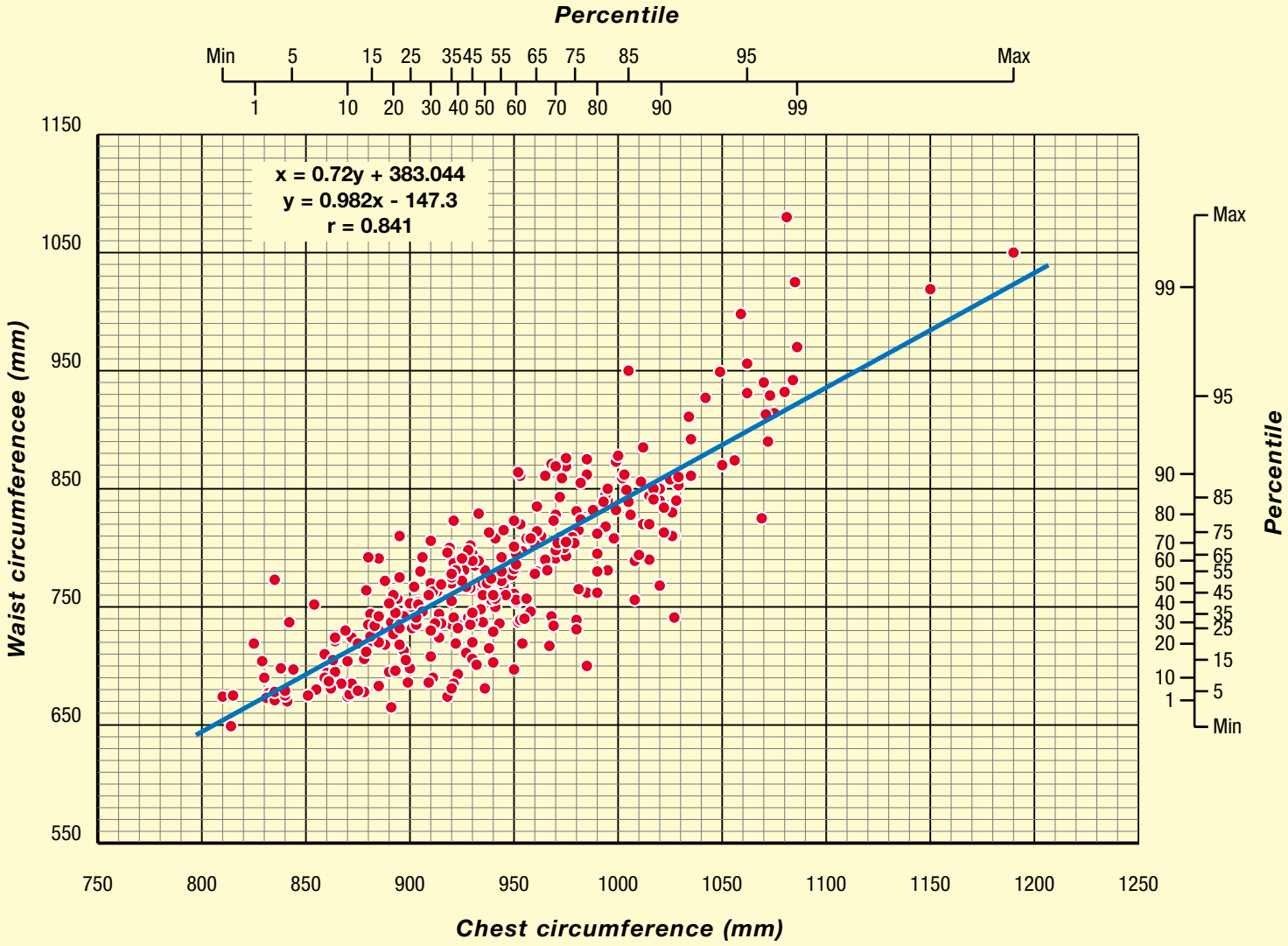


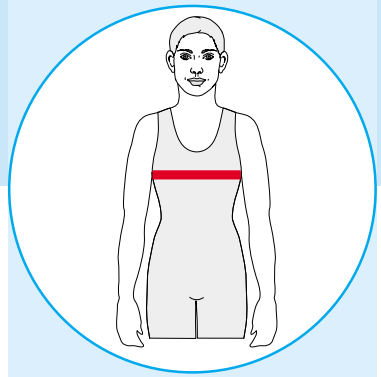


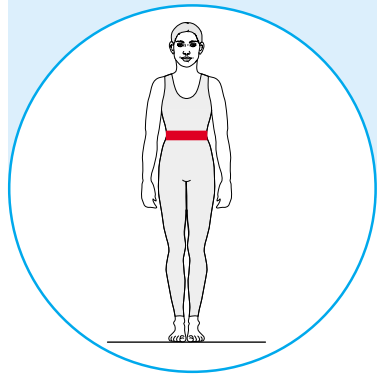
Chest circumference
Vertical trunk circumference

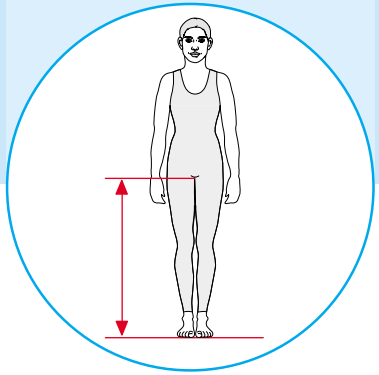


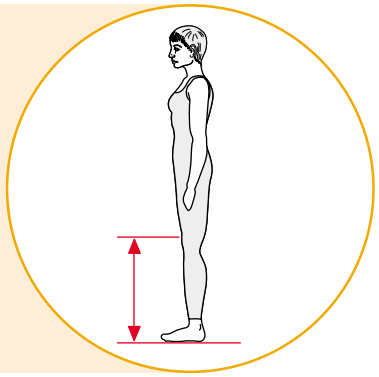
Chest circumference
Waist circumference



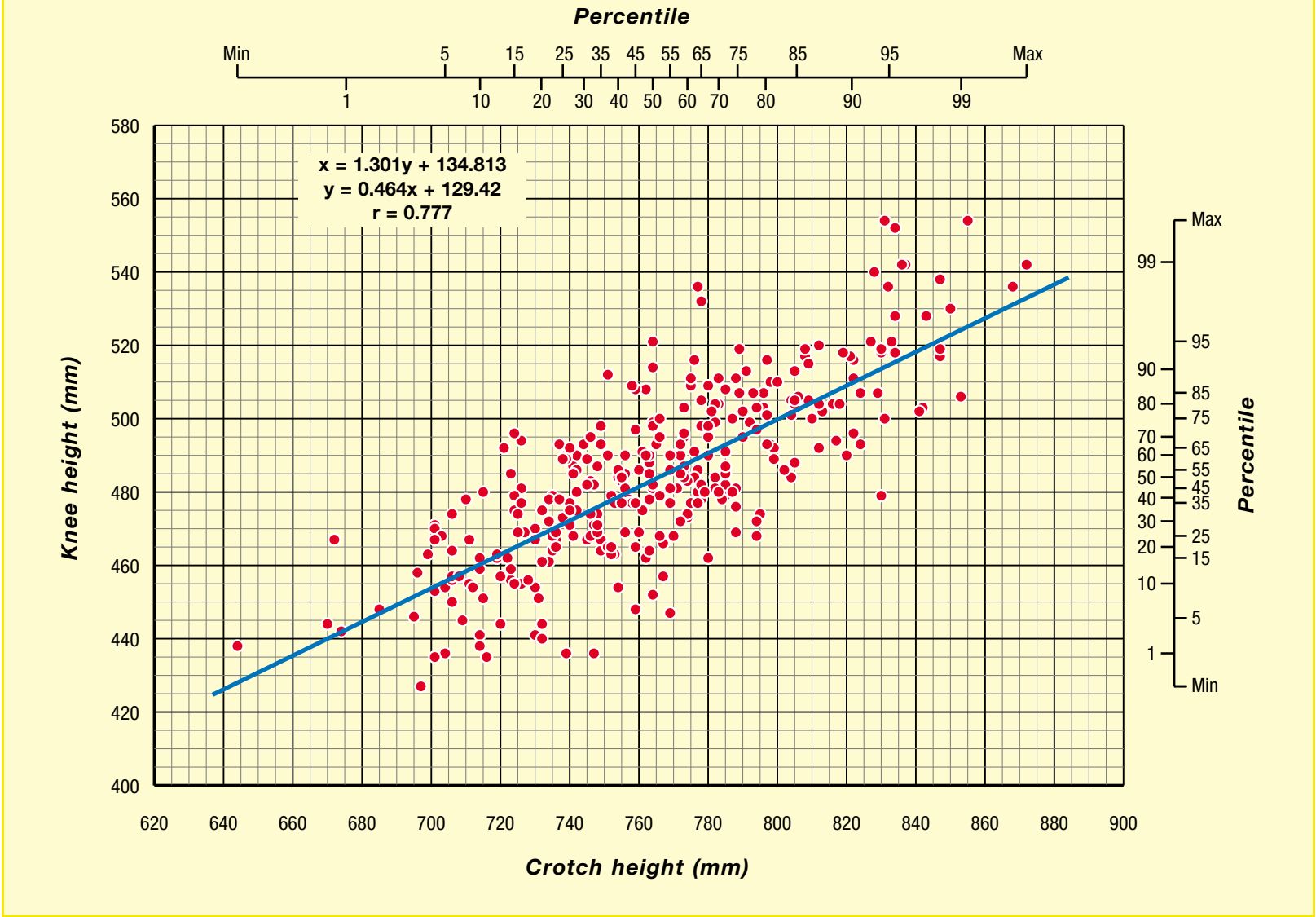




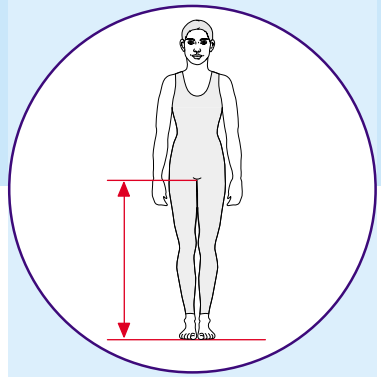


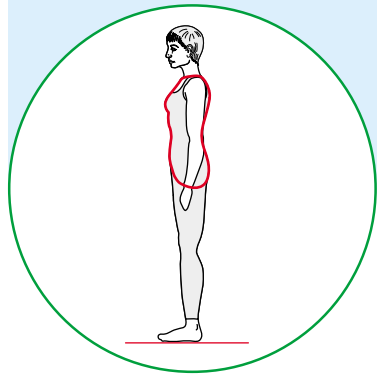


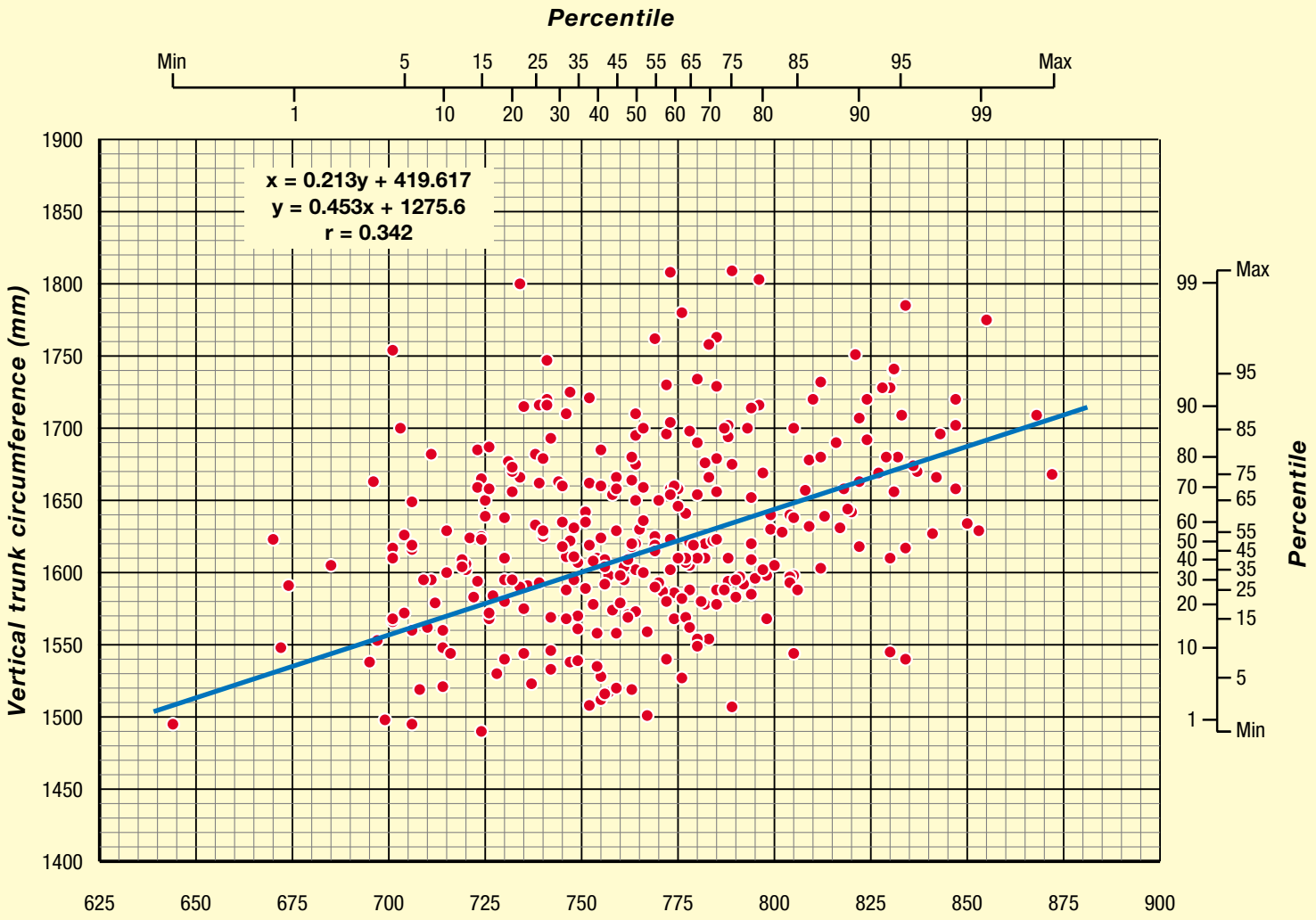
Crotch Height
Knee Height

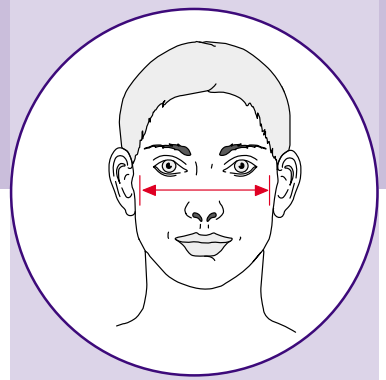


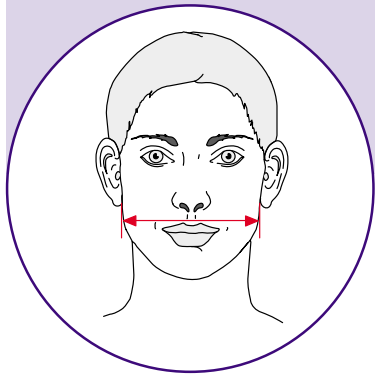
Crotch Height
Vertical Trunk Circumference



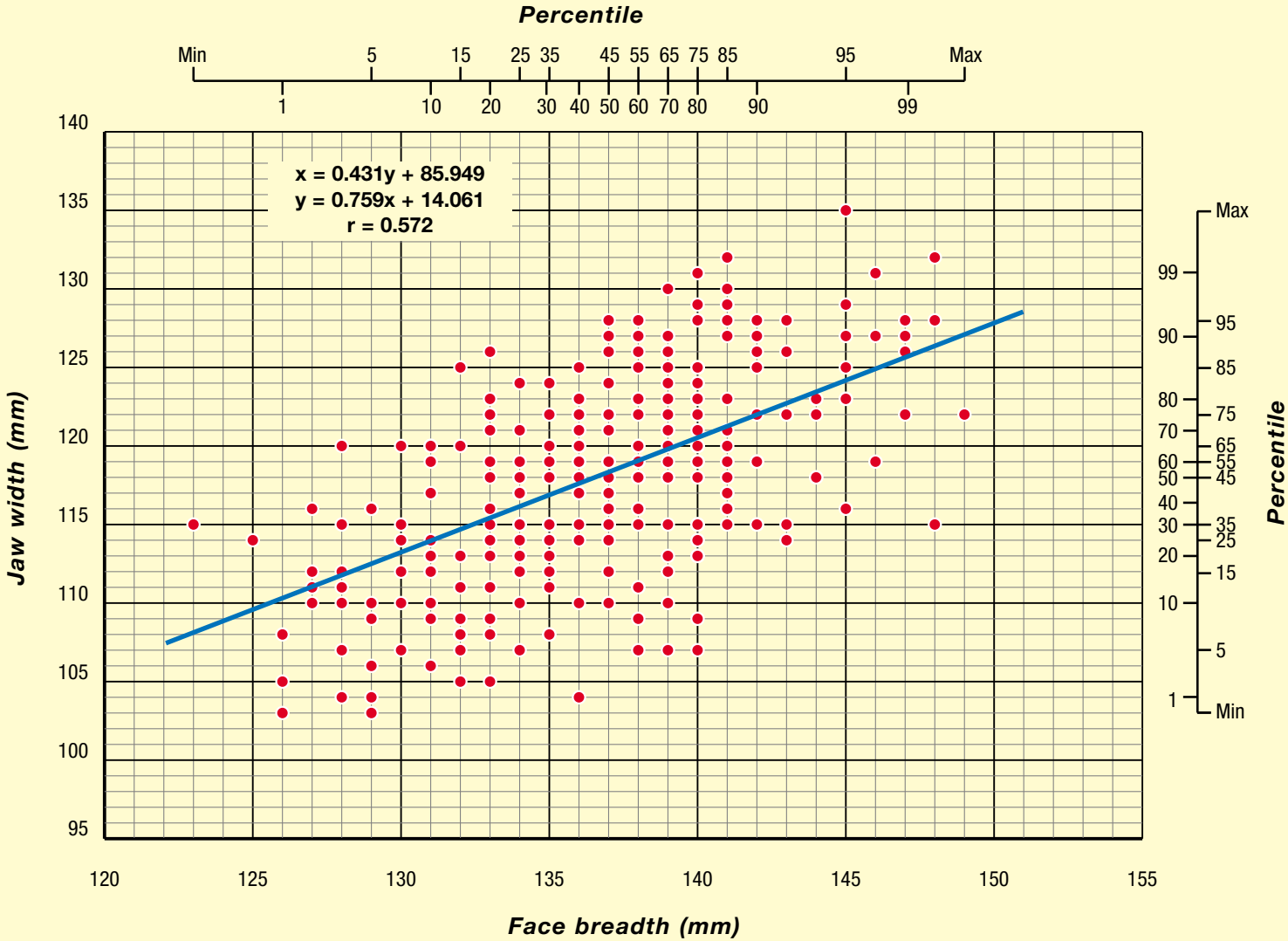




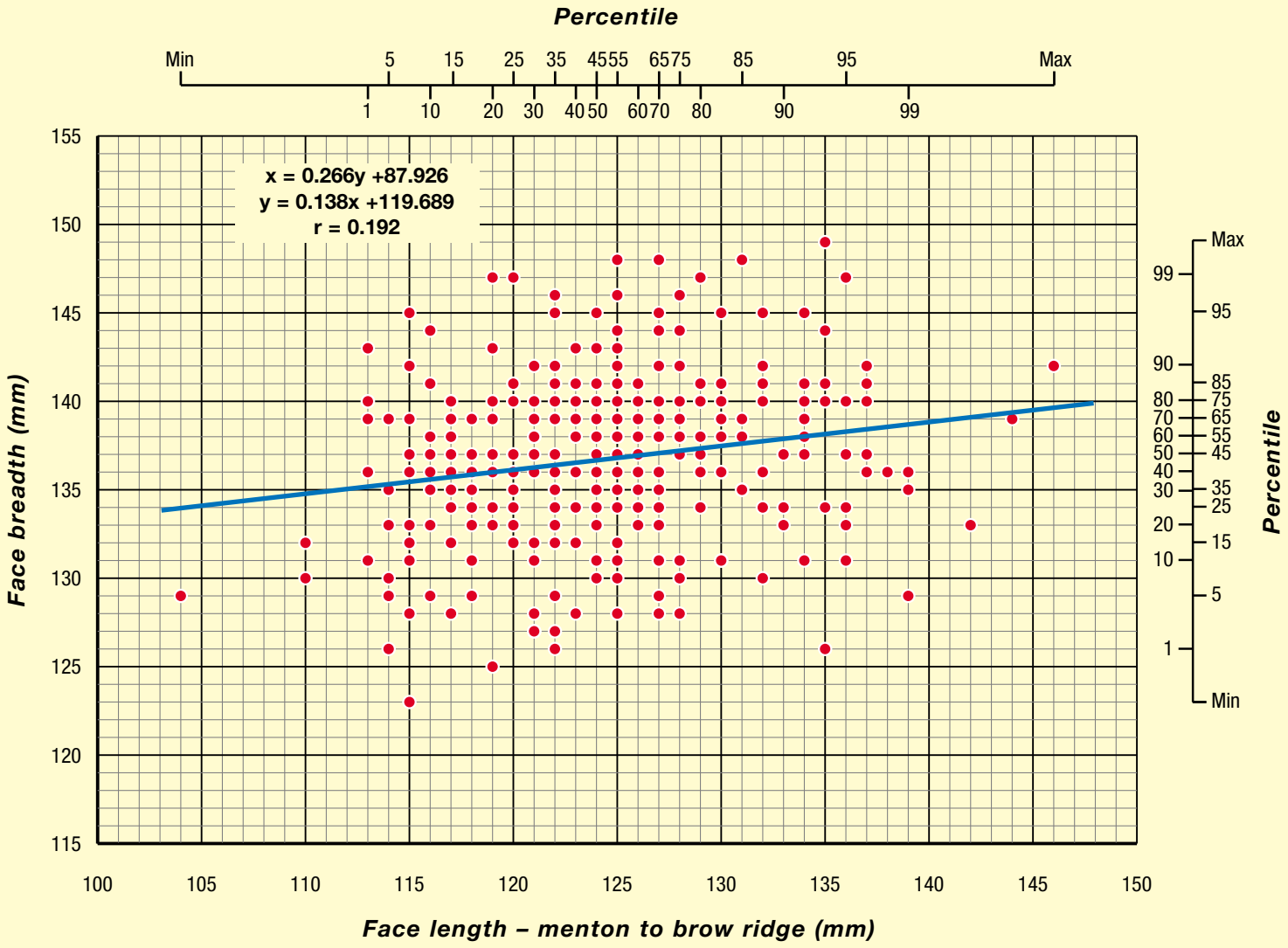


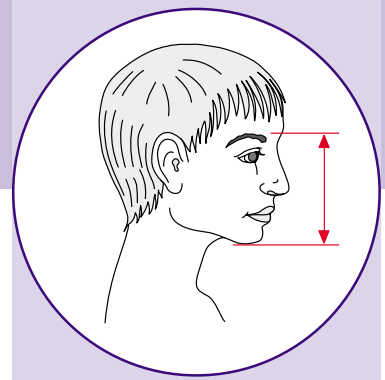


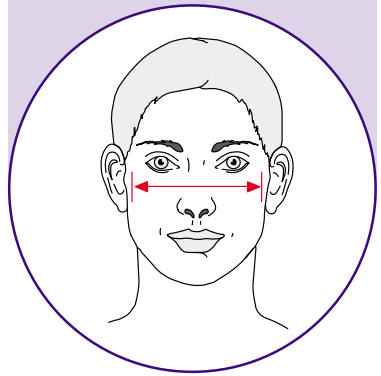
Face Breadth
Jaw Width

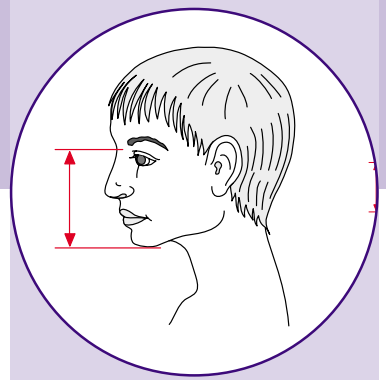


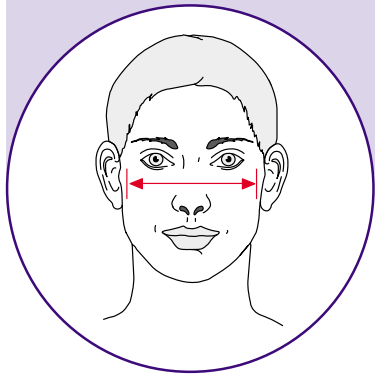
Face Length - menton to brow ridge
Face Breadth



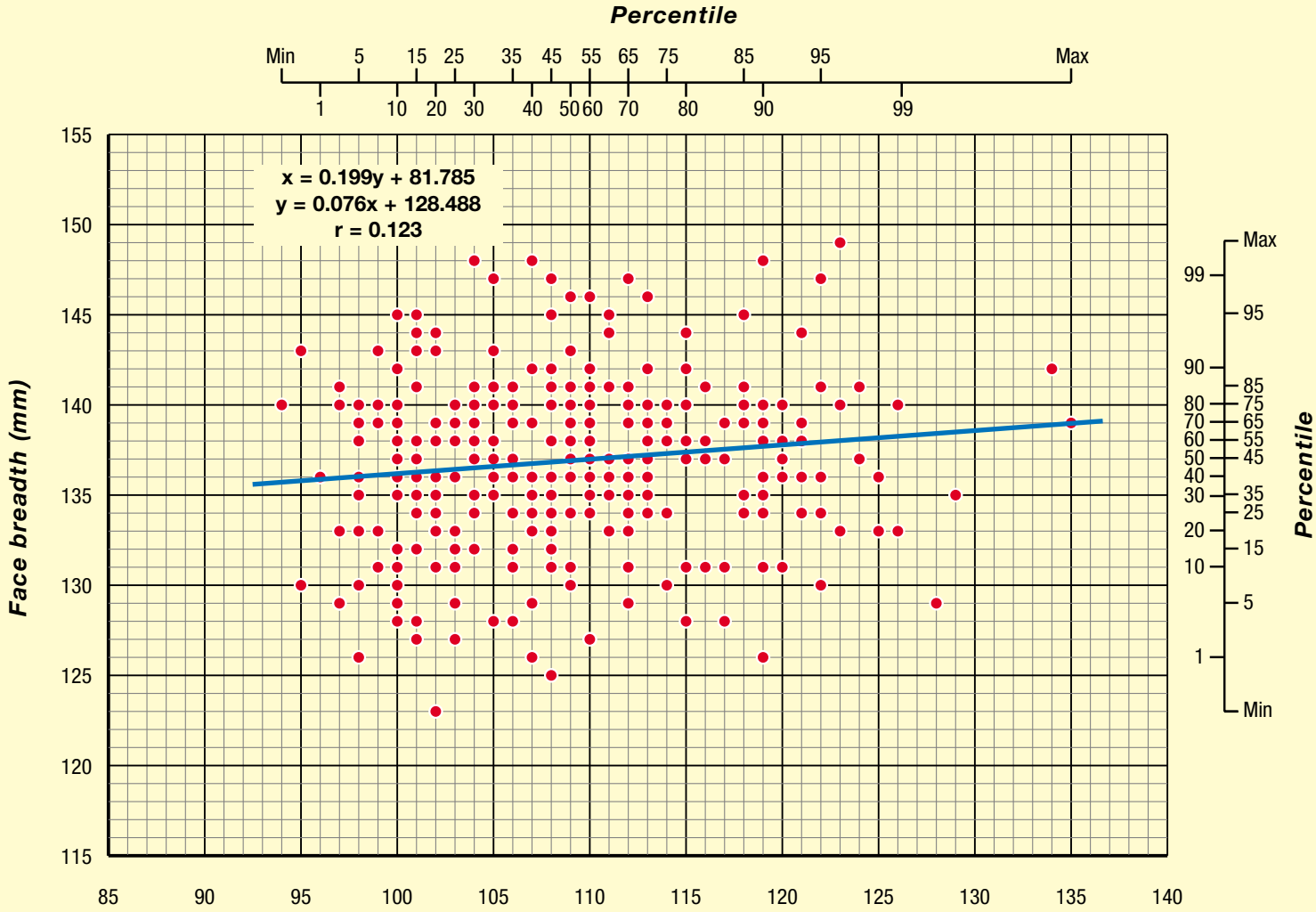




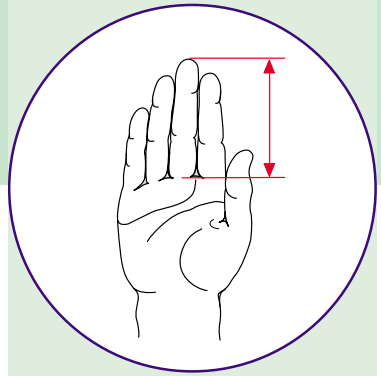


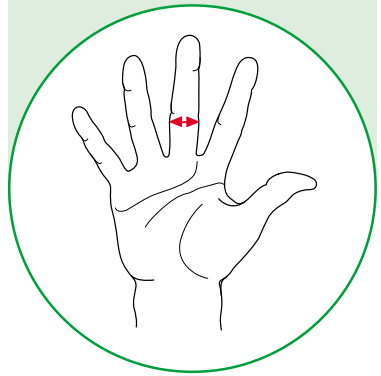


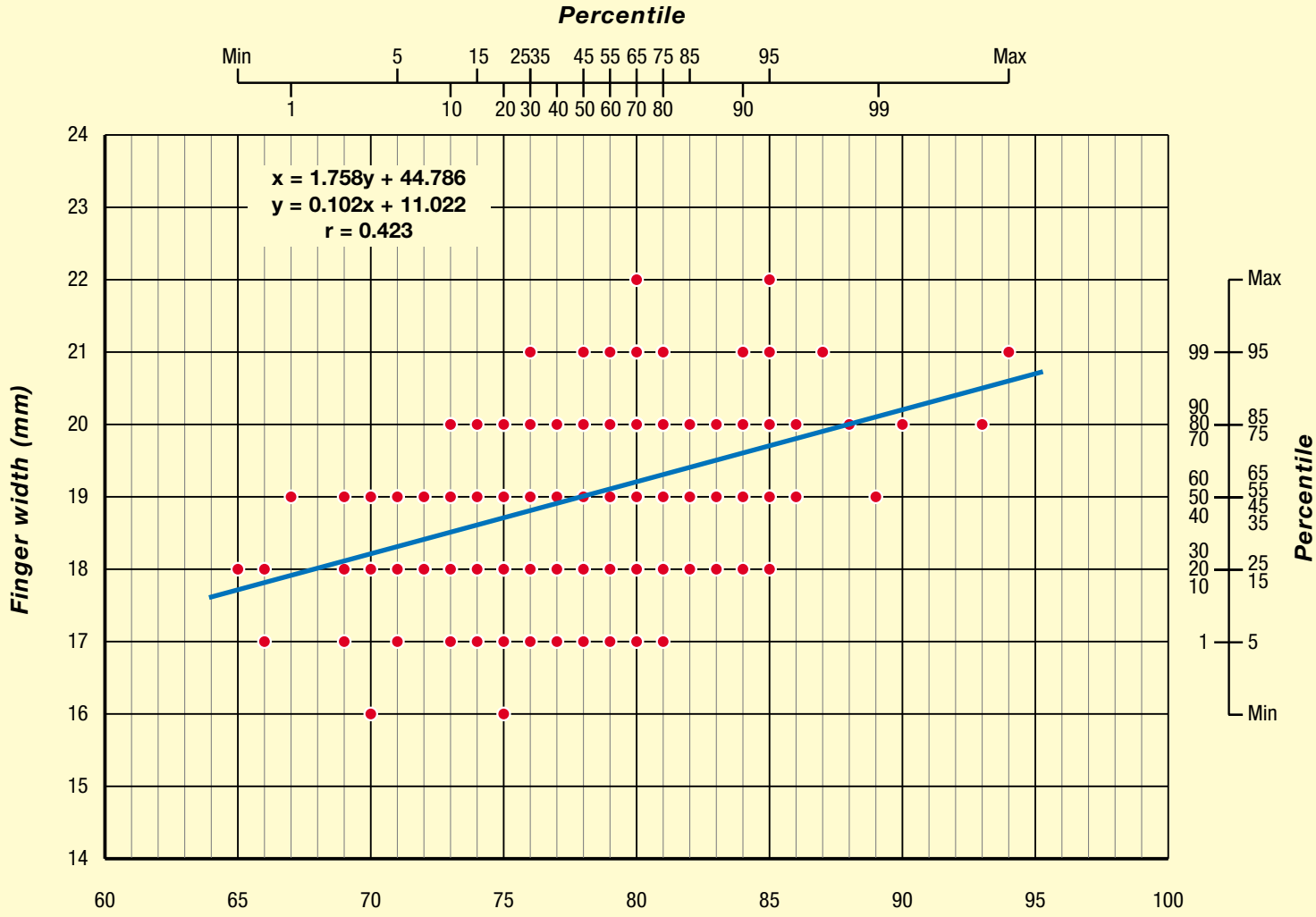
Face Length – menton to naison
Face Breadth

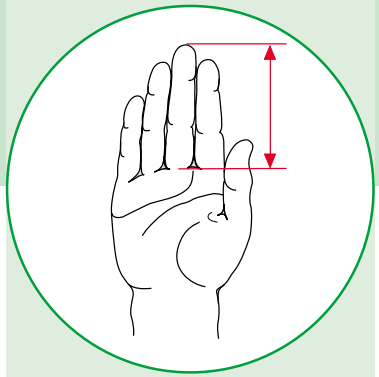


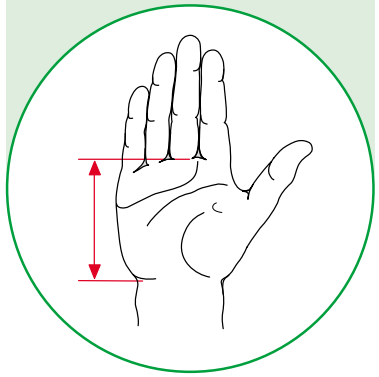
Finger Length
Finger Width



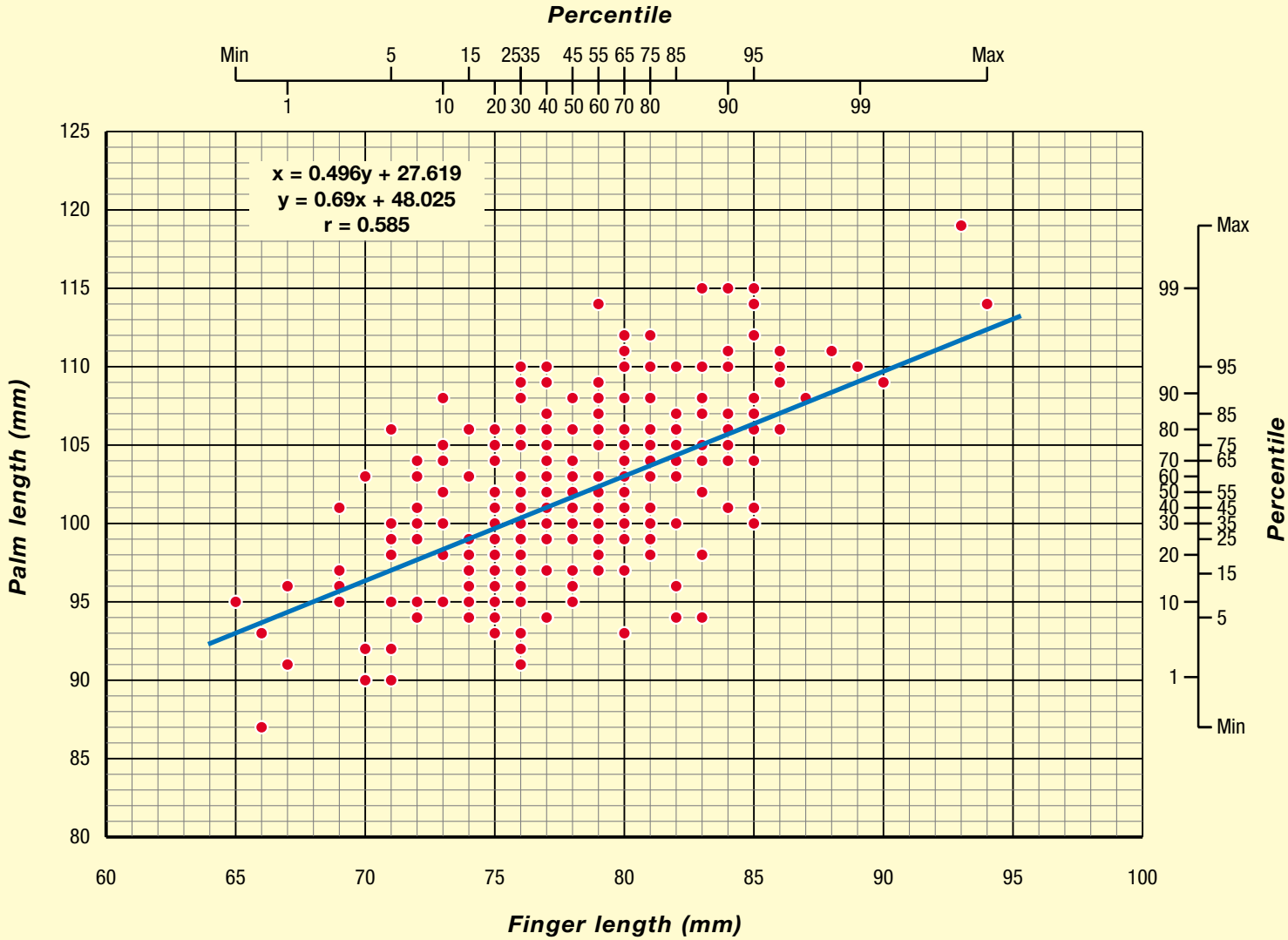




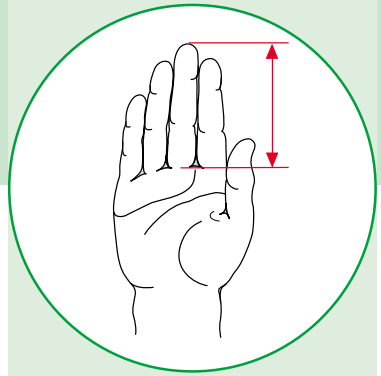


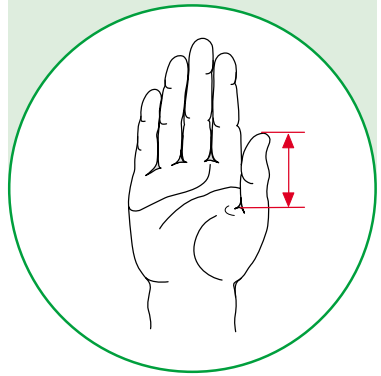


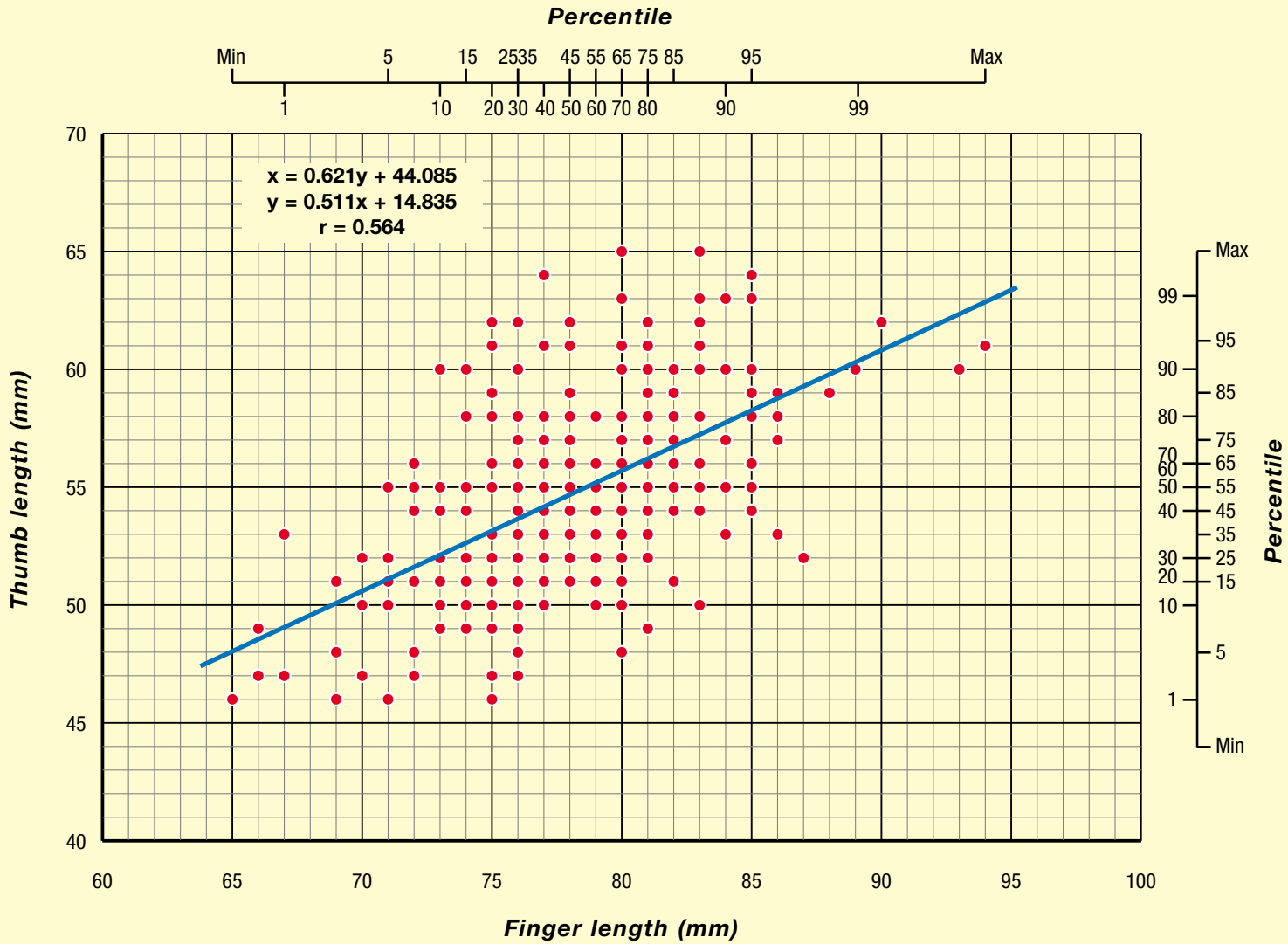
Finger Length
Palm Length

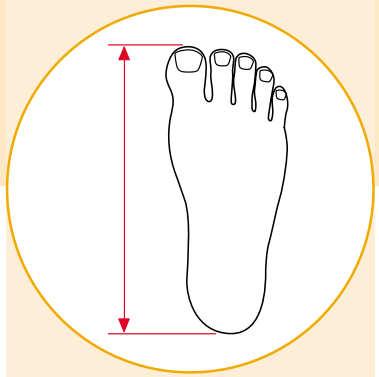


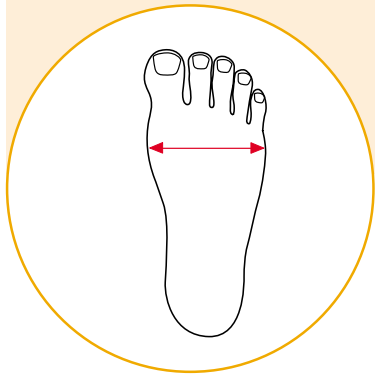
Finger Length
Thumb Length



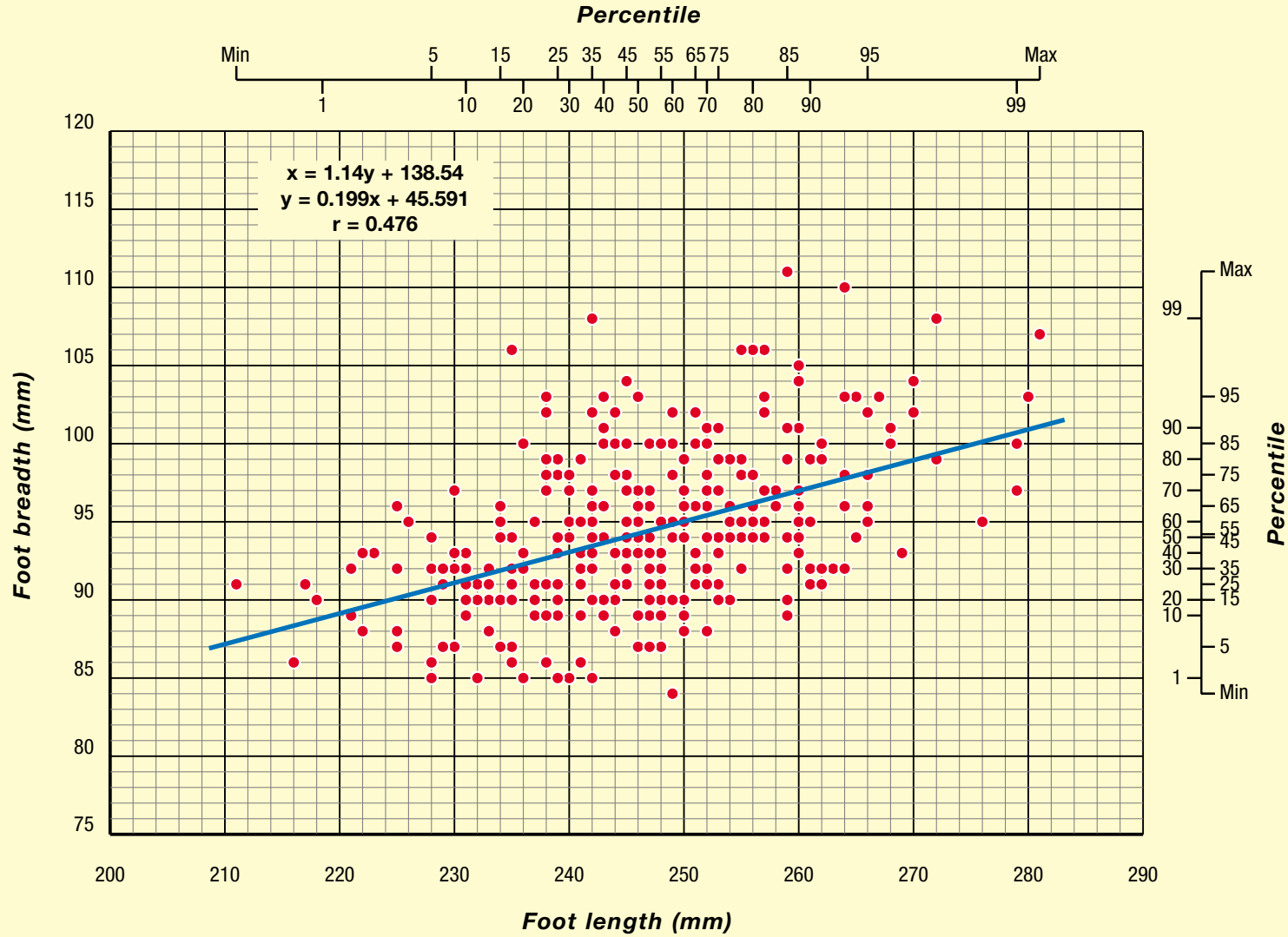




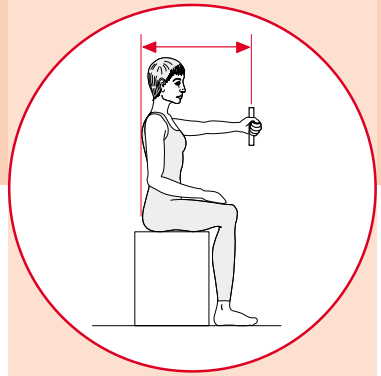


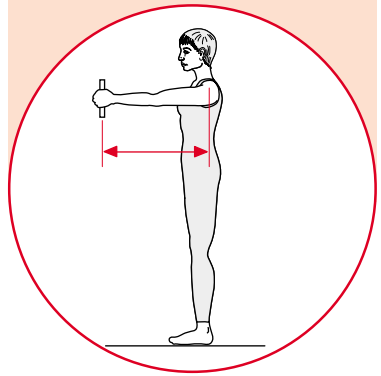


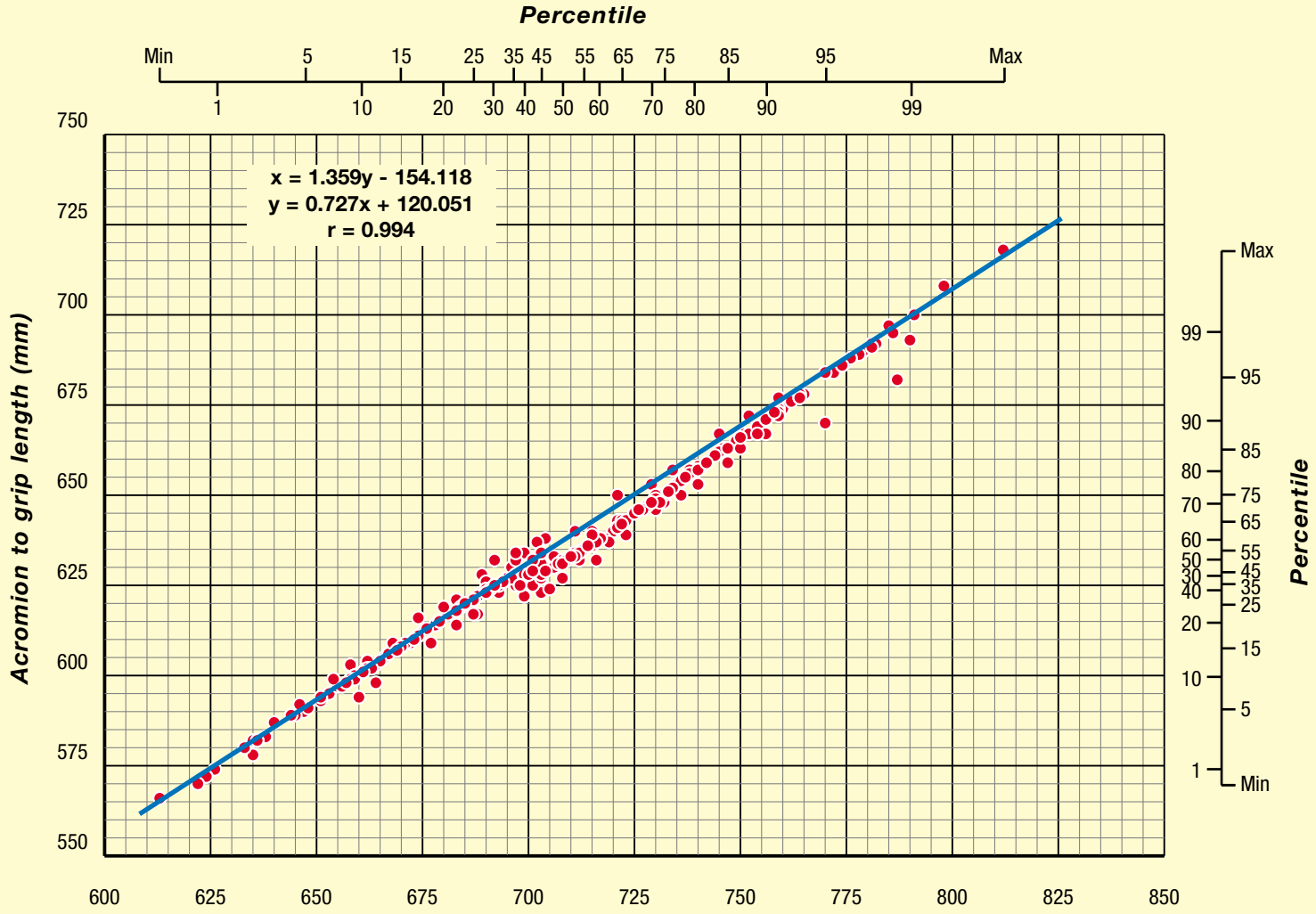
Foot Length
Foot Breadth

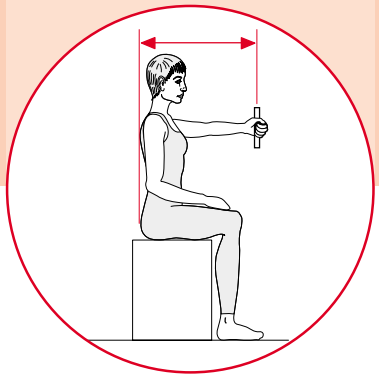


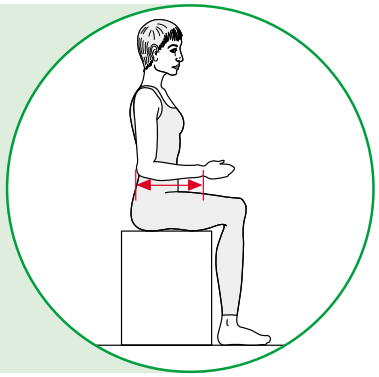
Forward Grip Reach
Acromion to Grip Length



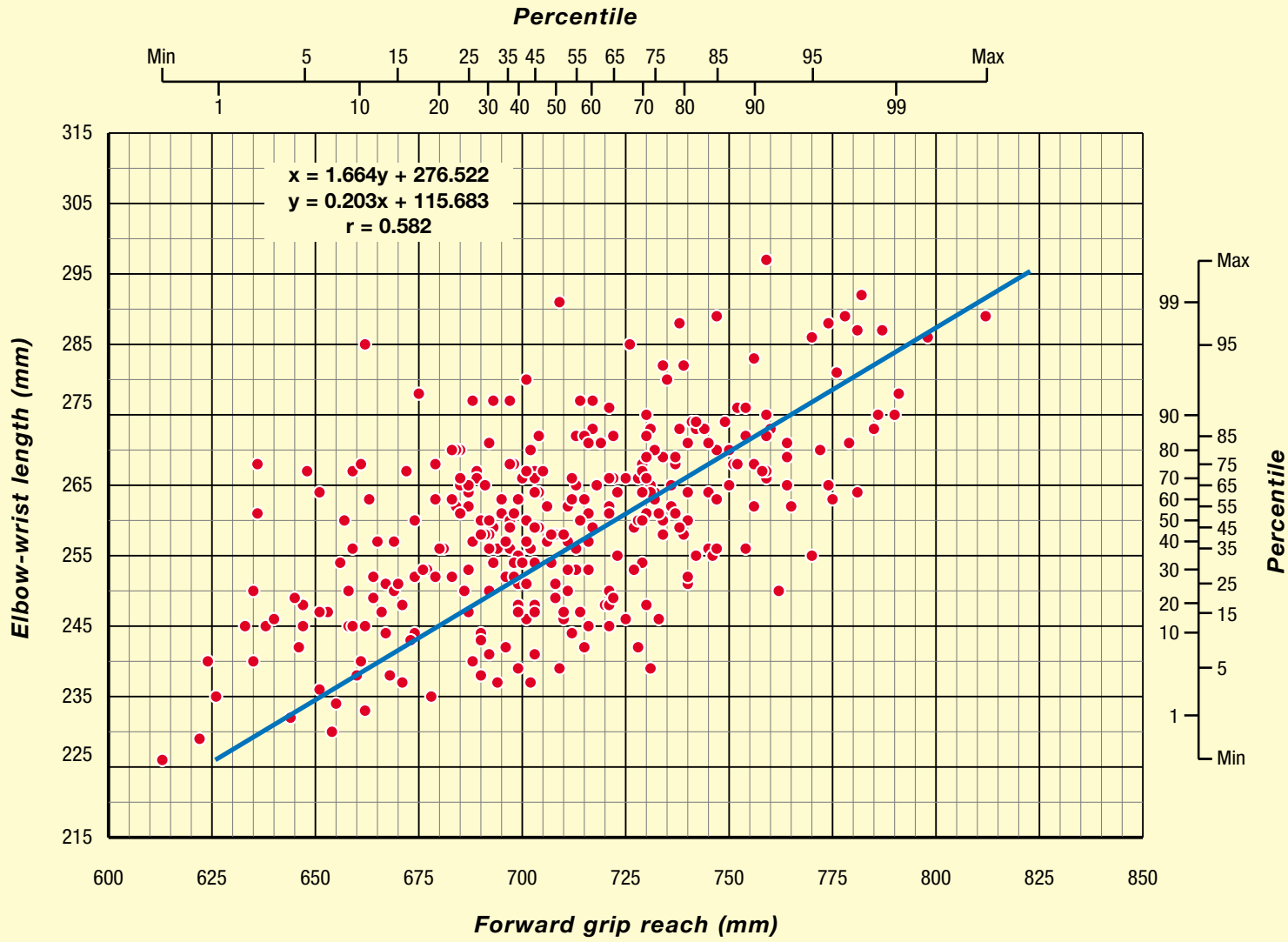








Forward Grip Reach
Elbow-wrist Length



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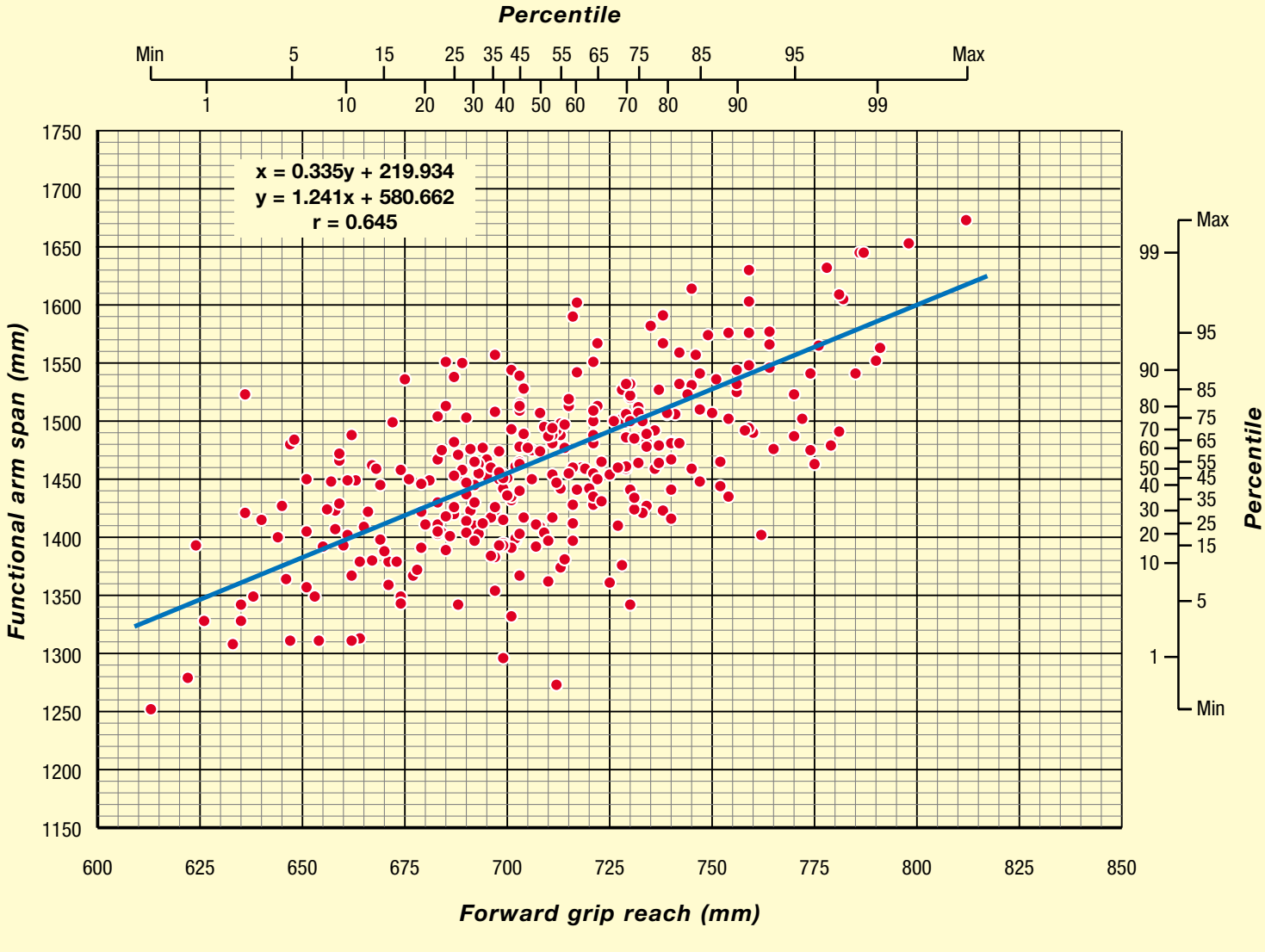
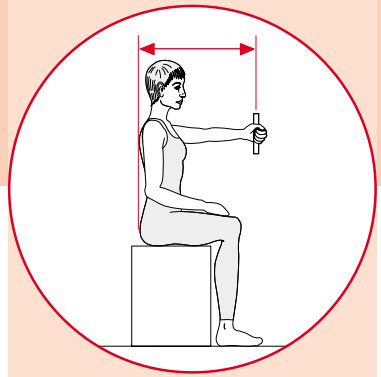
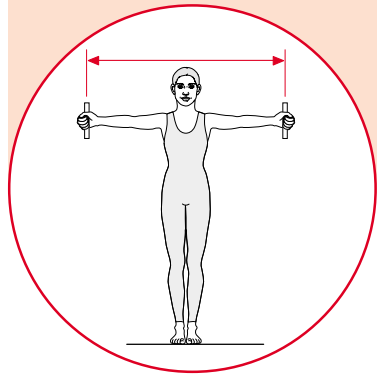
Forward Grip Reach
Functional Arm Span







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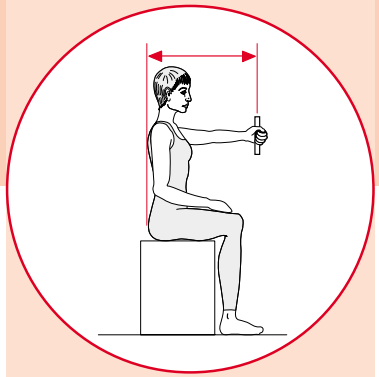
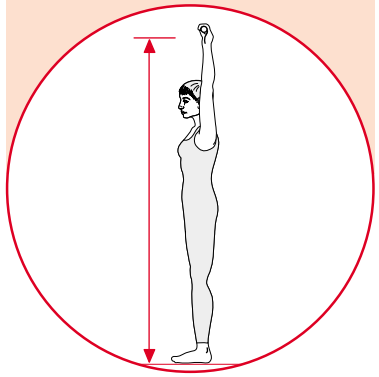
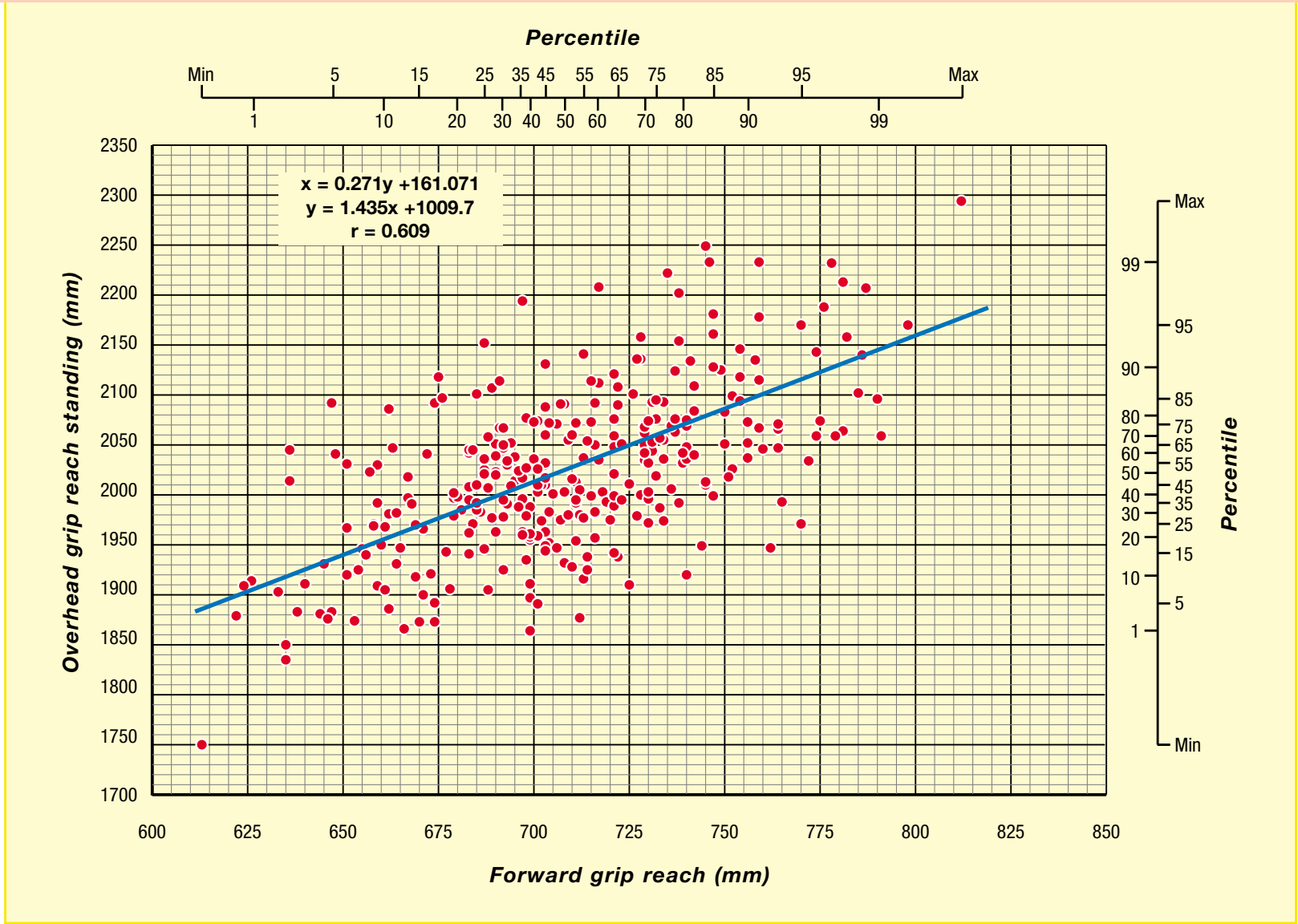
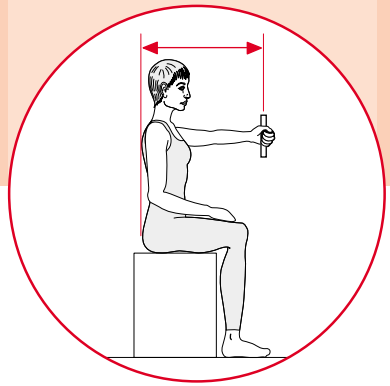


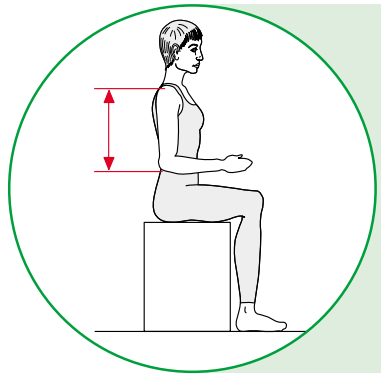


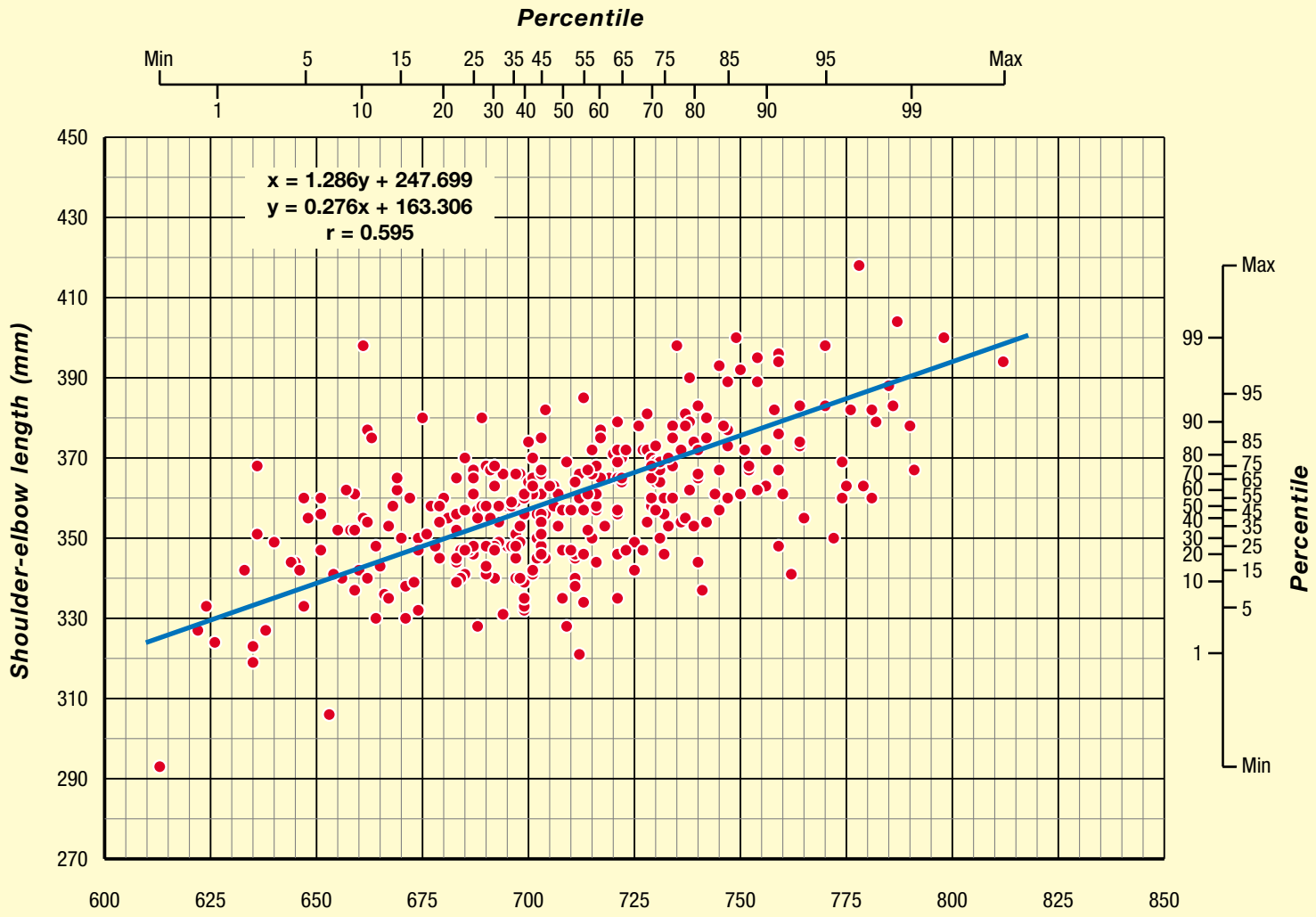
Forward Grip Reach
Overhead Grip Reach Standing



Forward Grip Reach
Shoulder-elbow Length







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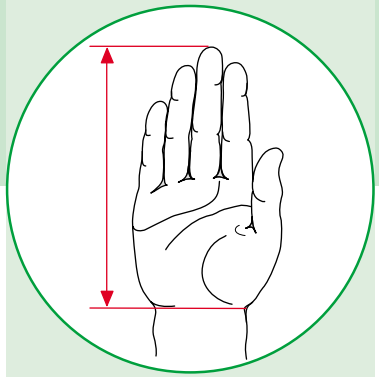
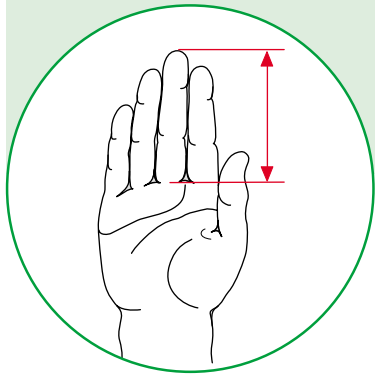
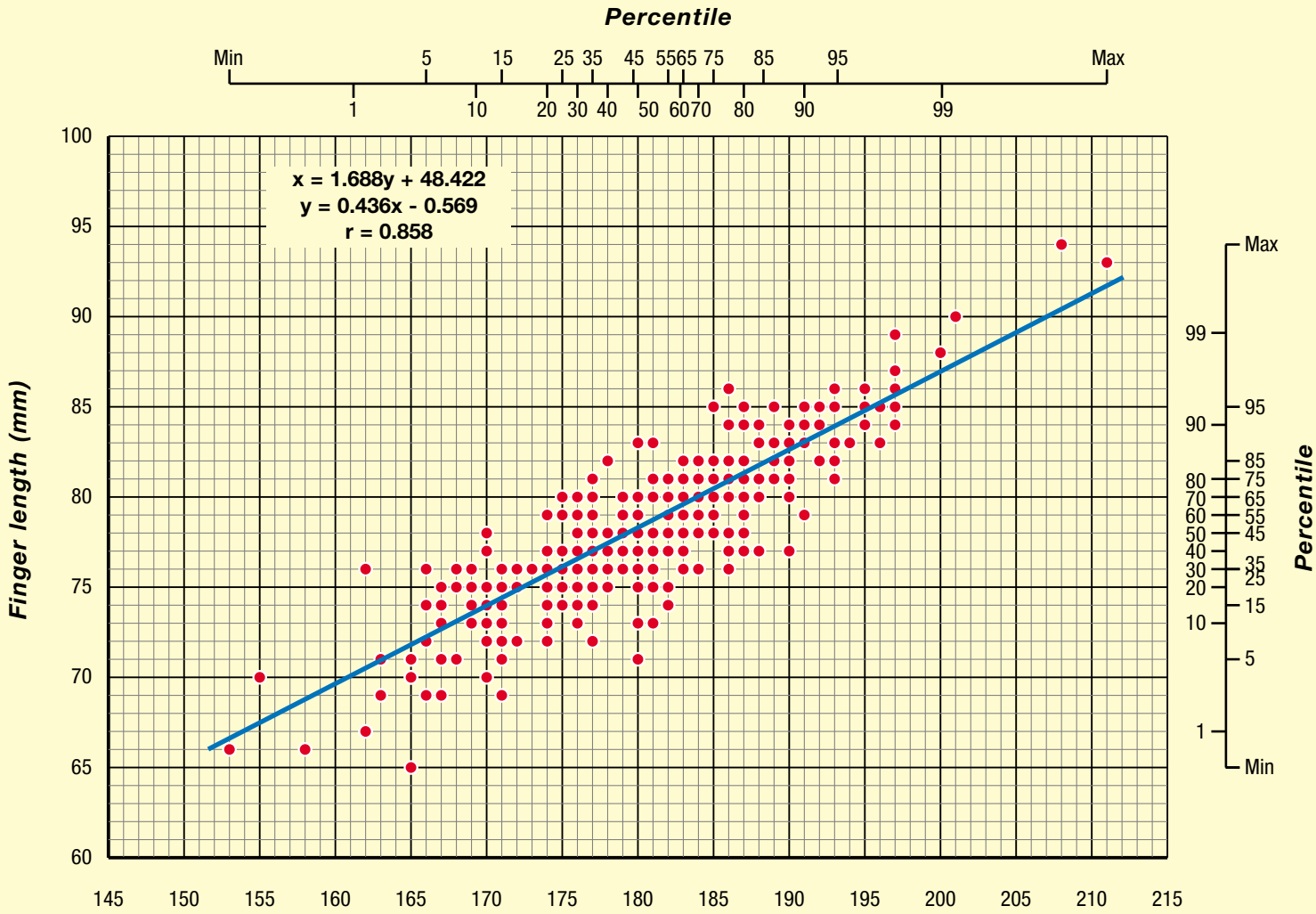
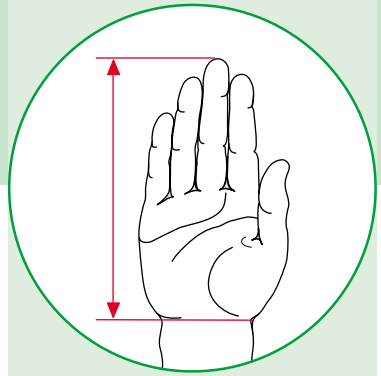


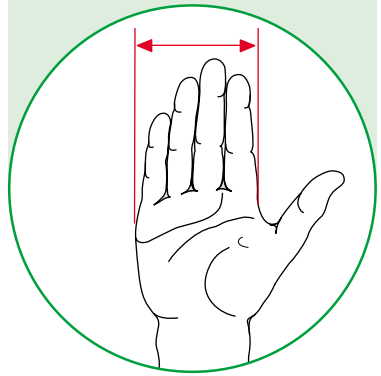


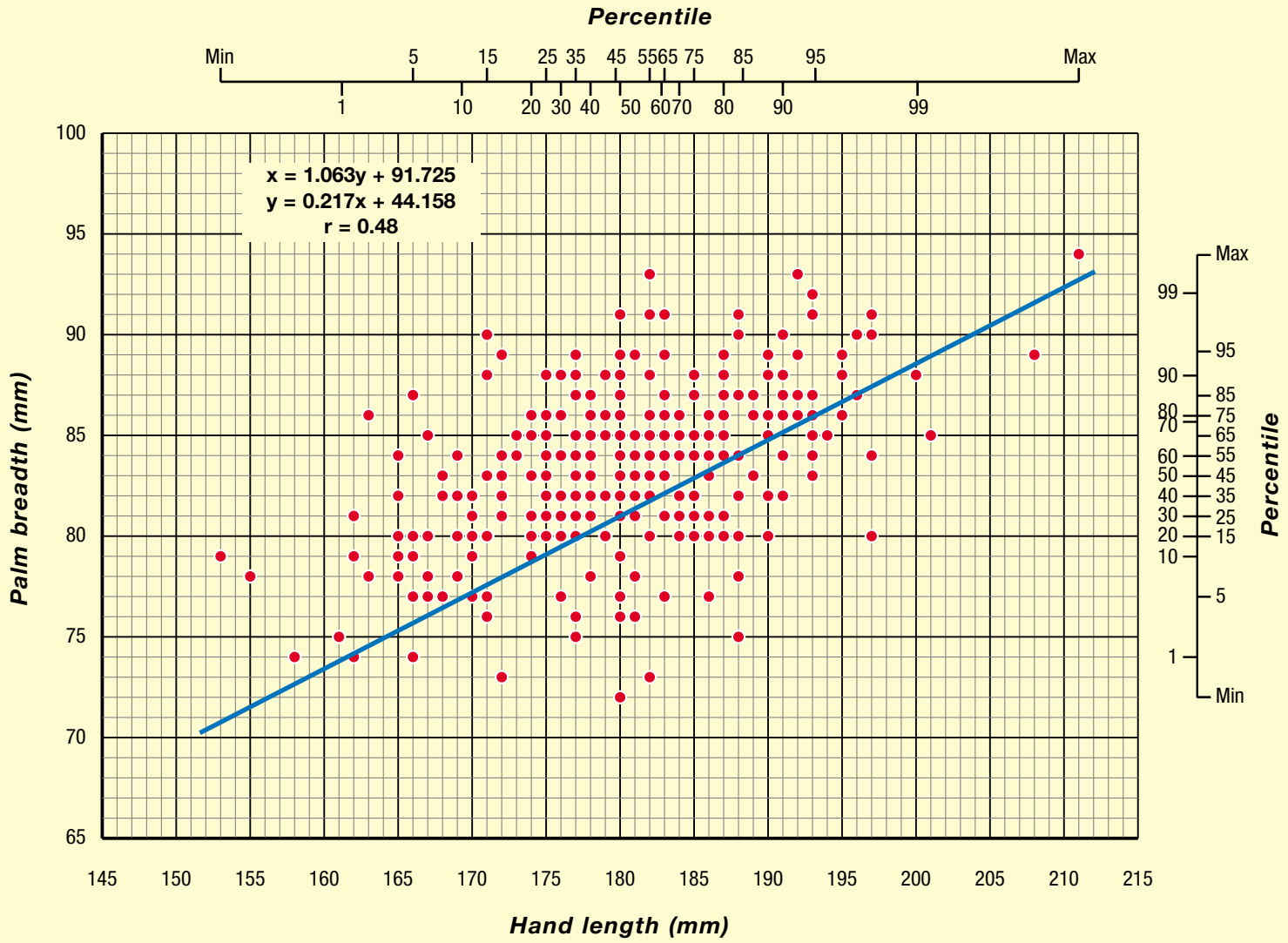
Hand Length
Finger Length

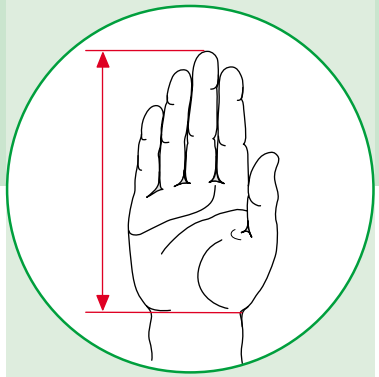


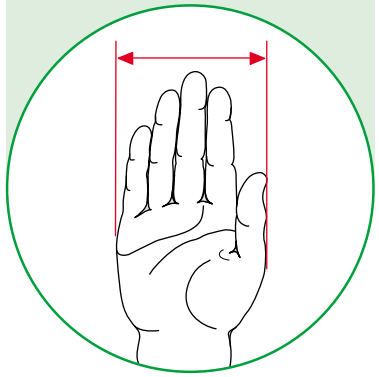
Hand length
Palm breadth



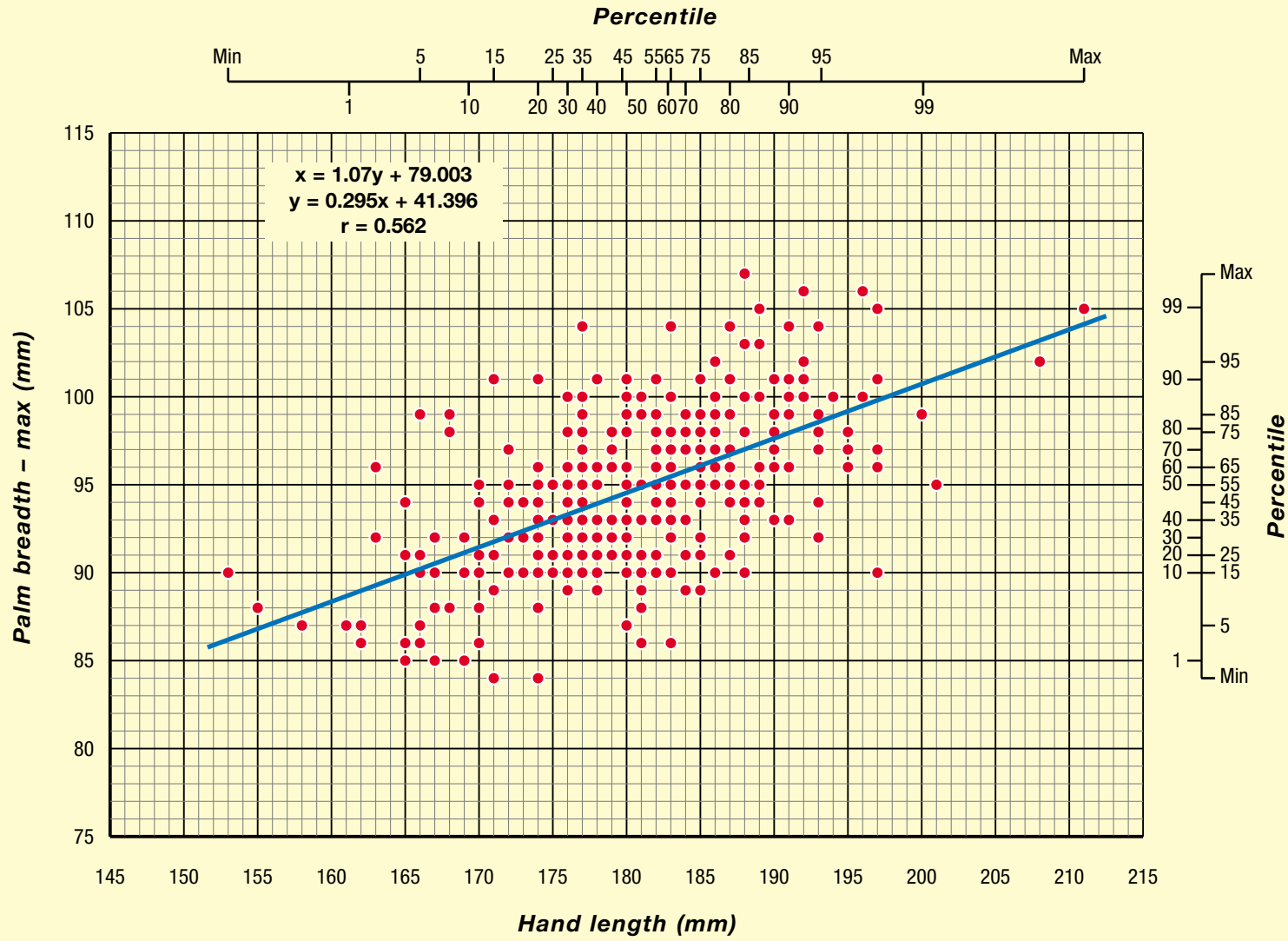




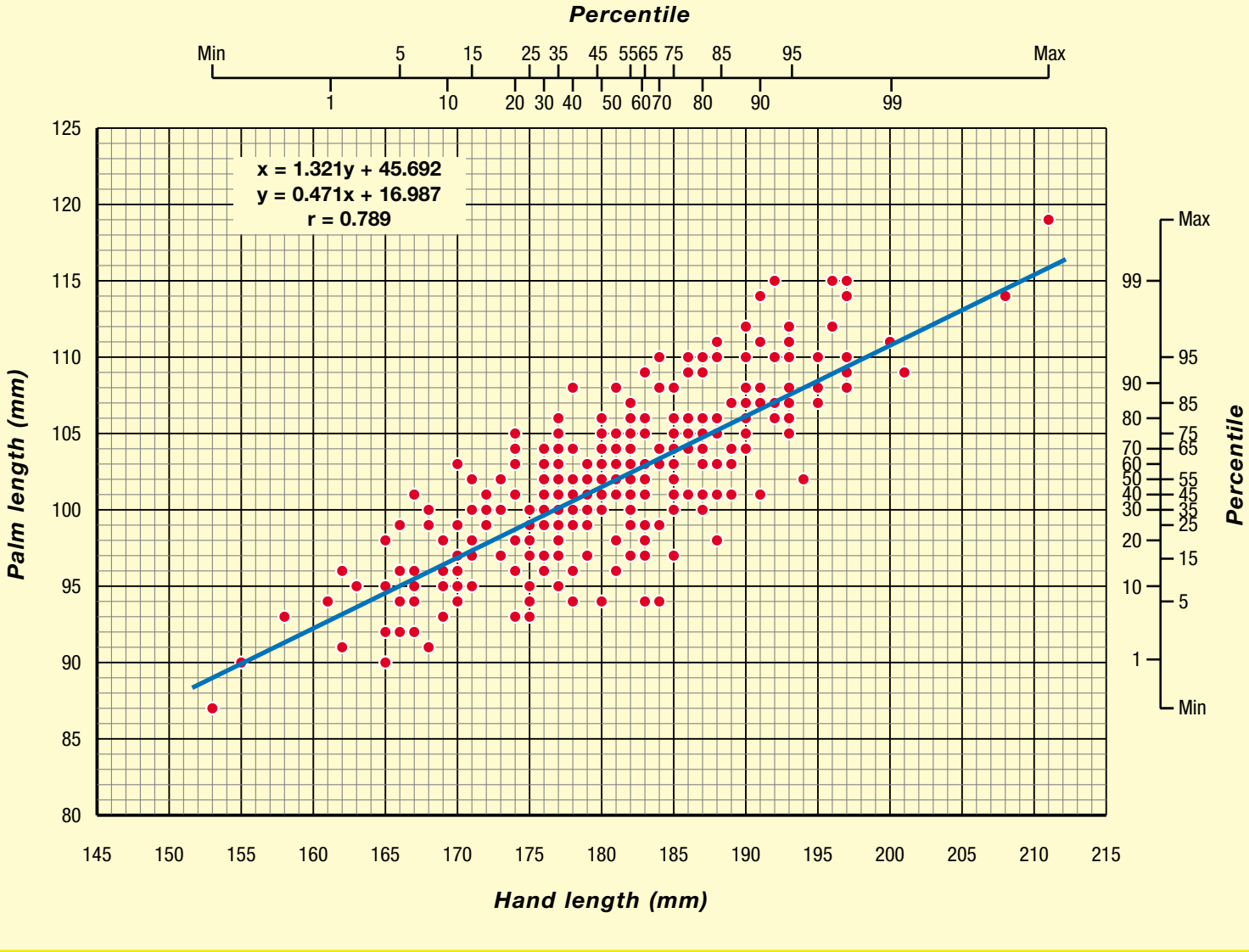


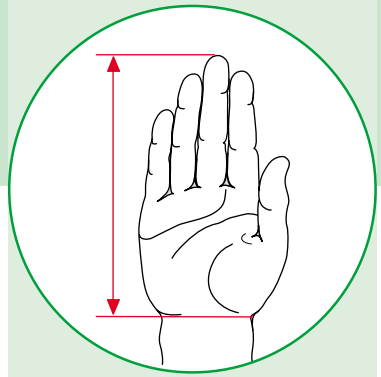


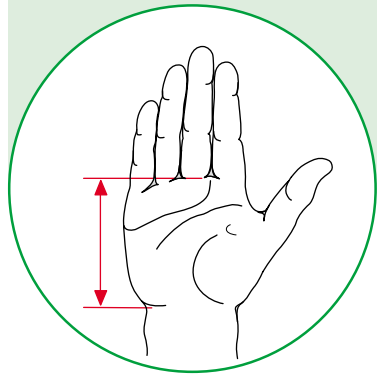
Hand Length
Palm Breadth – max

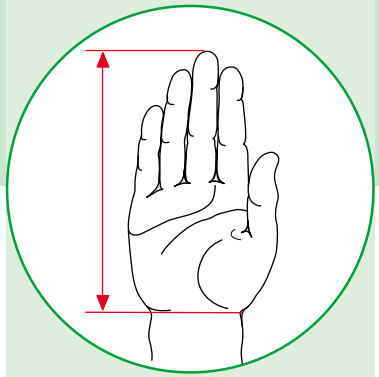


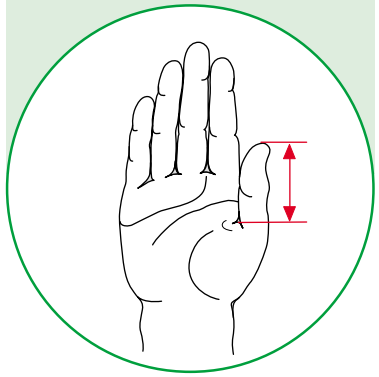
Hand length
Palm length



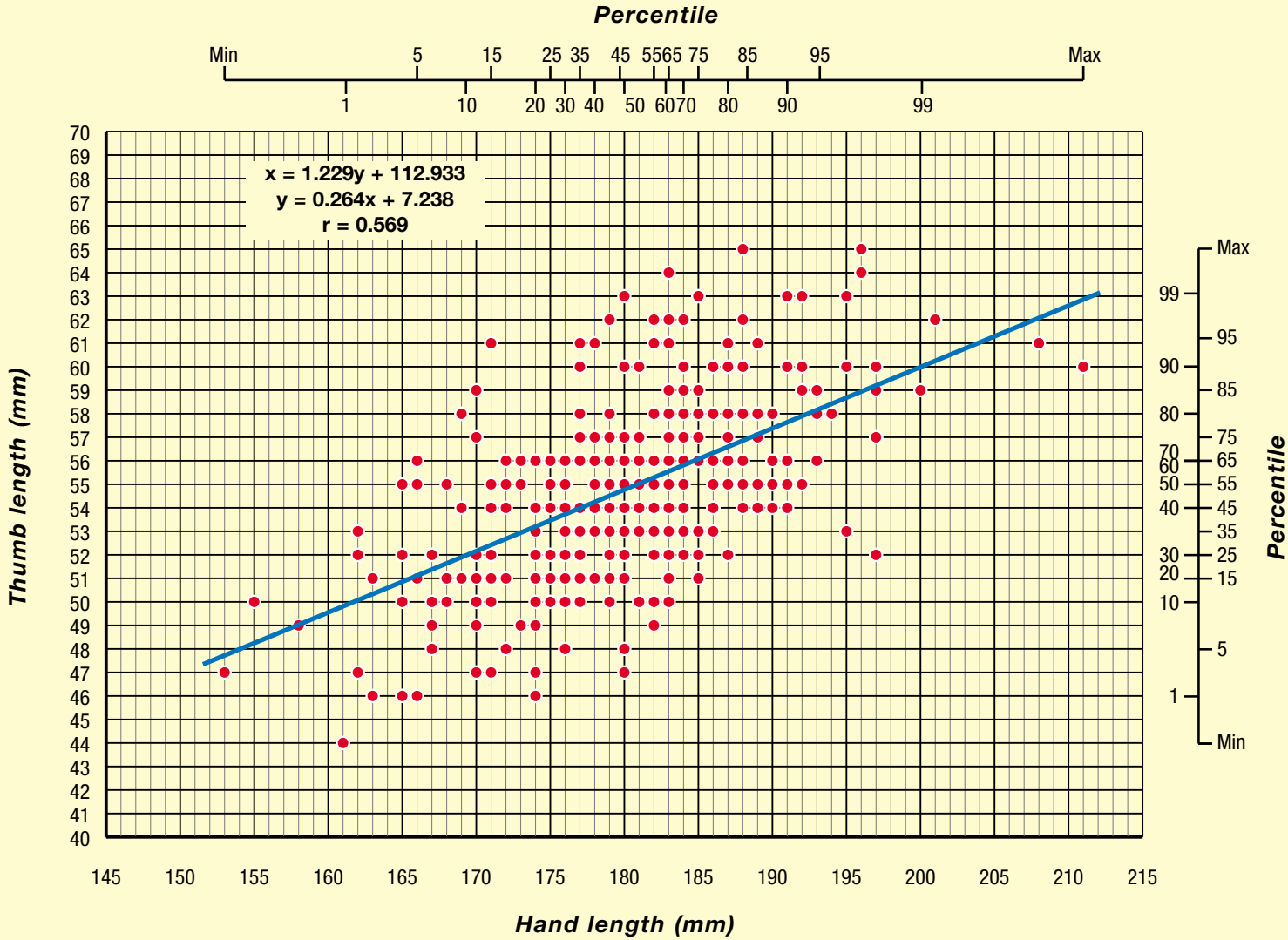




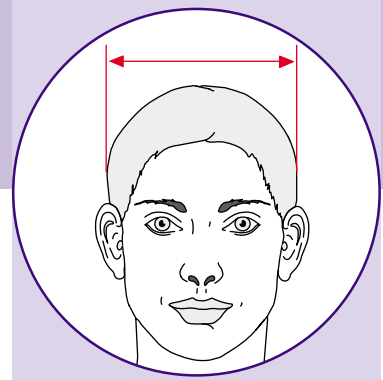


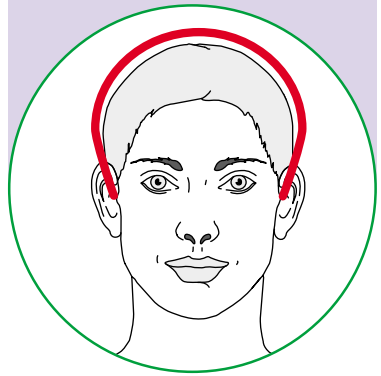


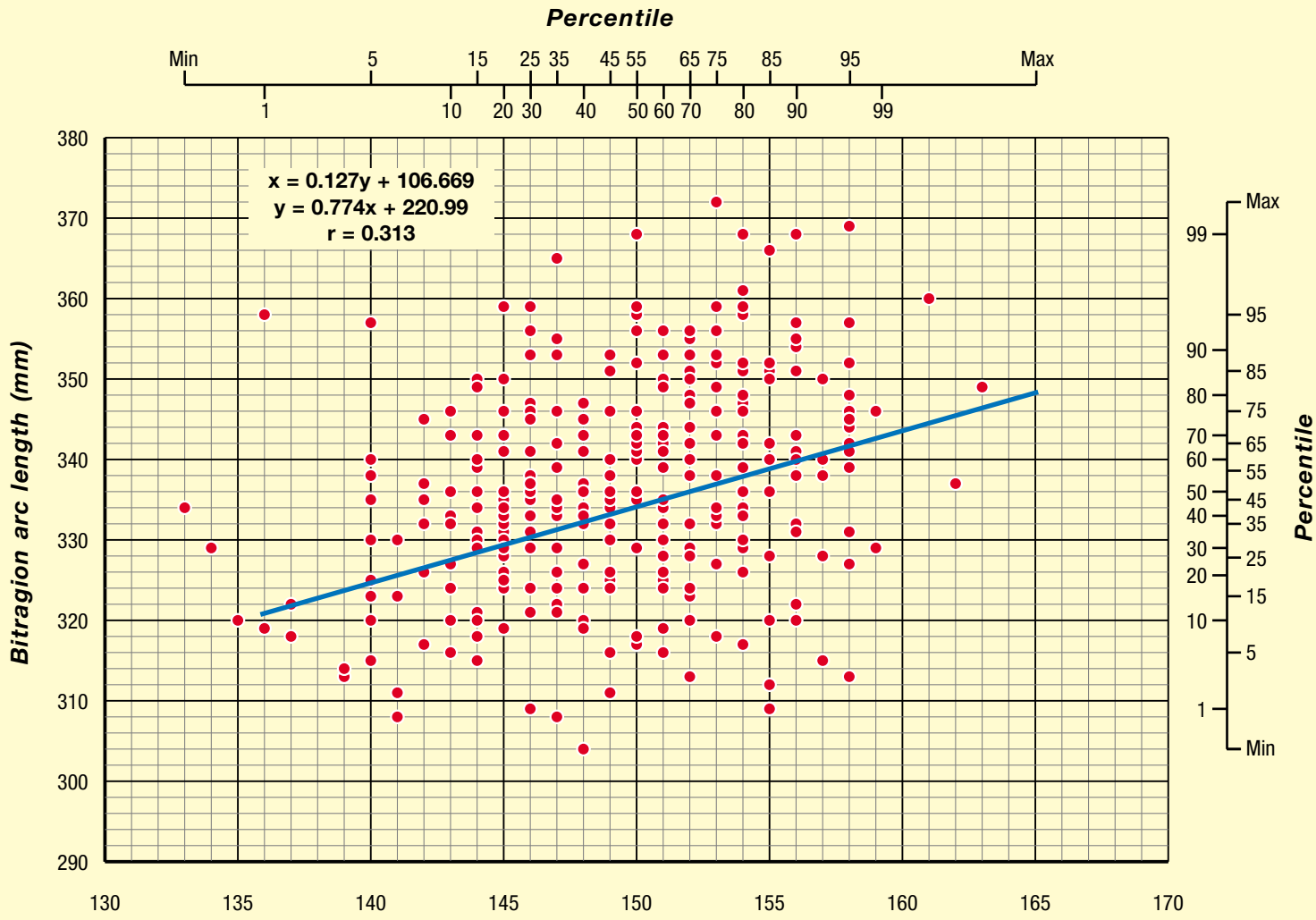
Hand Length
Thumb Length



Head Breadth
Bitragion Arc Length







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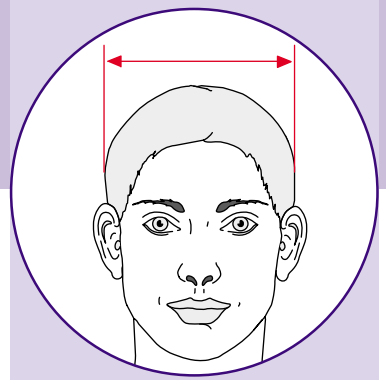
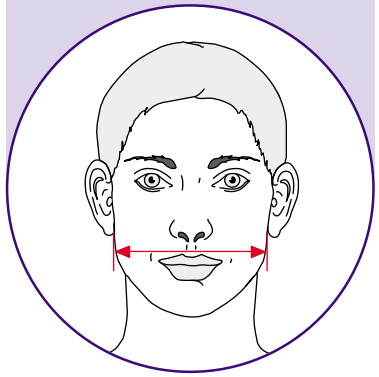
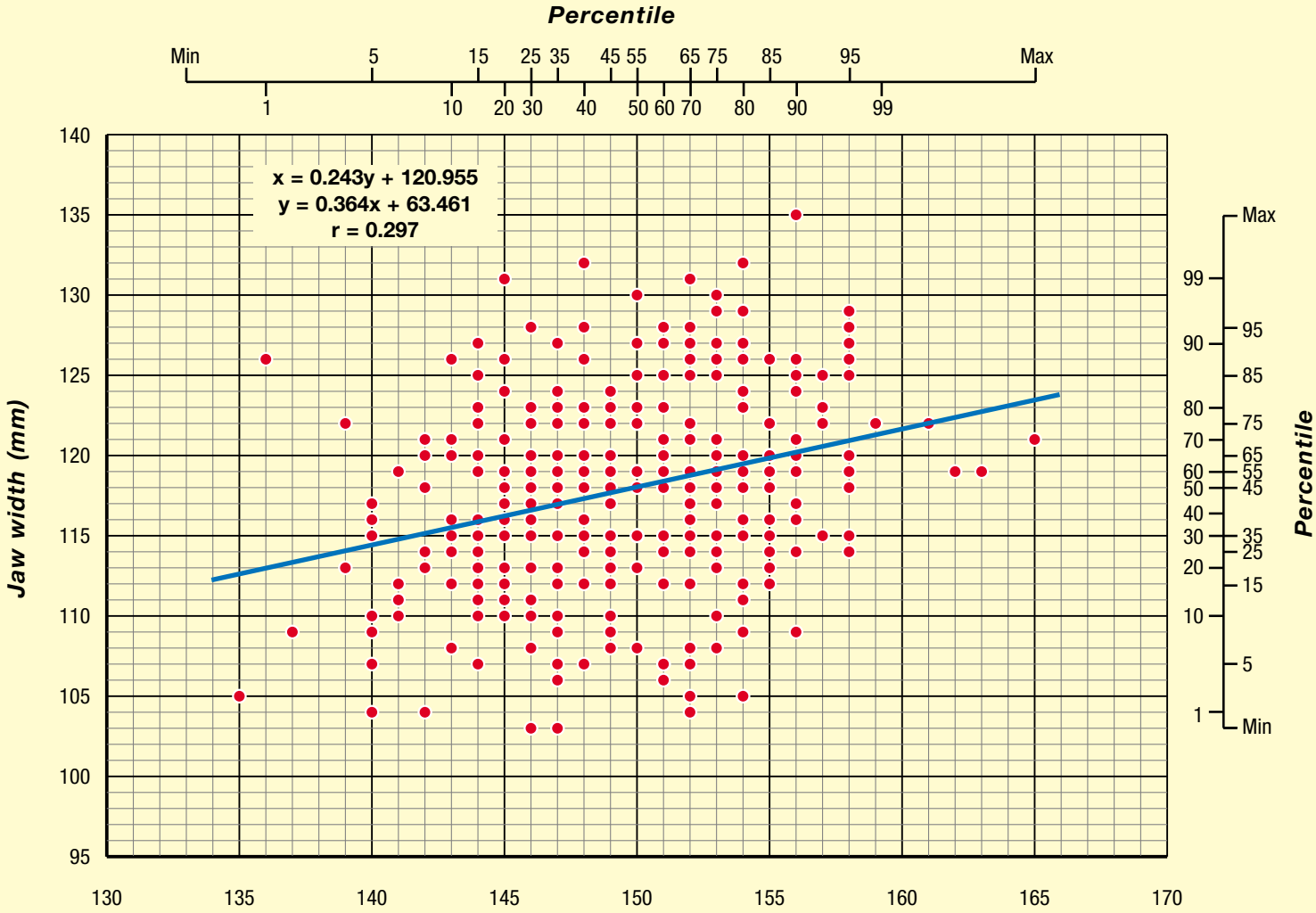
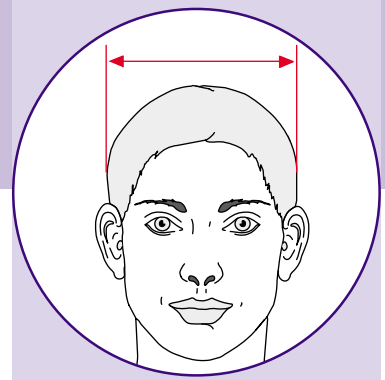


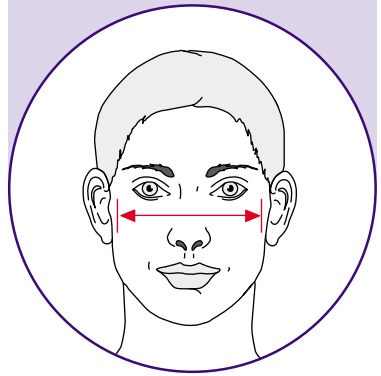


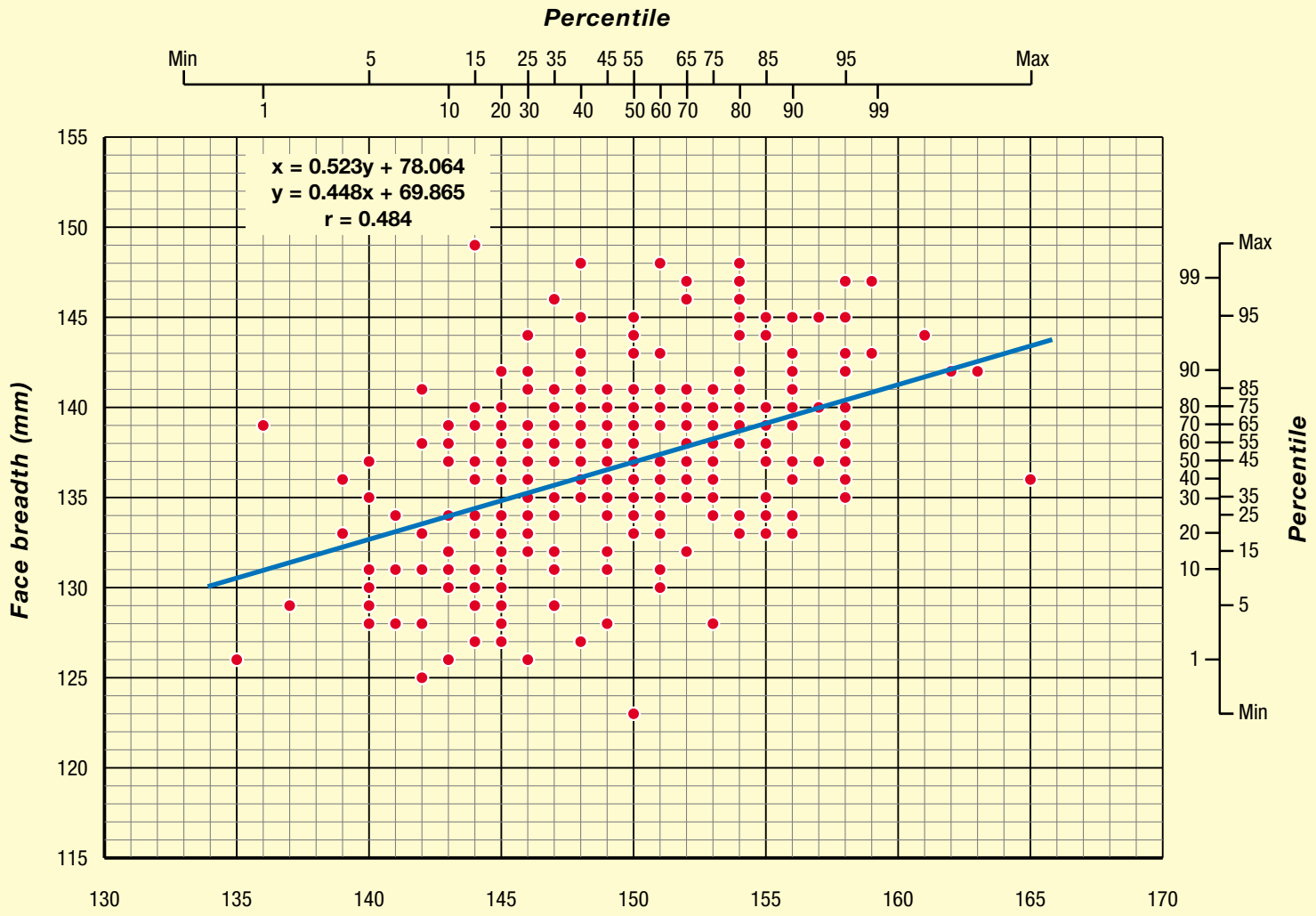
Head Breadth
Jaw Width

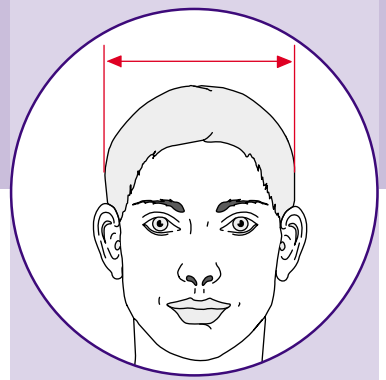


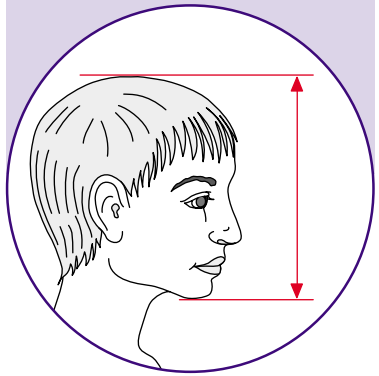
Head Breadth
Face Breadth



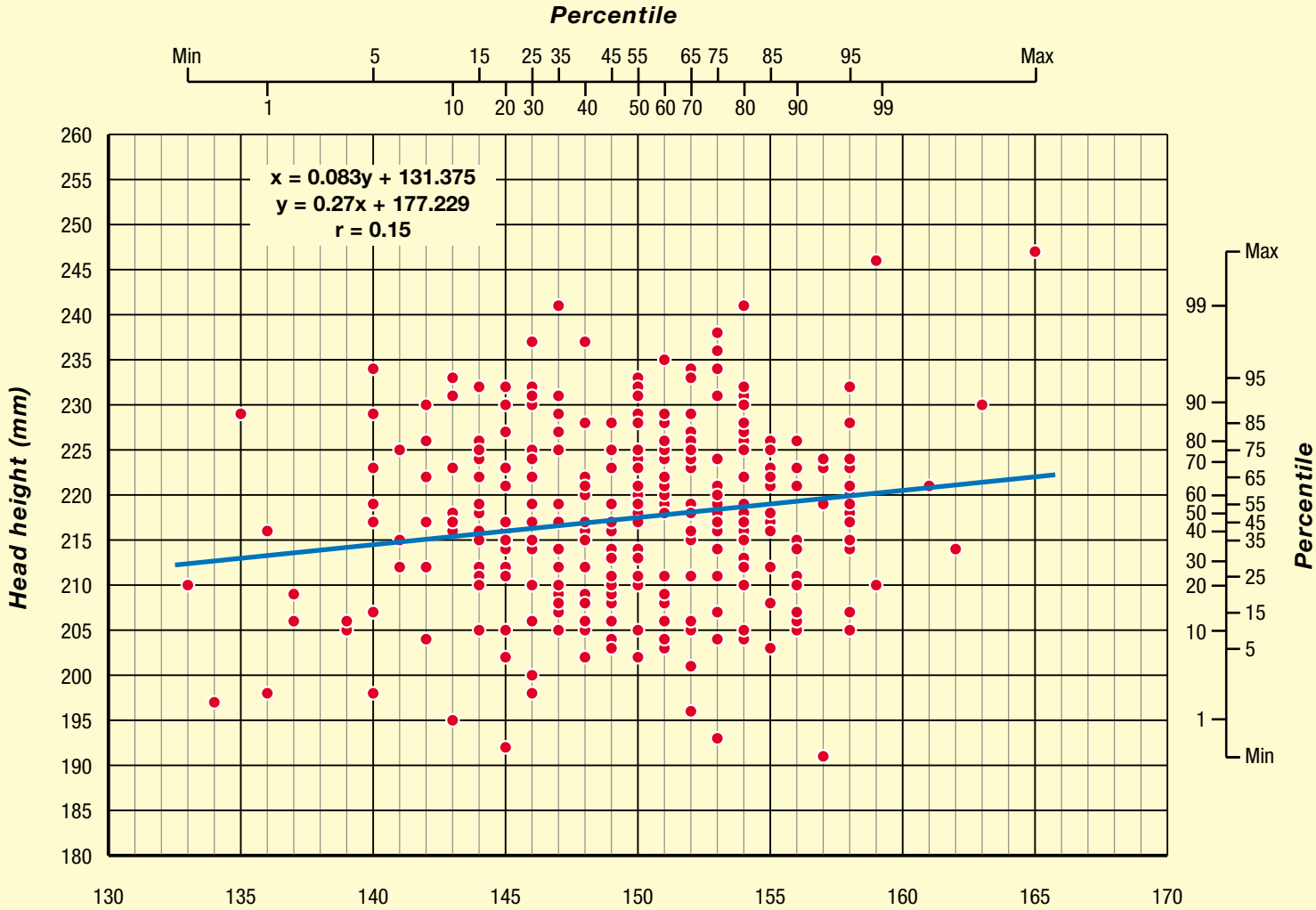




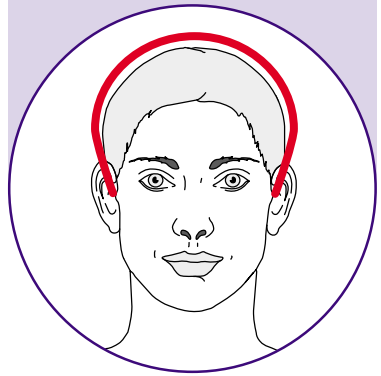


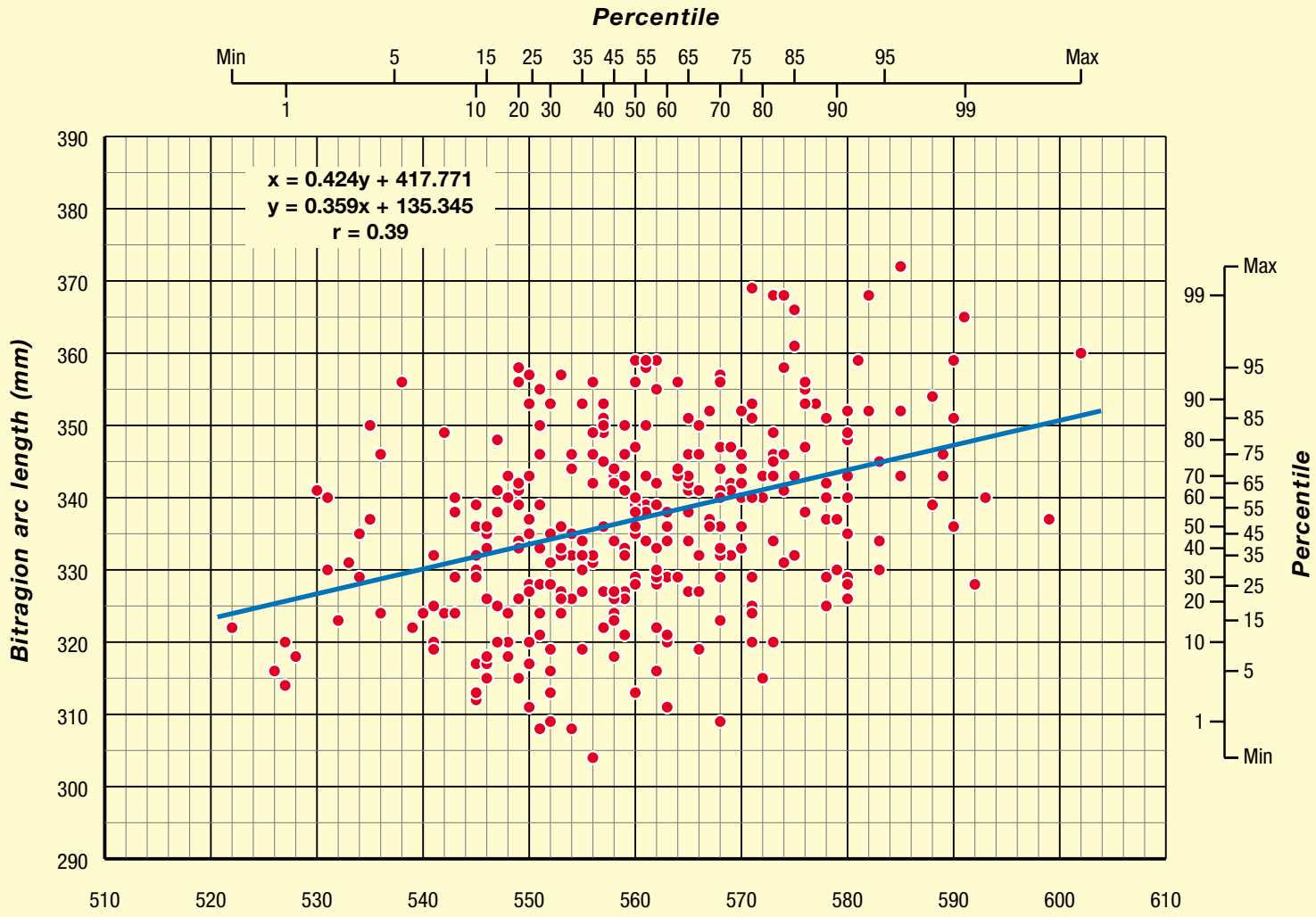


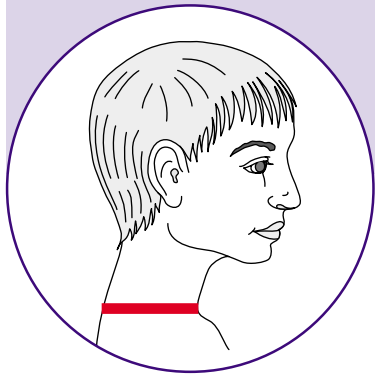
Head Breadth
Head Height



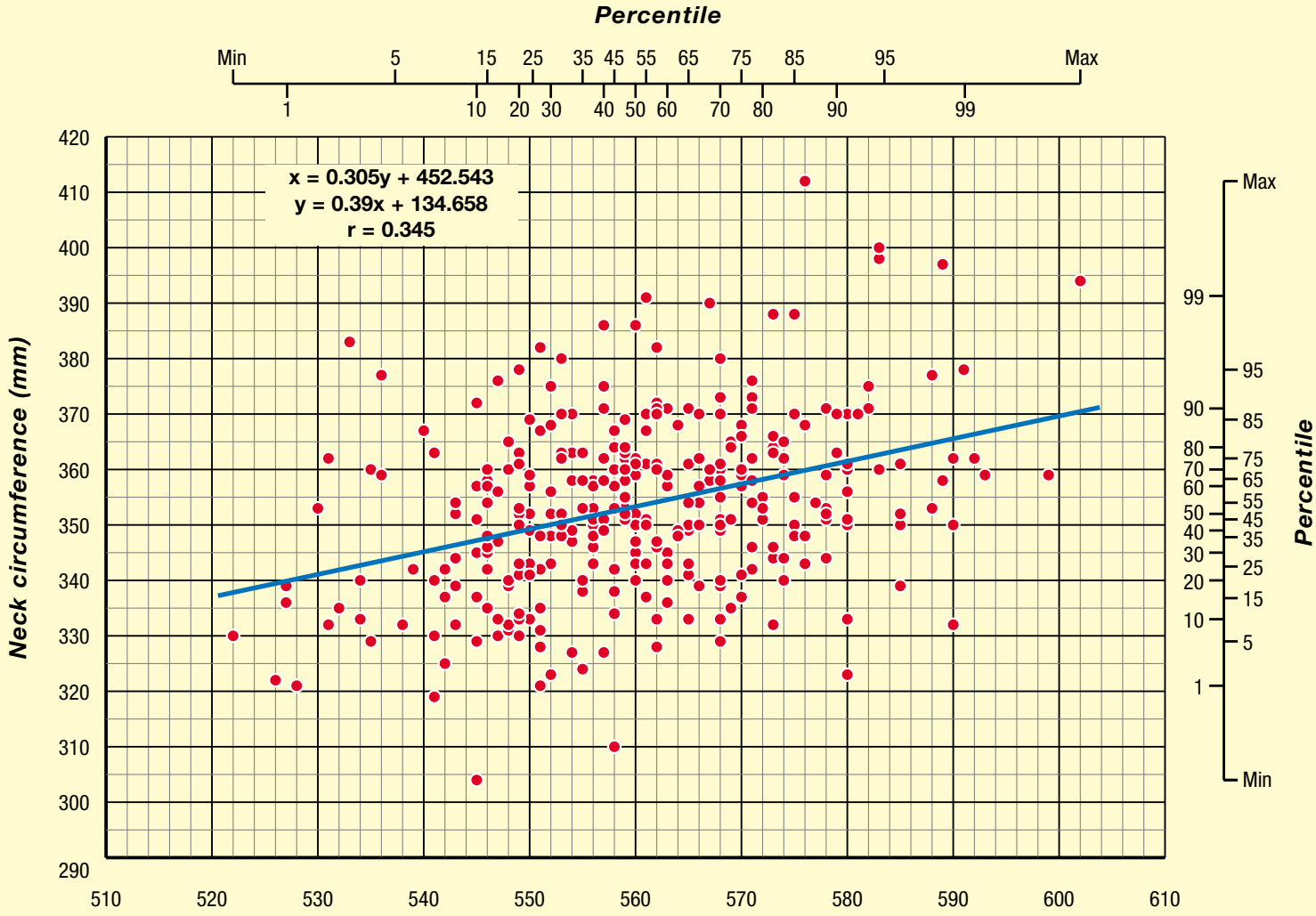
Head Circumference
Bitragion Arc length



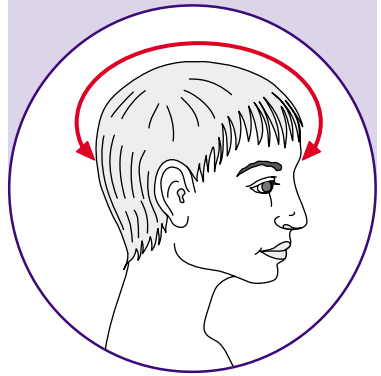


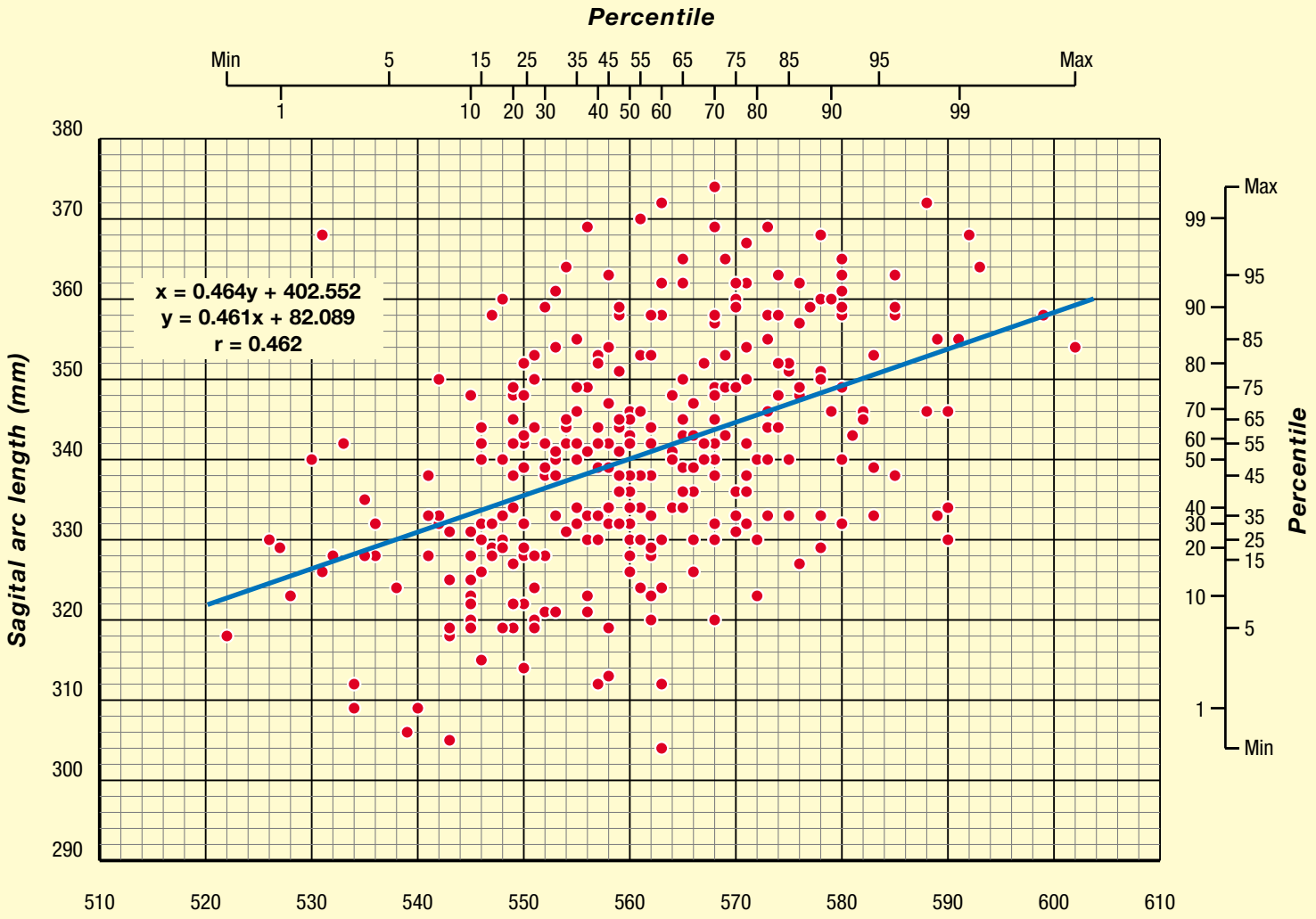


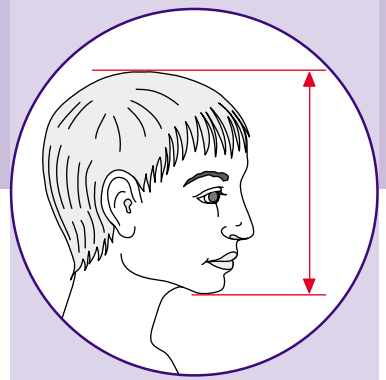
Head Circumference
Neck Circumference

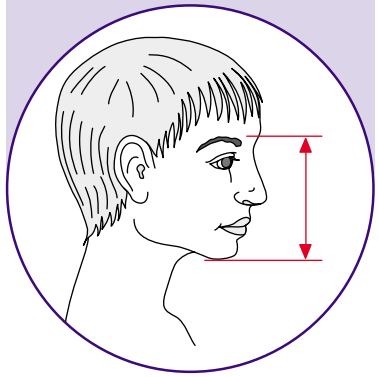


Head Circumference
Sagital Arc Length

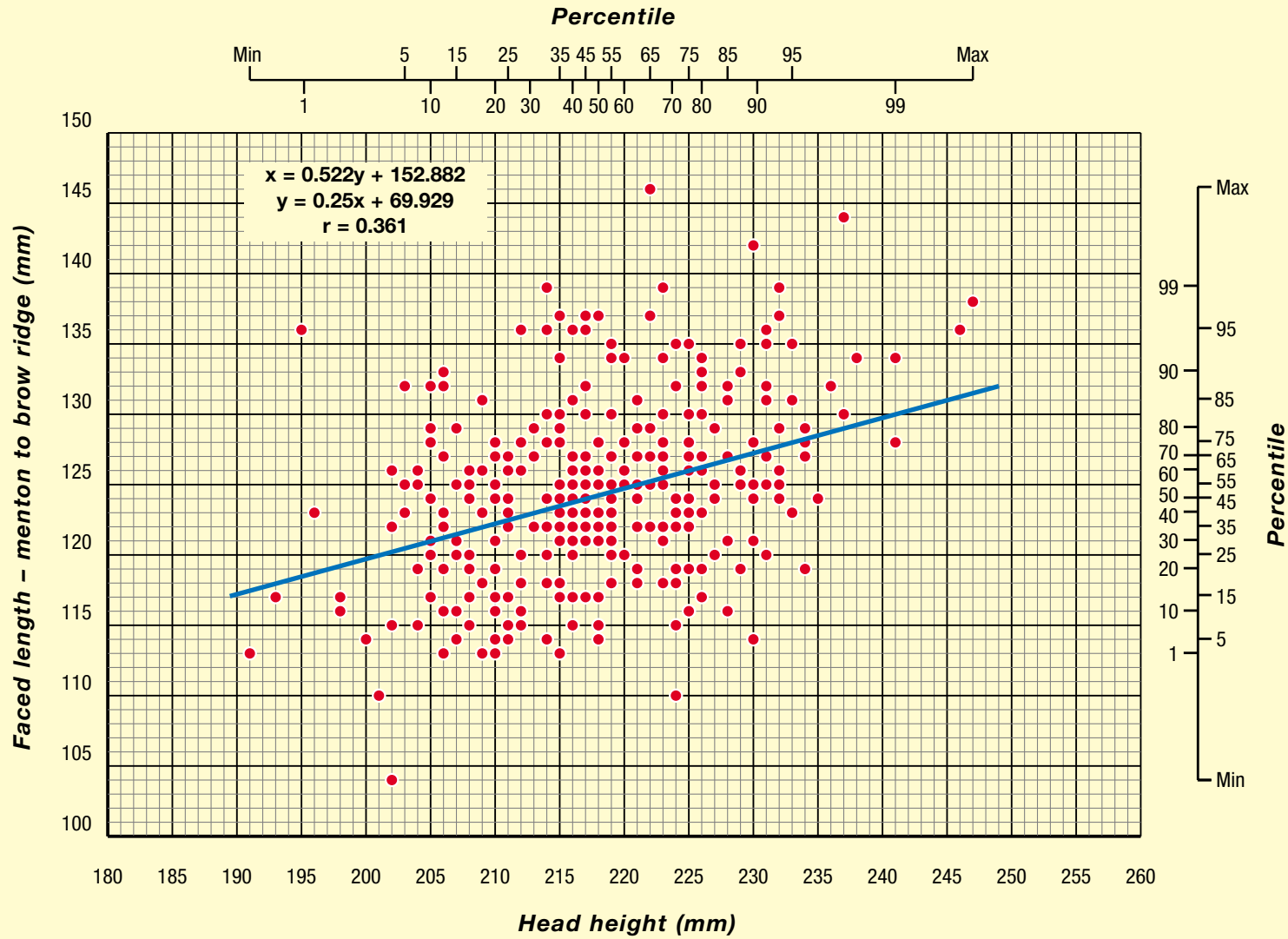




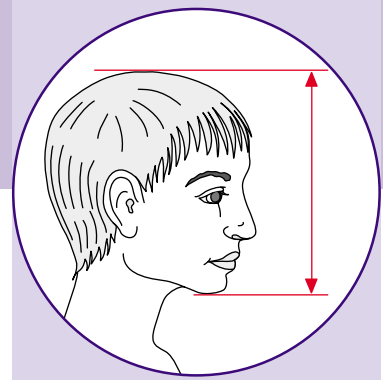


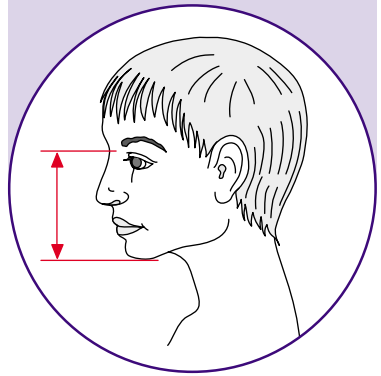


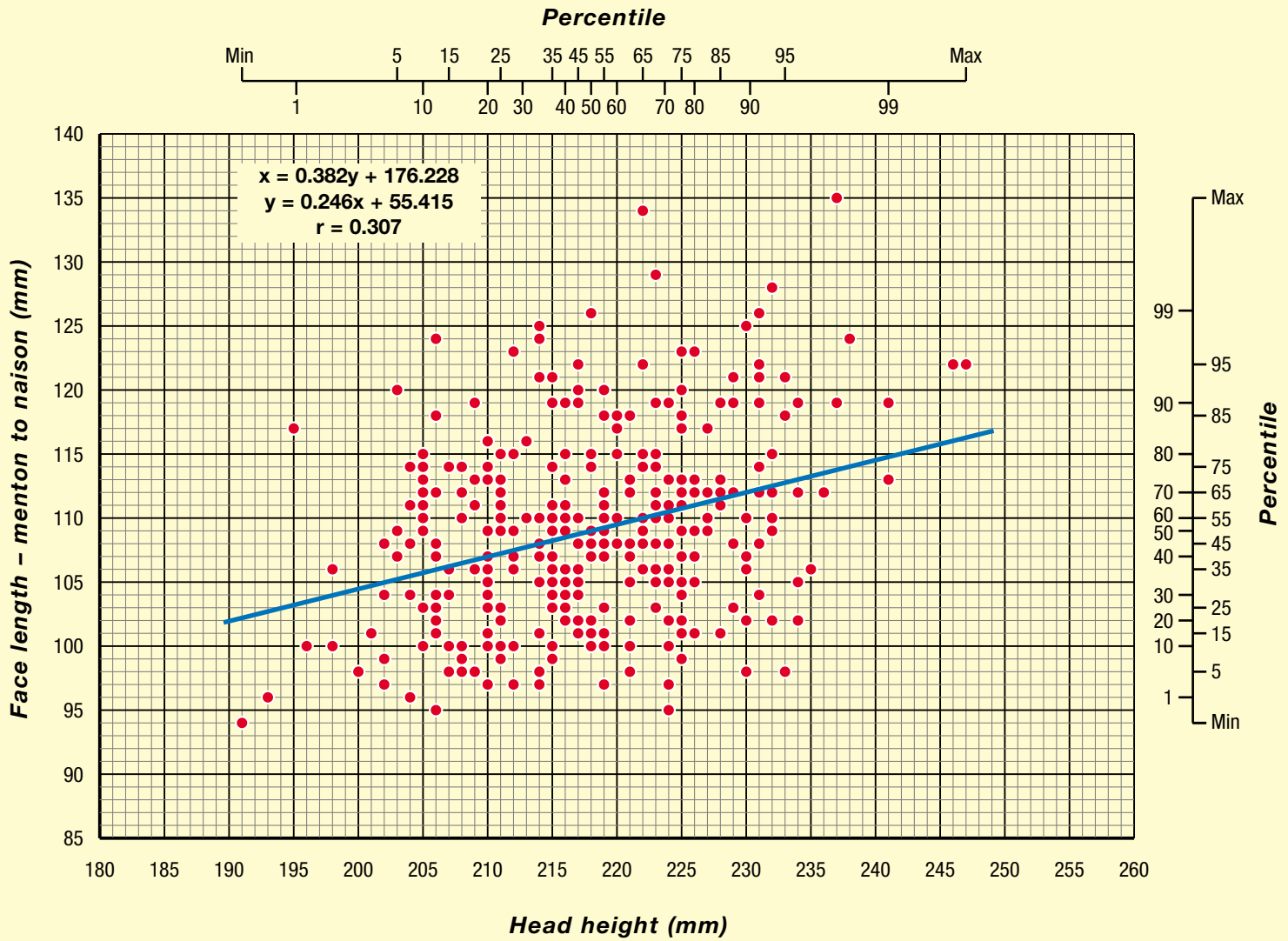
Head Height
Face Length – menton to brow ridge

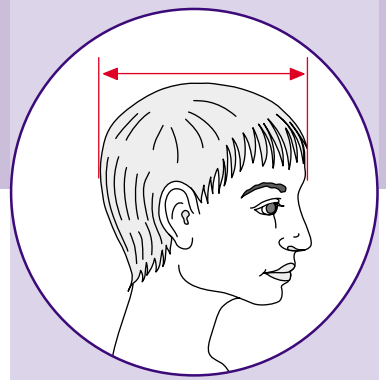


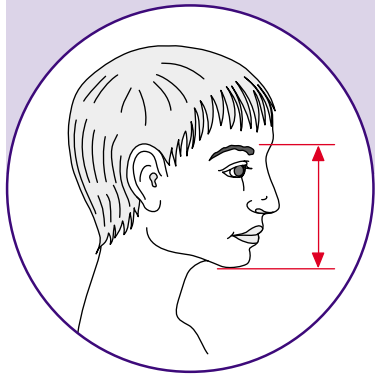
Head Height
Face Length – menton to naison



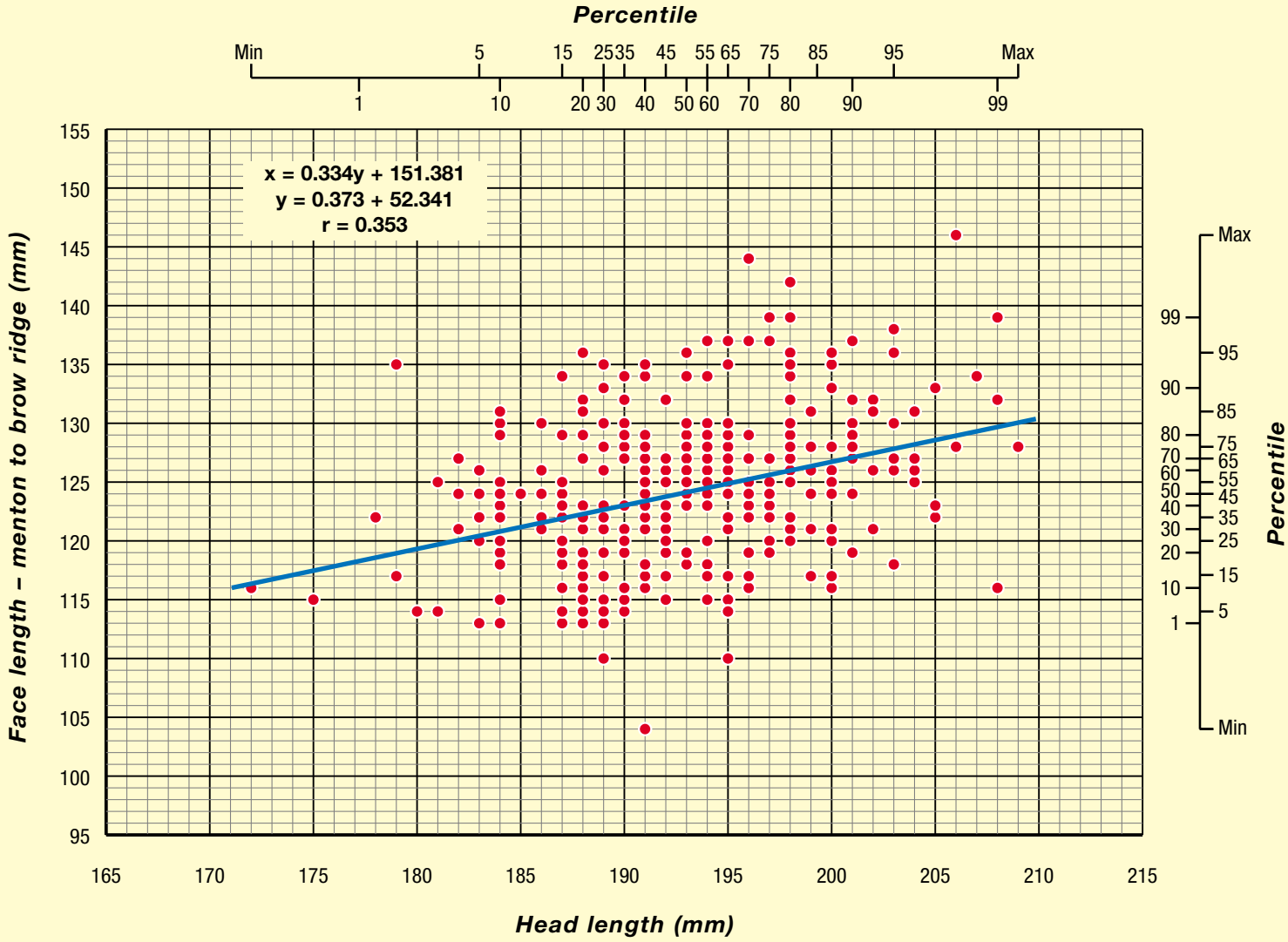




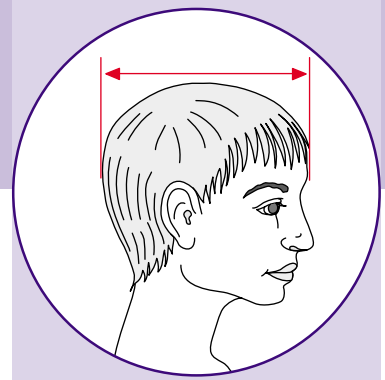


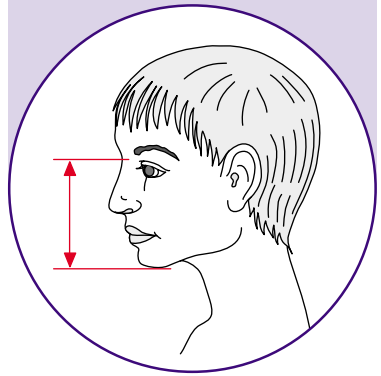


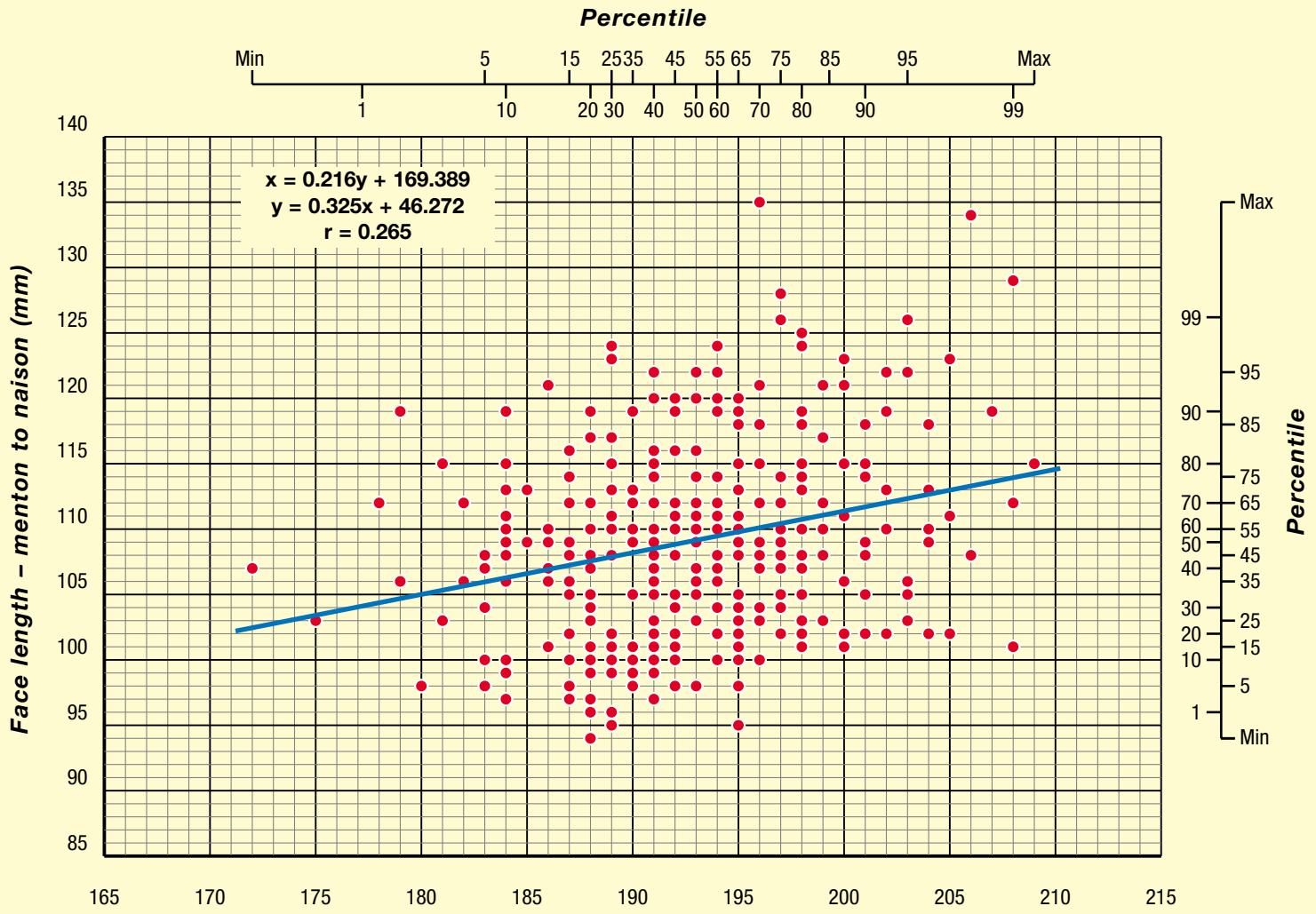
Head Length
Face Length – menton to brow ridge

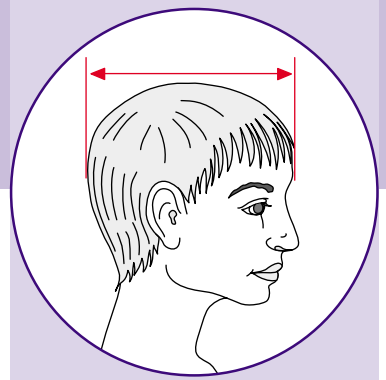


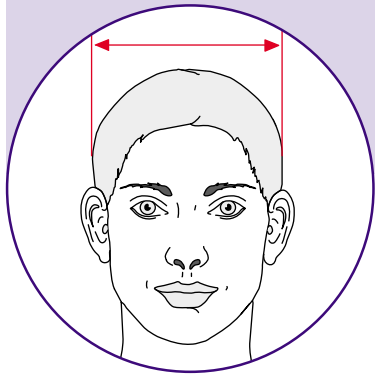
Head Length
Face Length – menton to naison



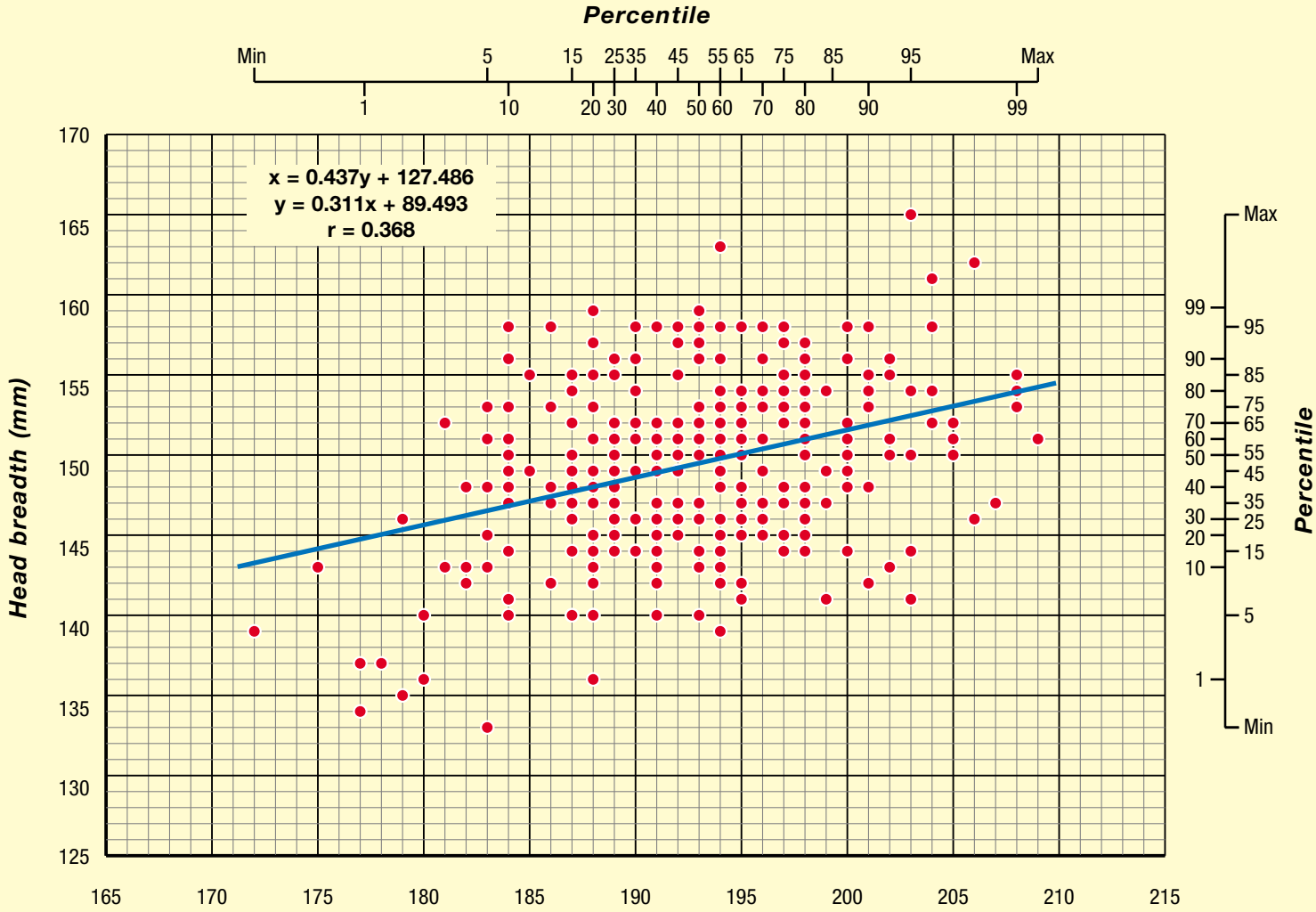




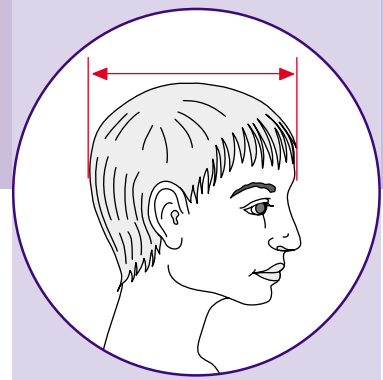


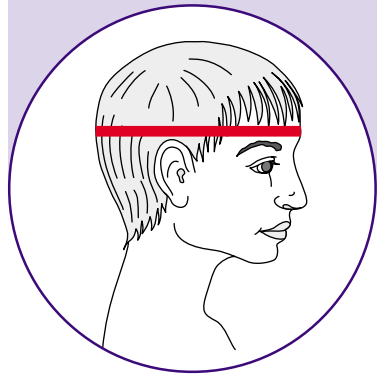


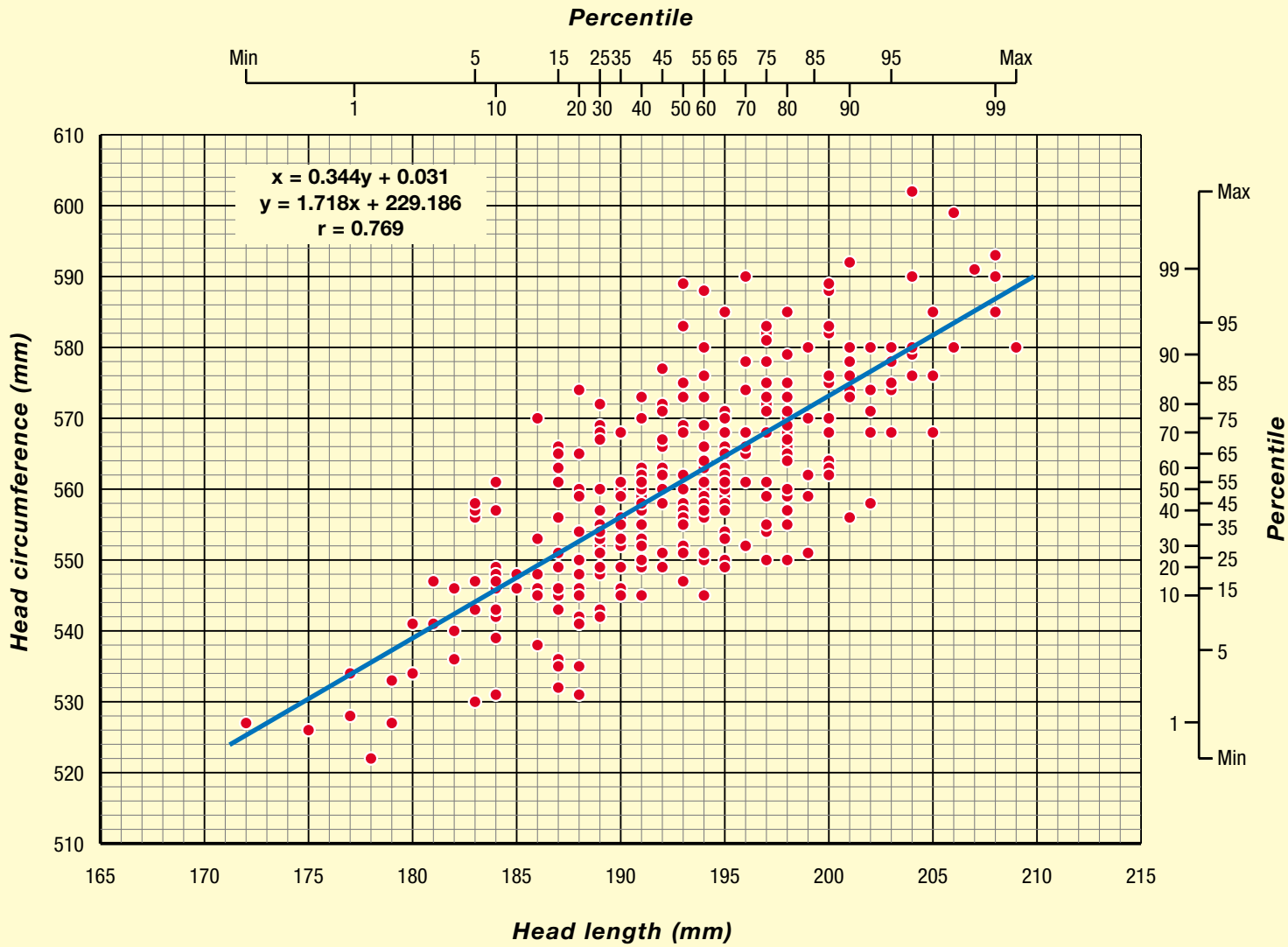
Head Length
Head Breadth

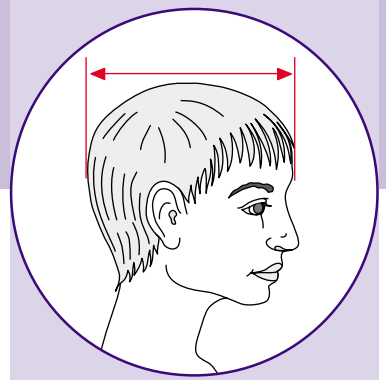


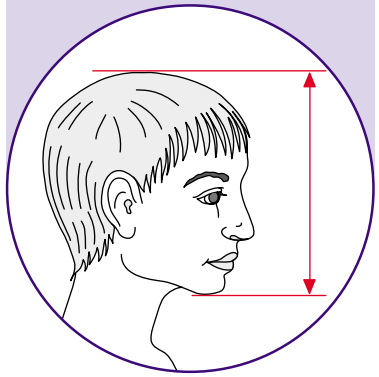
Head Length
Head Circumference



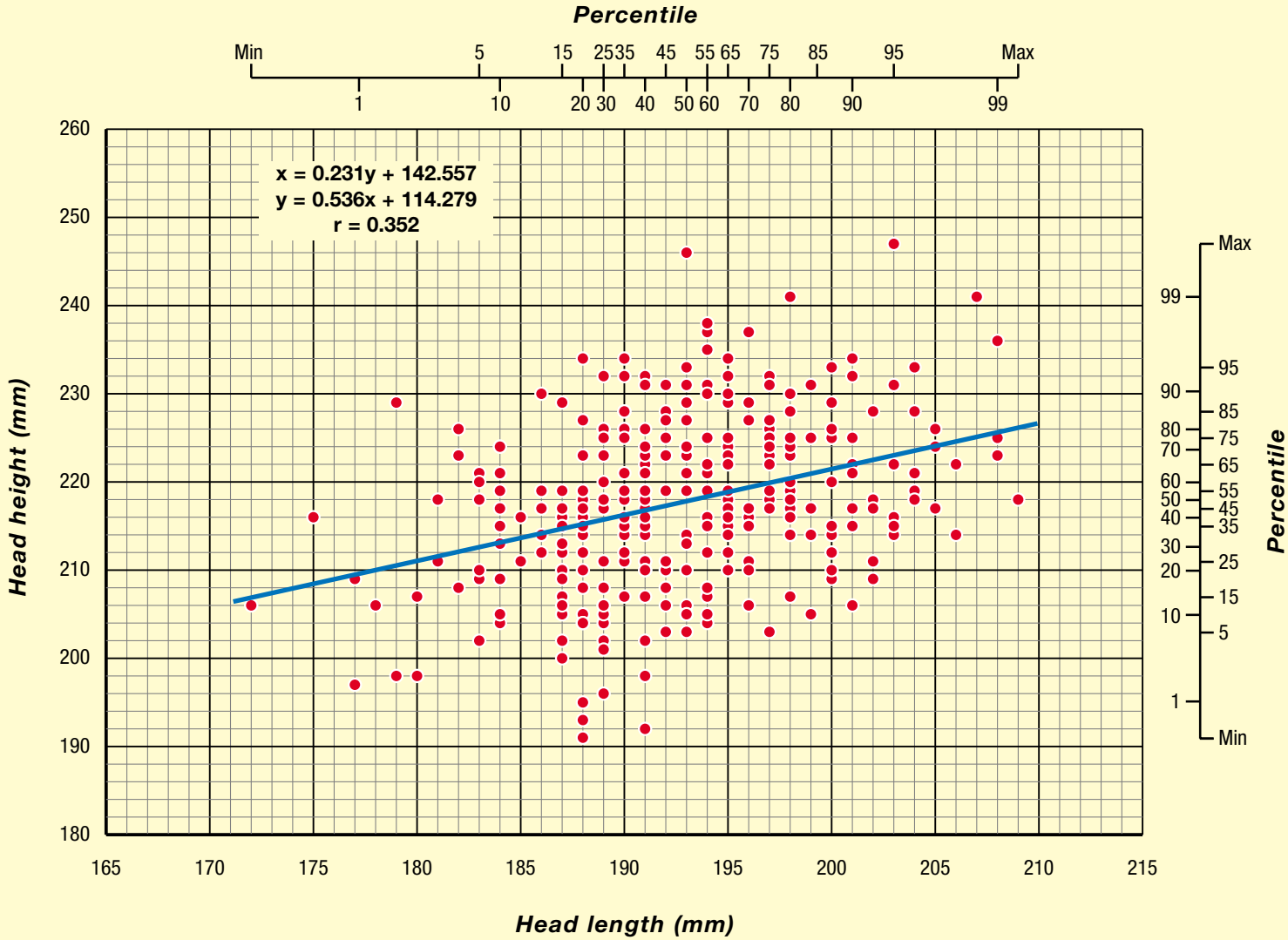




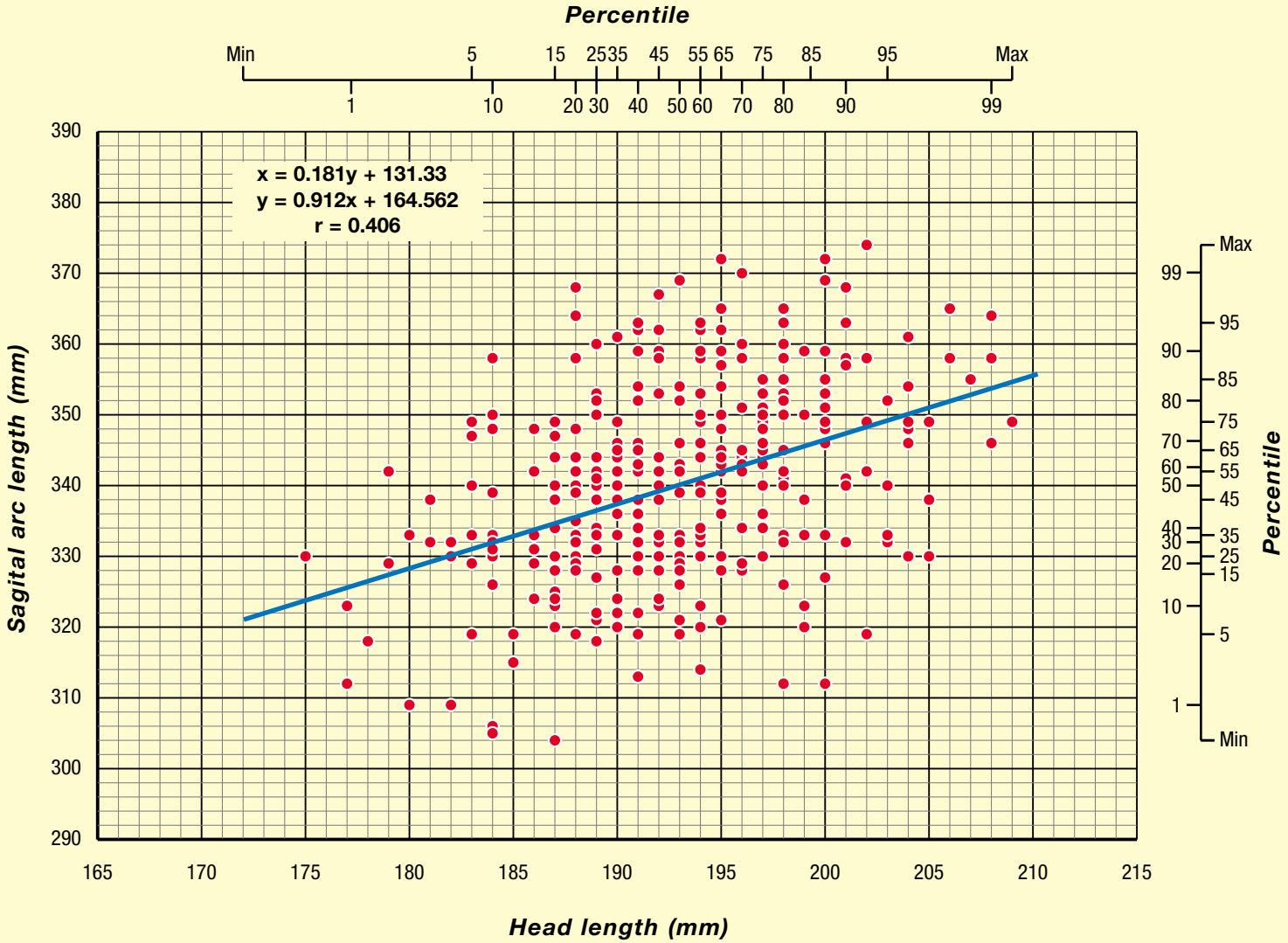


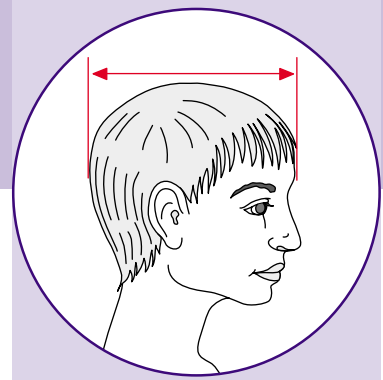


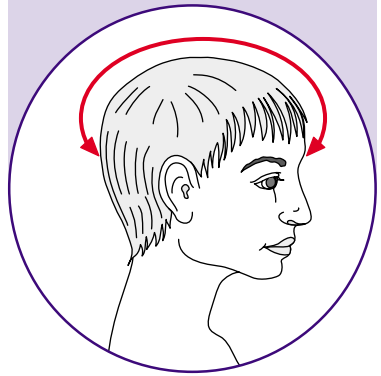
Head Length
Head Height

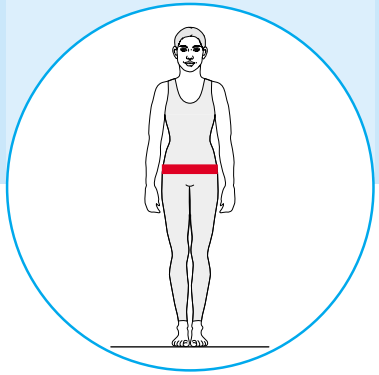


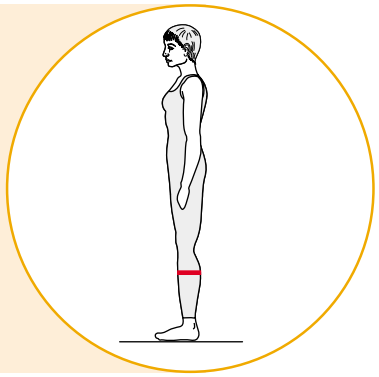
Head Length
Sagital Arc Length



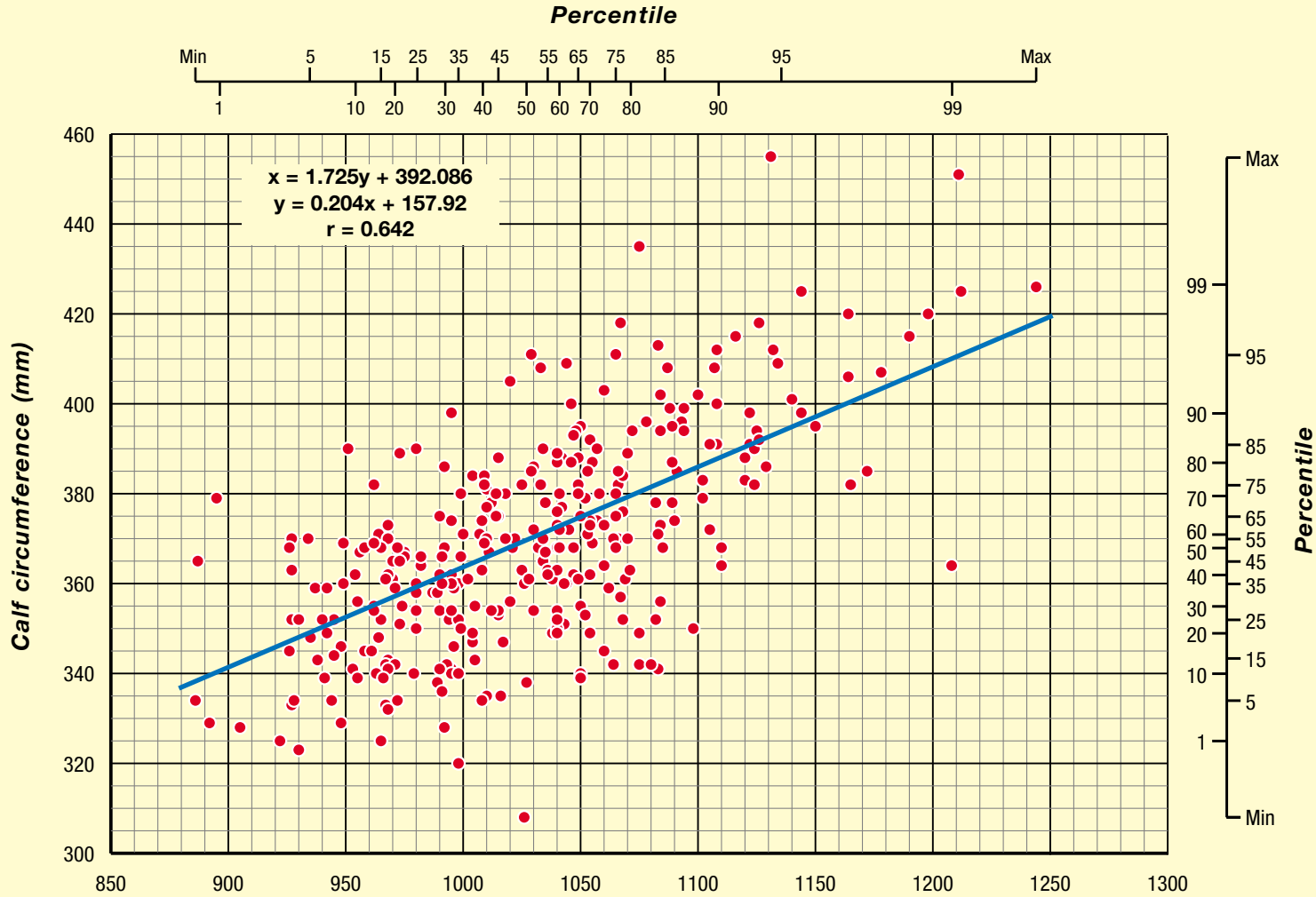




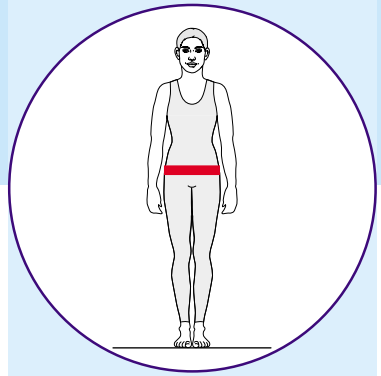


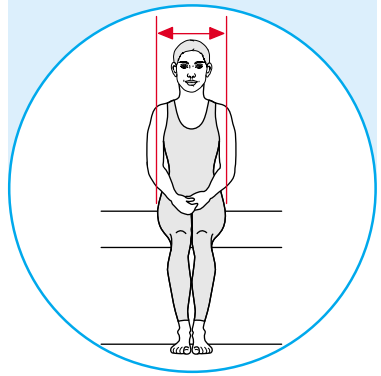


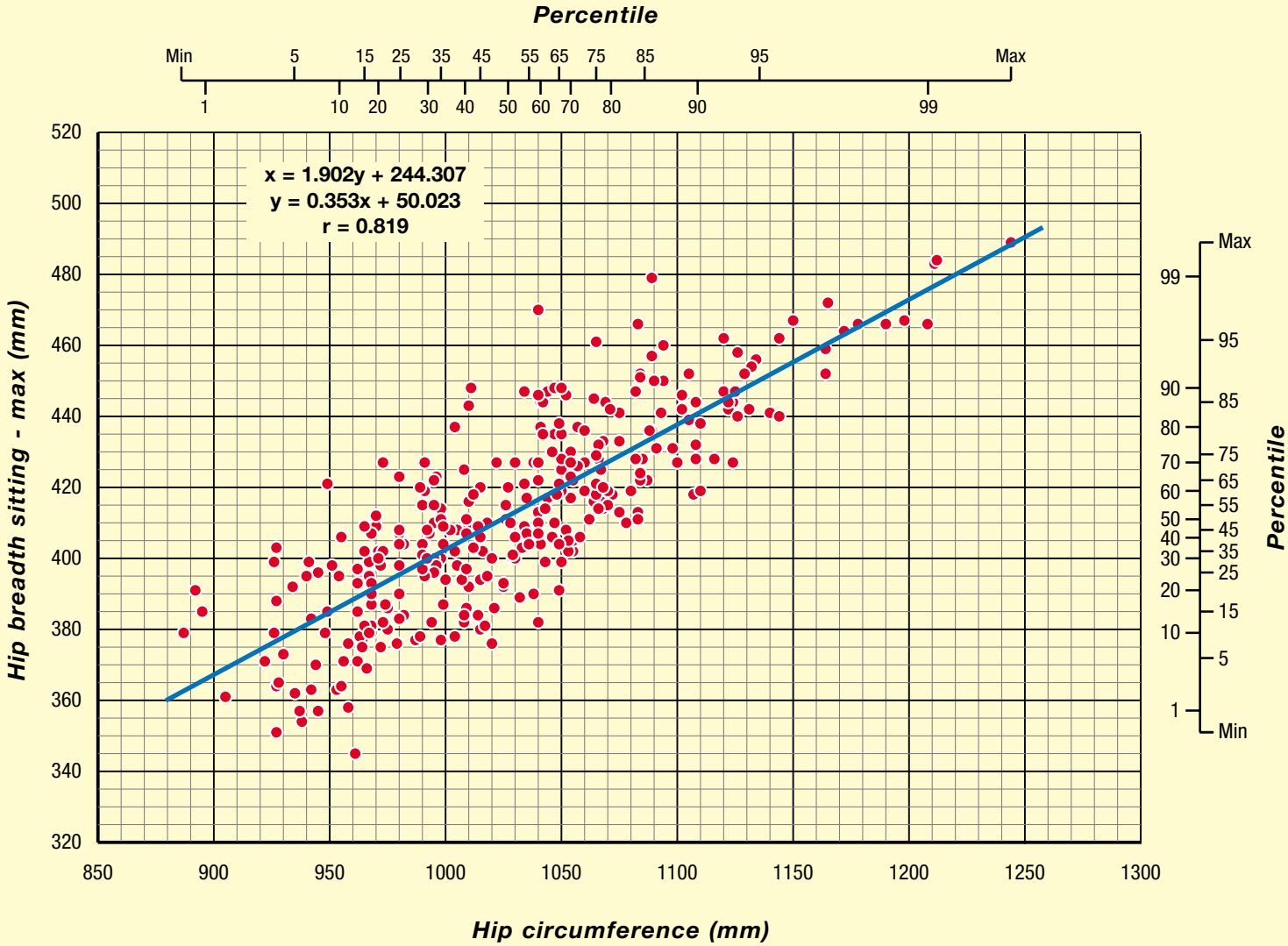
Hip Circumference
Calf Circumference

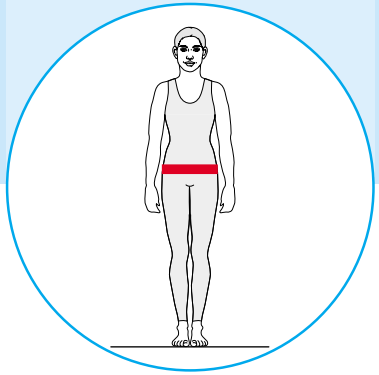


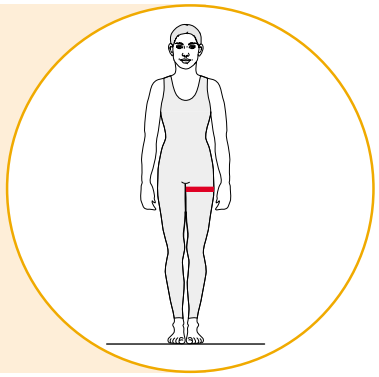
Hip Circumference
Hip Breadth Sitting - max



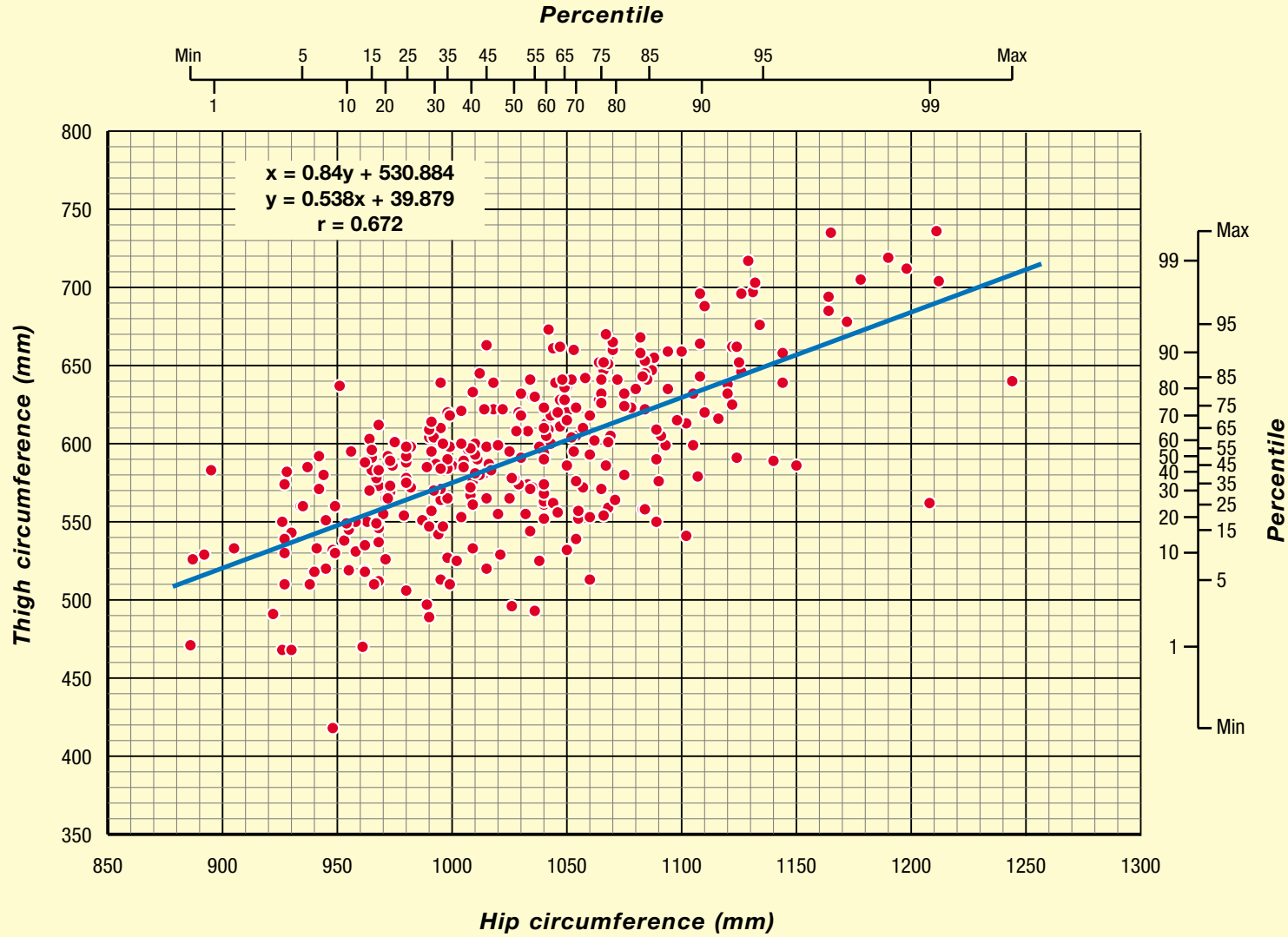




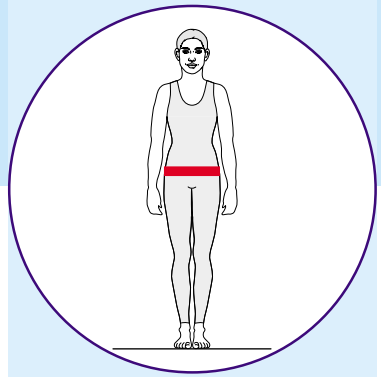


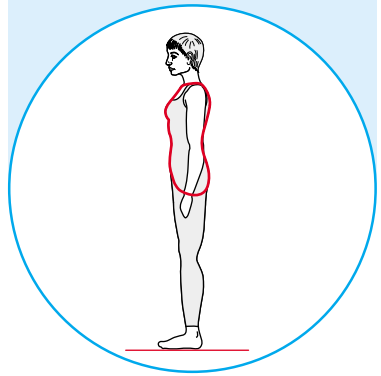


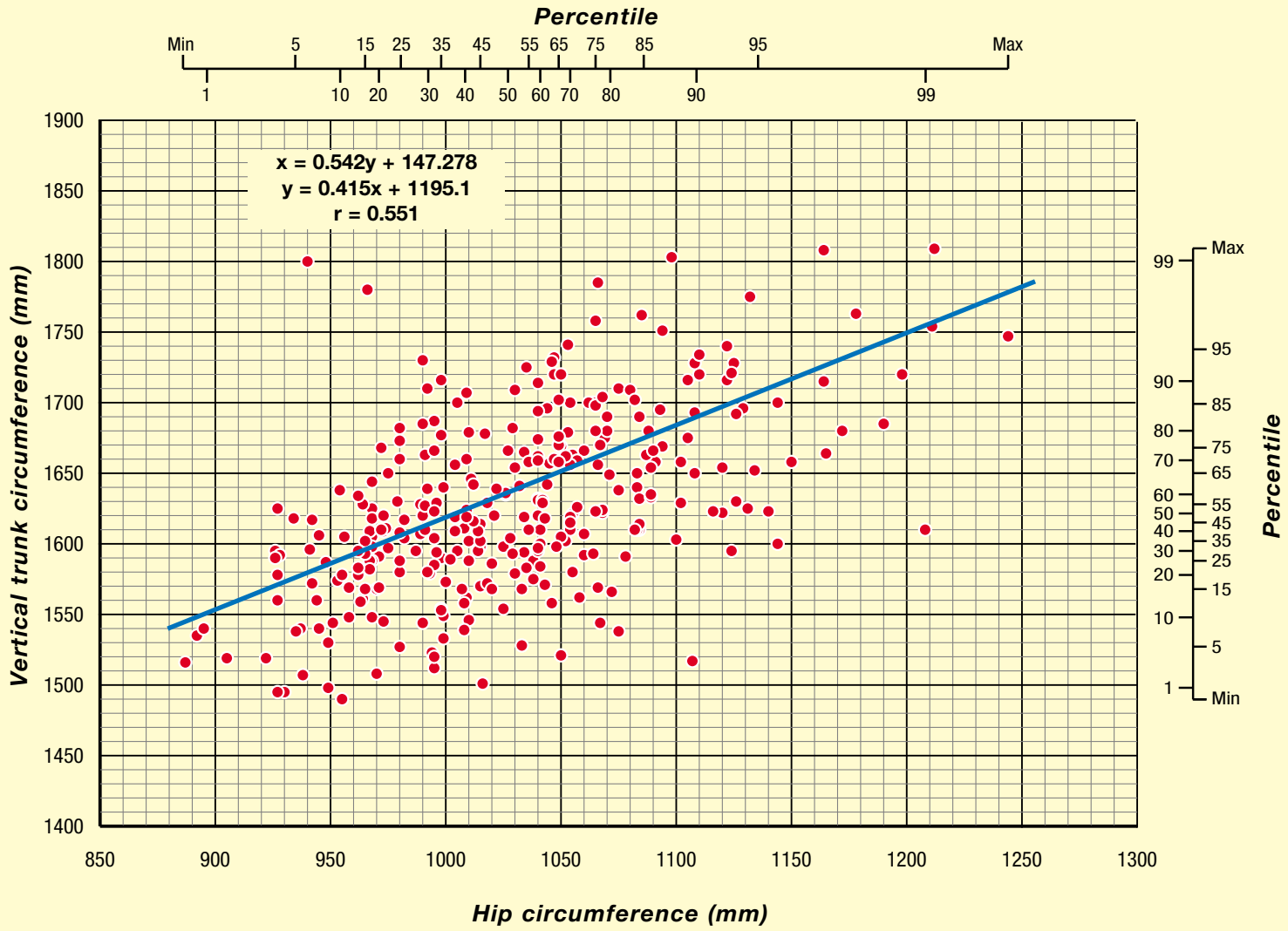
Hip Circumference
Thigh Circumference

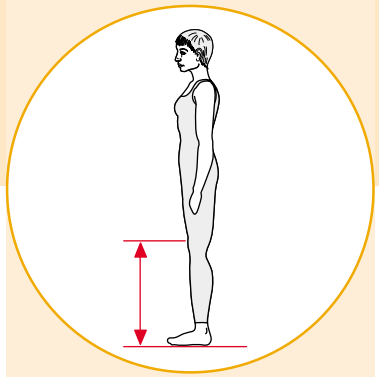


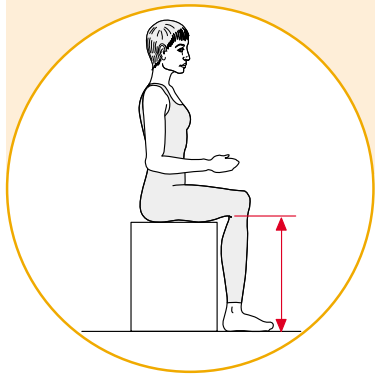
Hip Circumference
Vertical Trunk Circumference



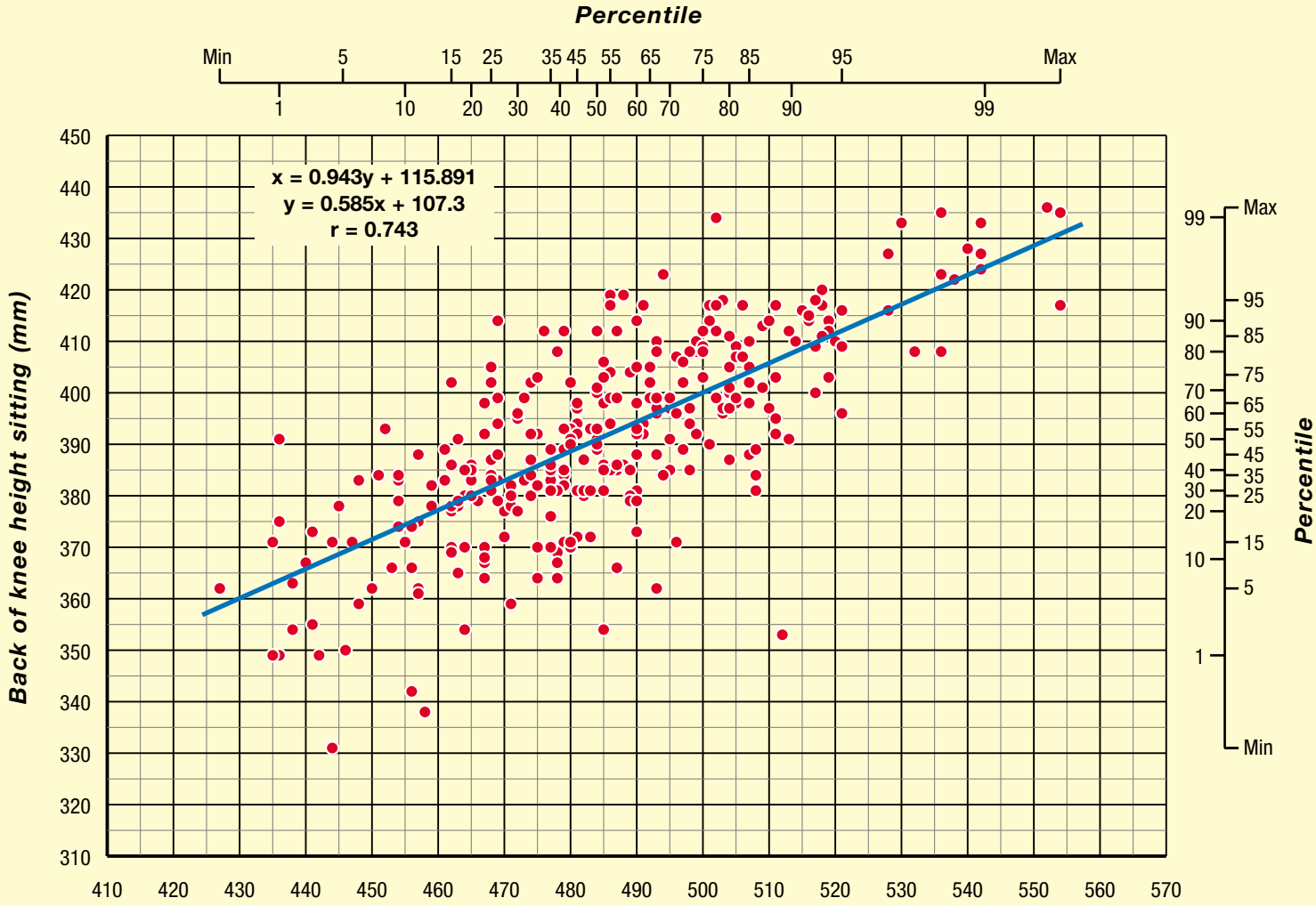




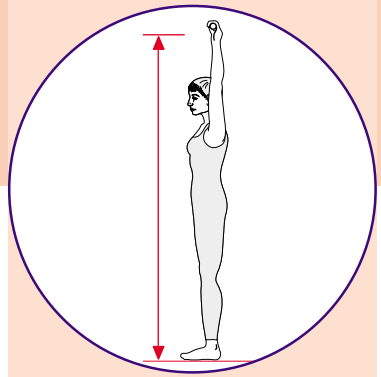


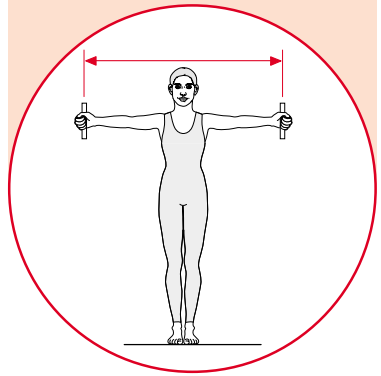


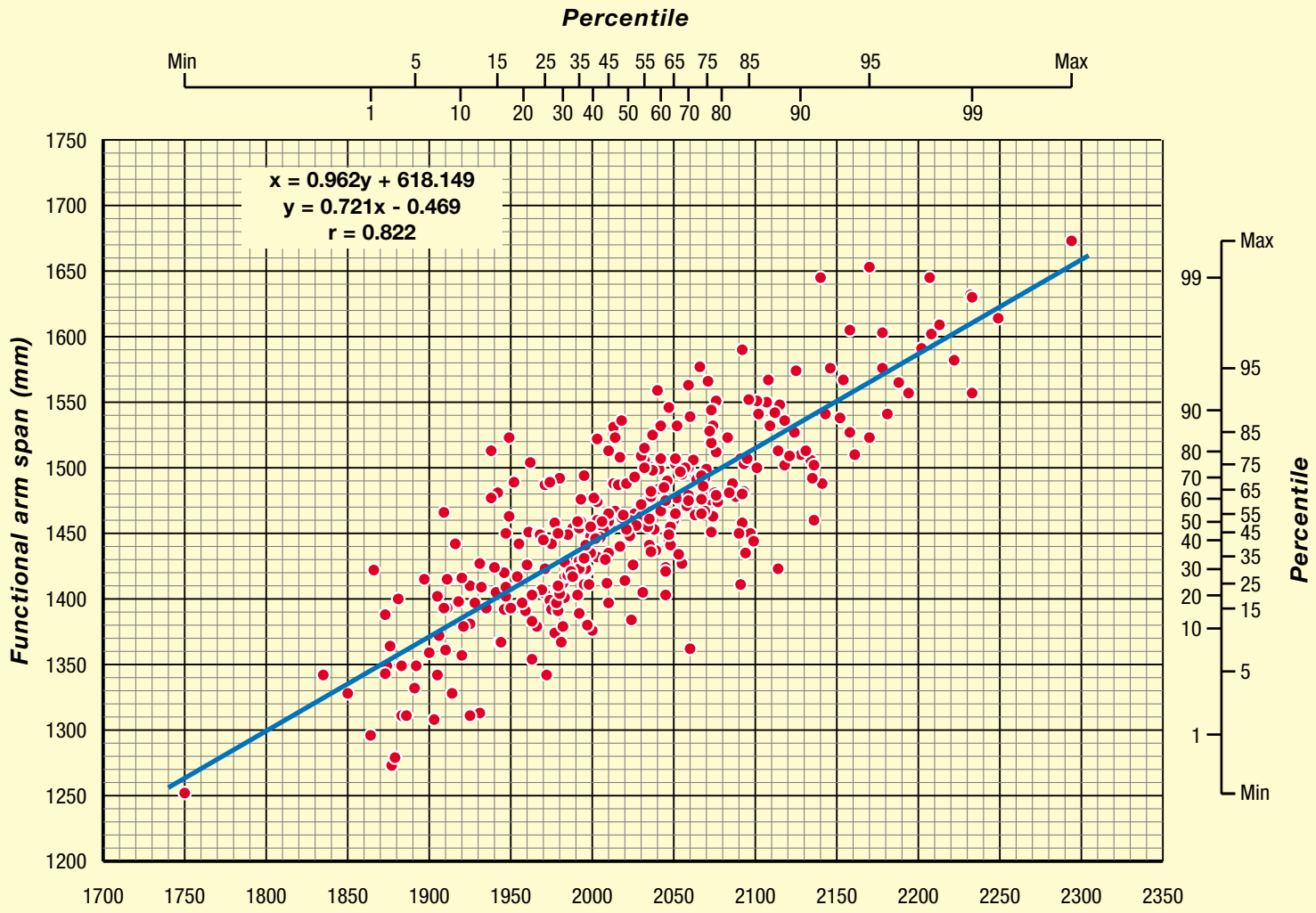
Knee Height
Back of Knee Height Sitting

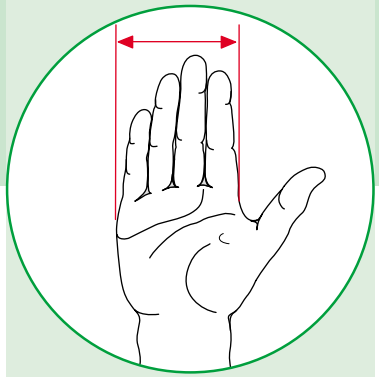


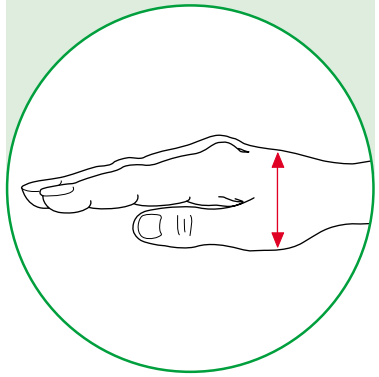
Overhead Grip Reach Standing
Functional Arm Span



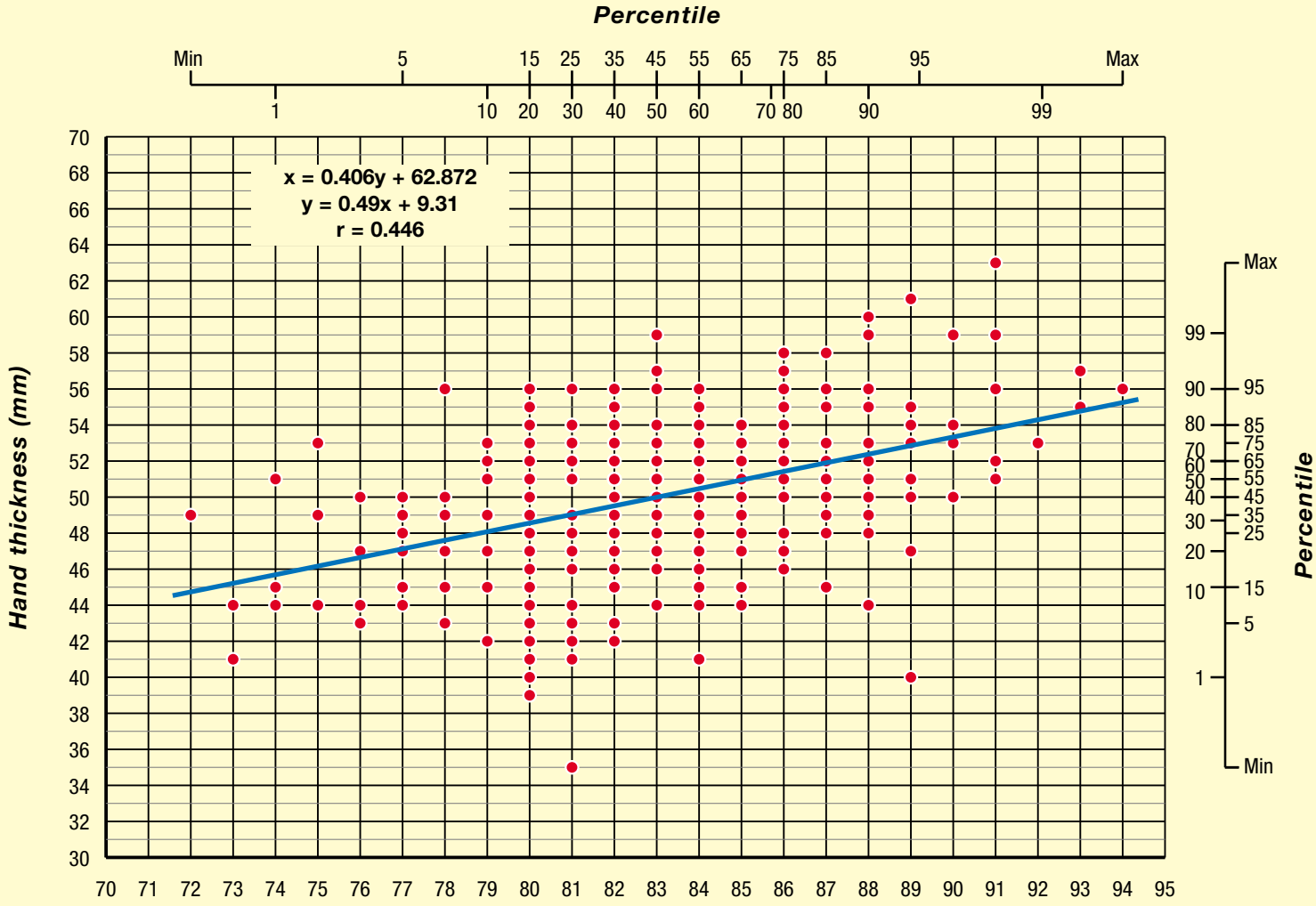




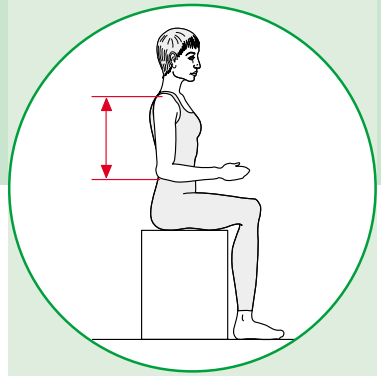


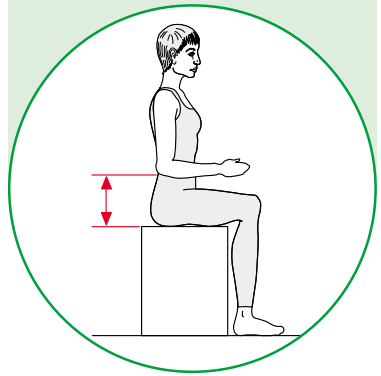


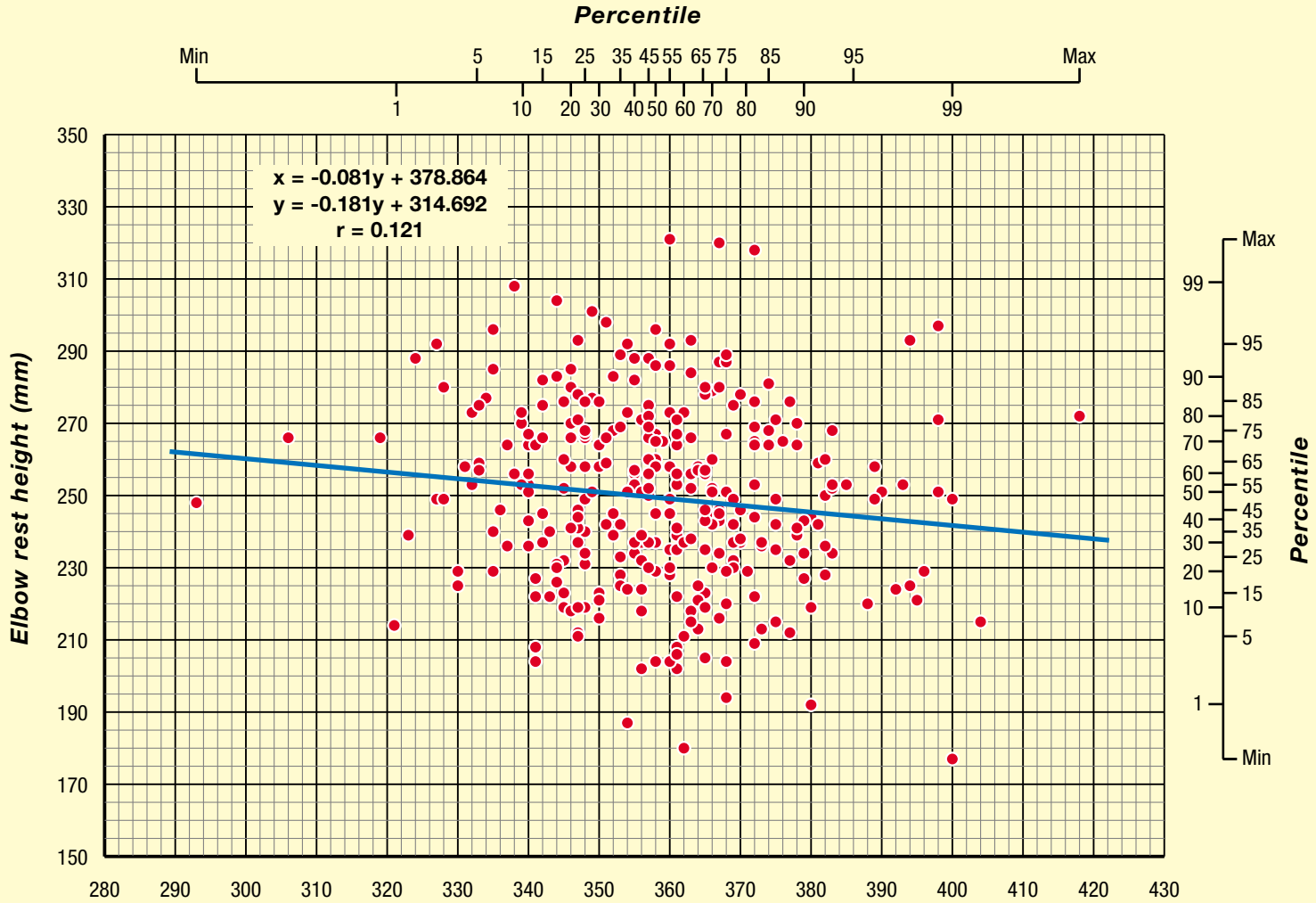
Palm Breadth
Hand Thickness

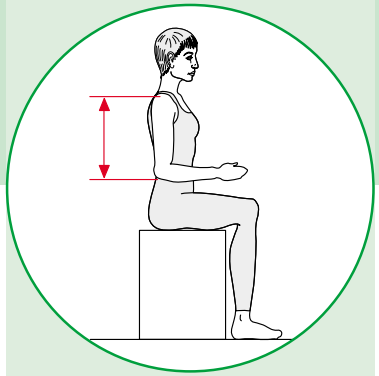


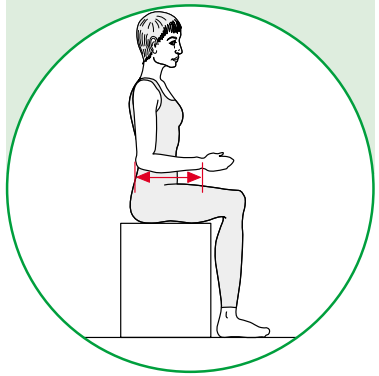
Shoulder to Elbow Length
Elbow Rest Height



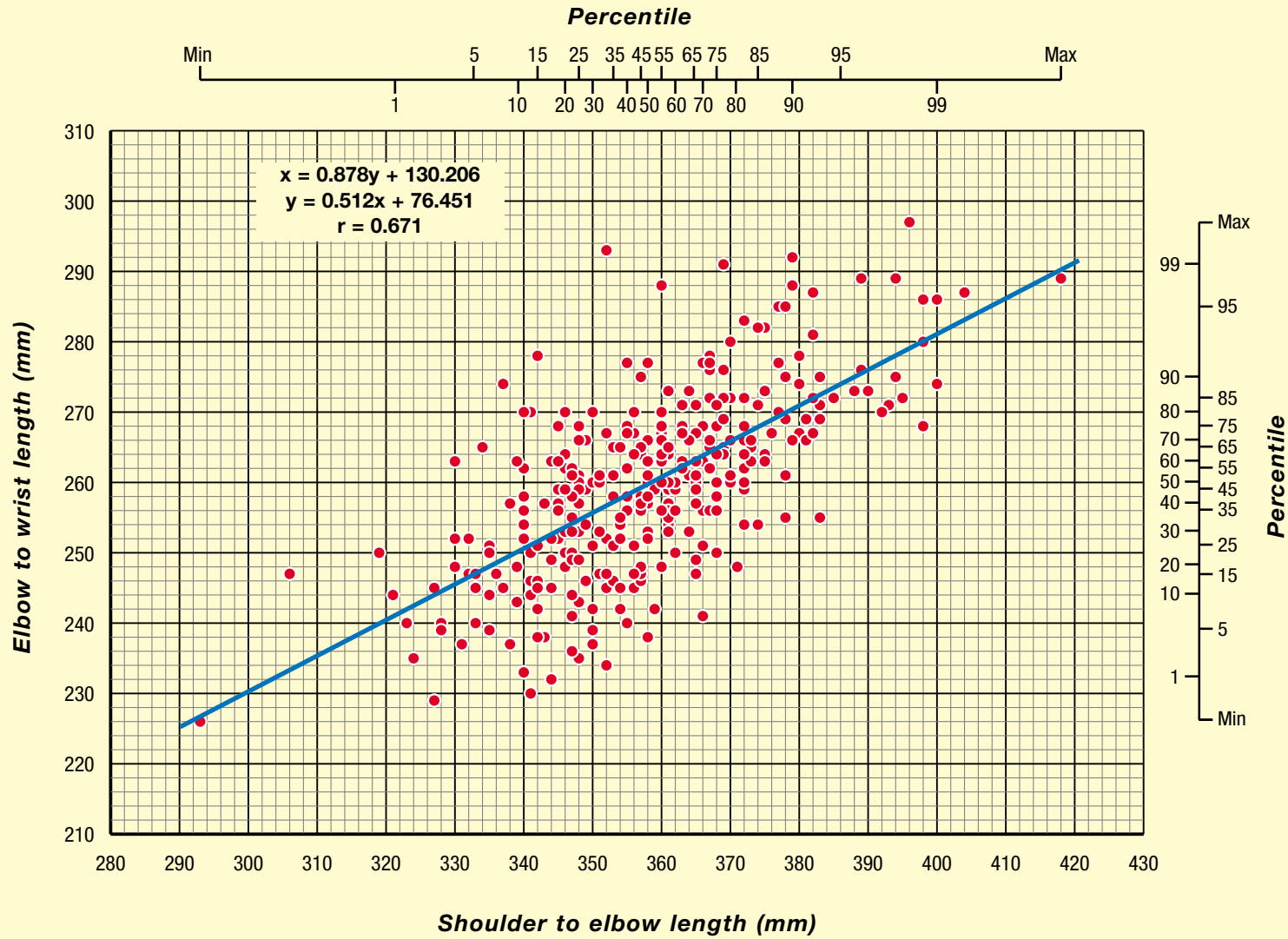




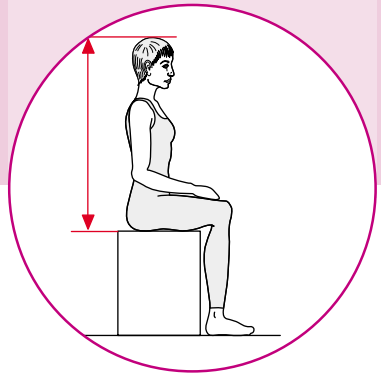


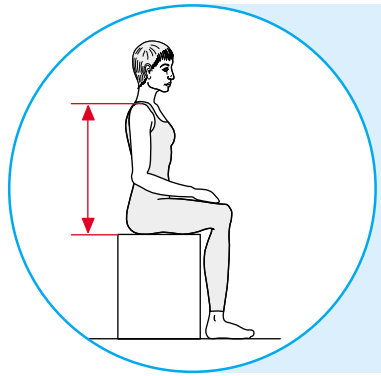


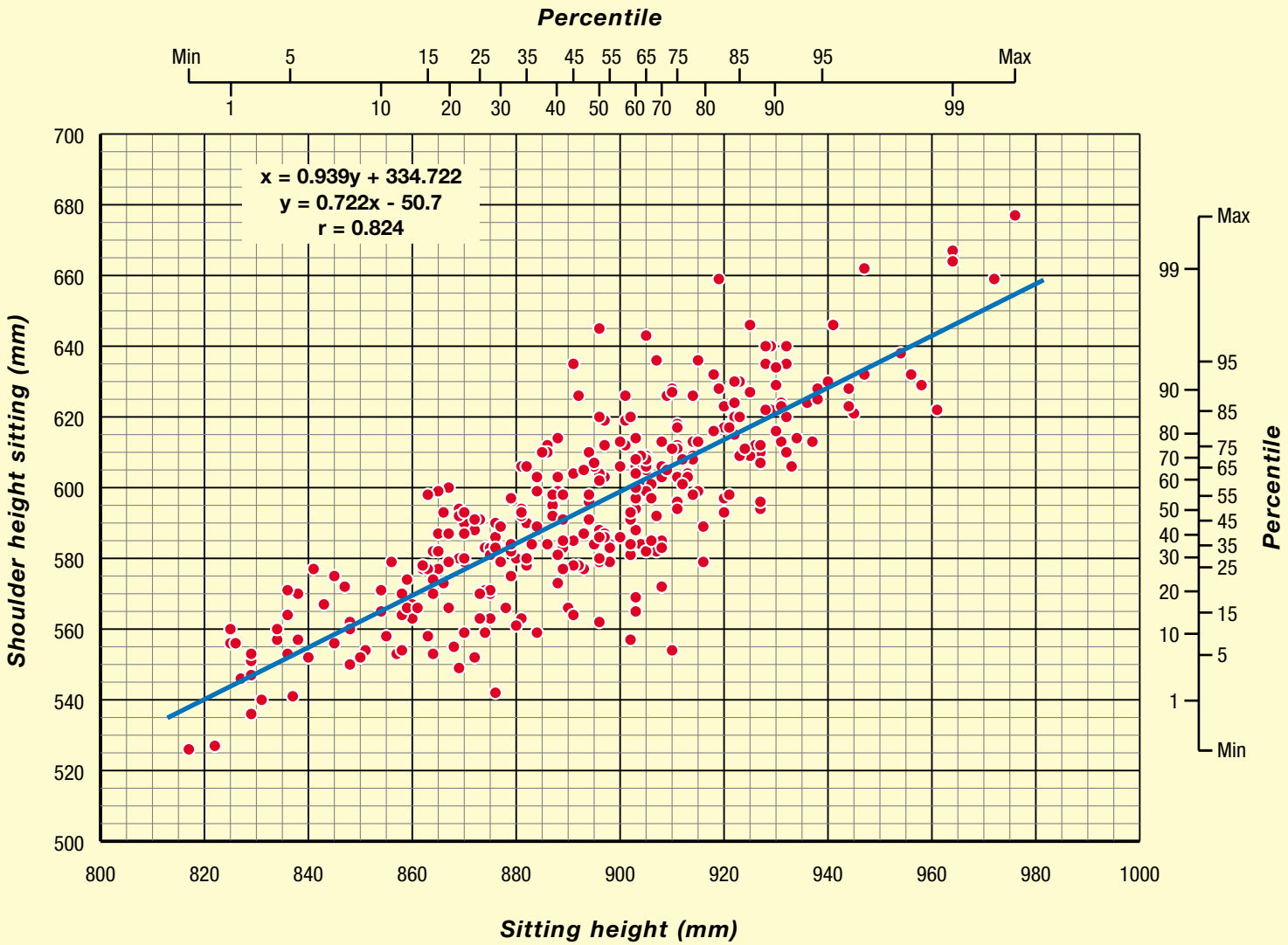
Shoulder to Elbow Length
Elbow to Wrist Length

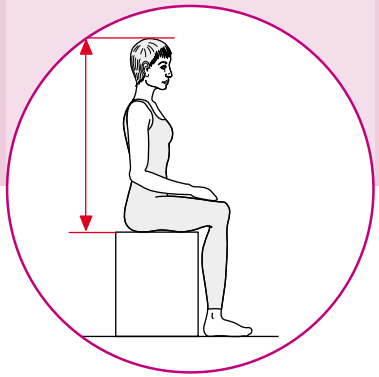


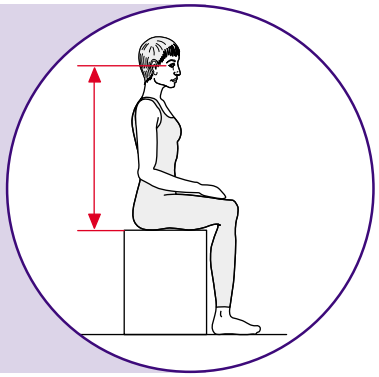
Sitting Height
Shoulder Height Sitting



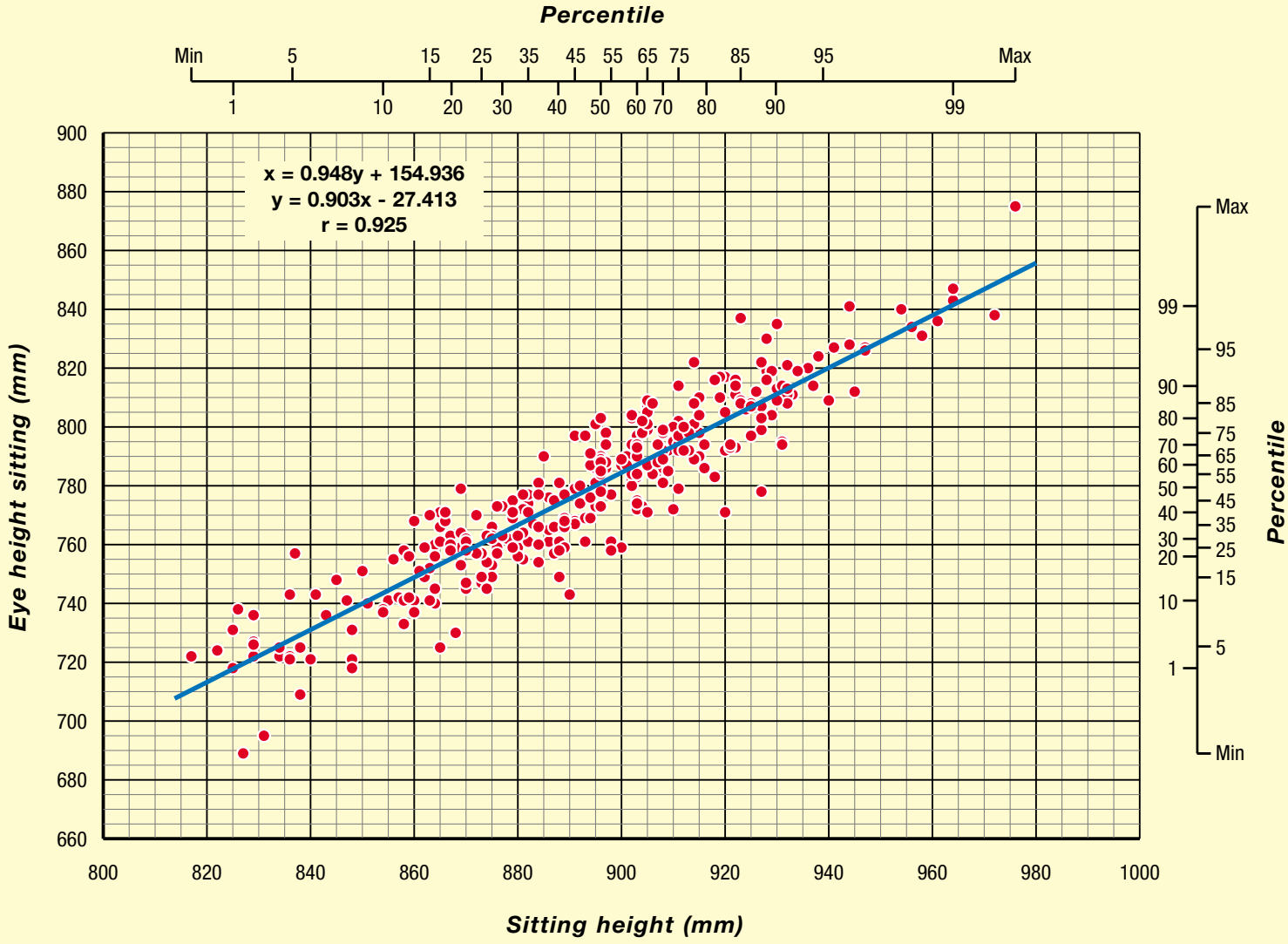




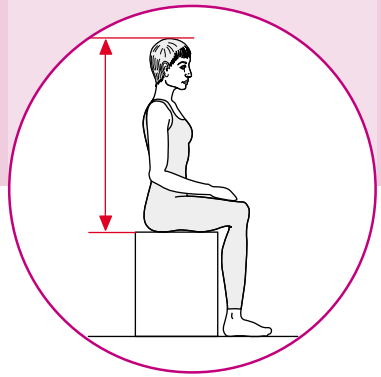


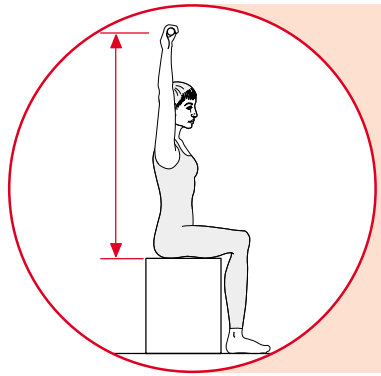


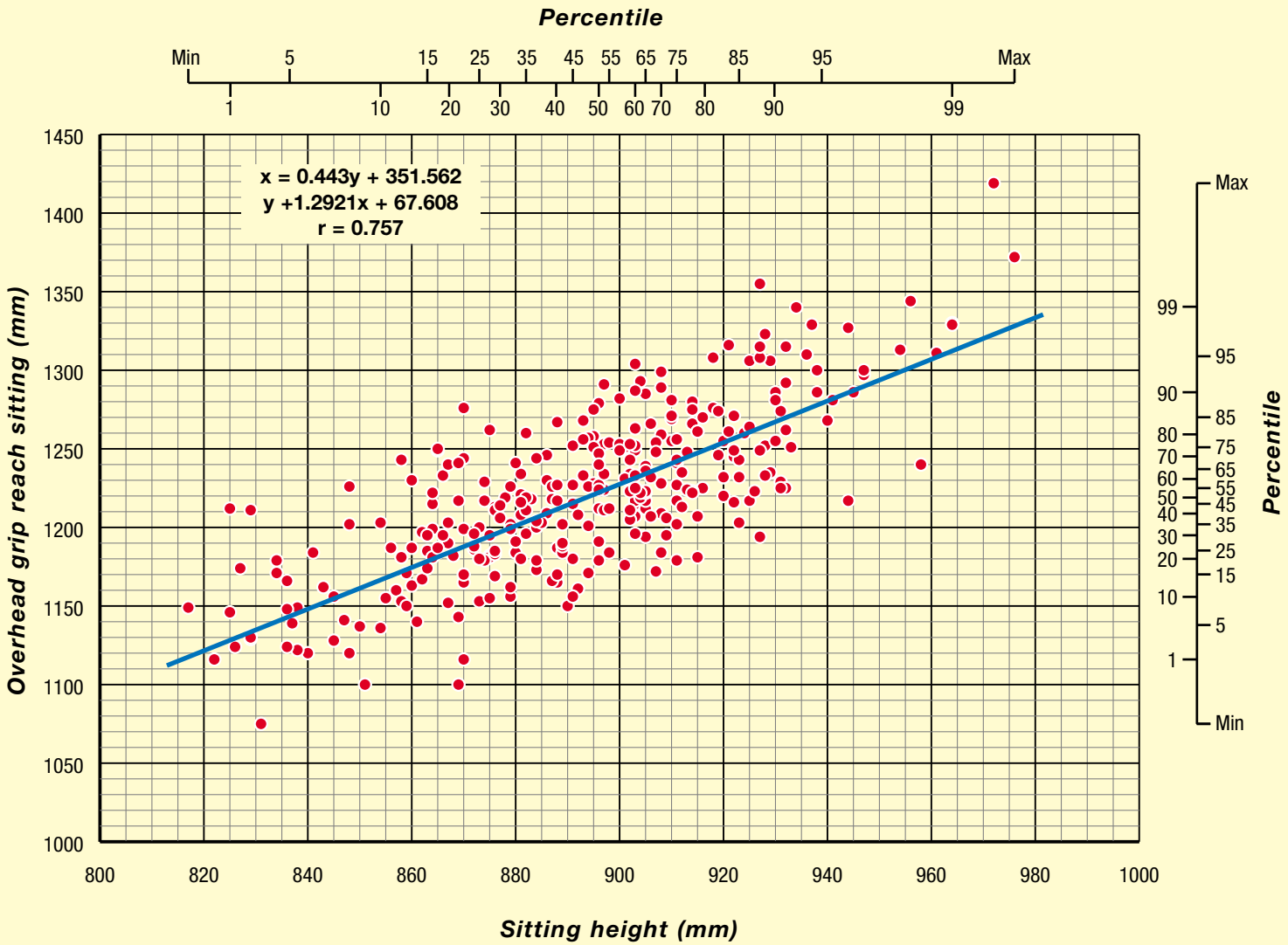
Sitting Height
Eye Height Sitting

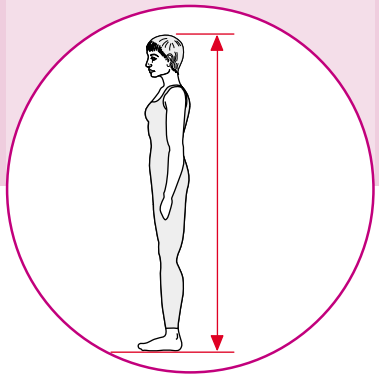


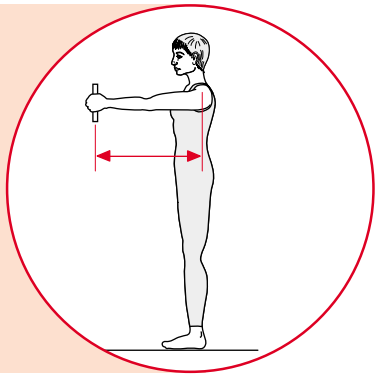
Sitting Height
Overhead Grip Reach Sitting



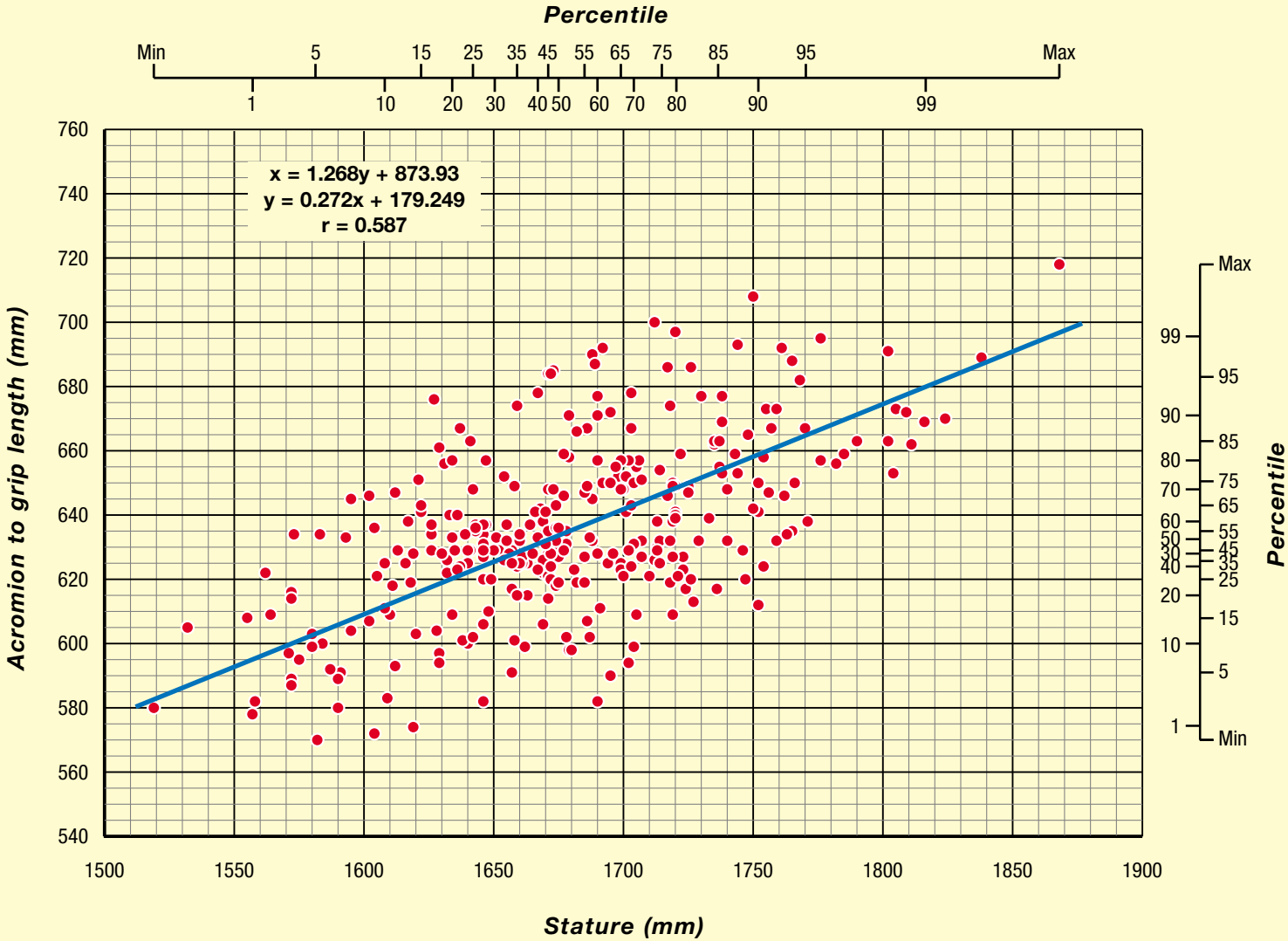




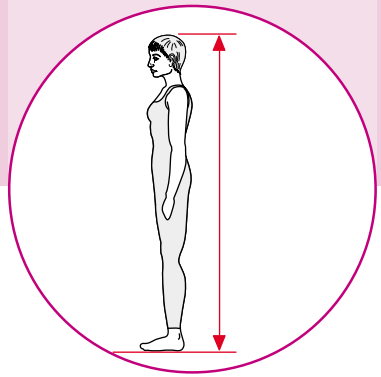


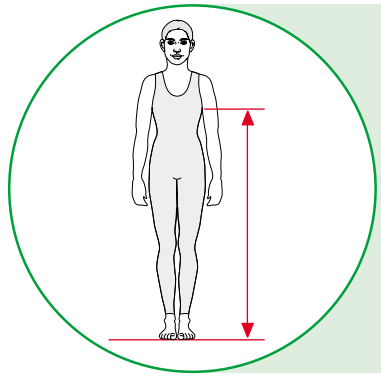


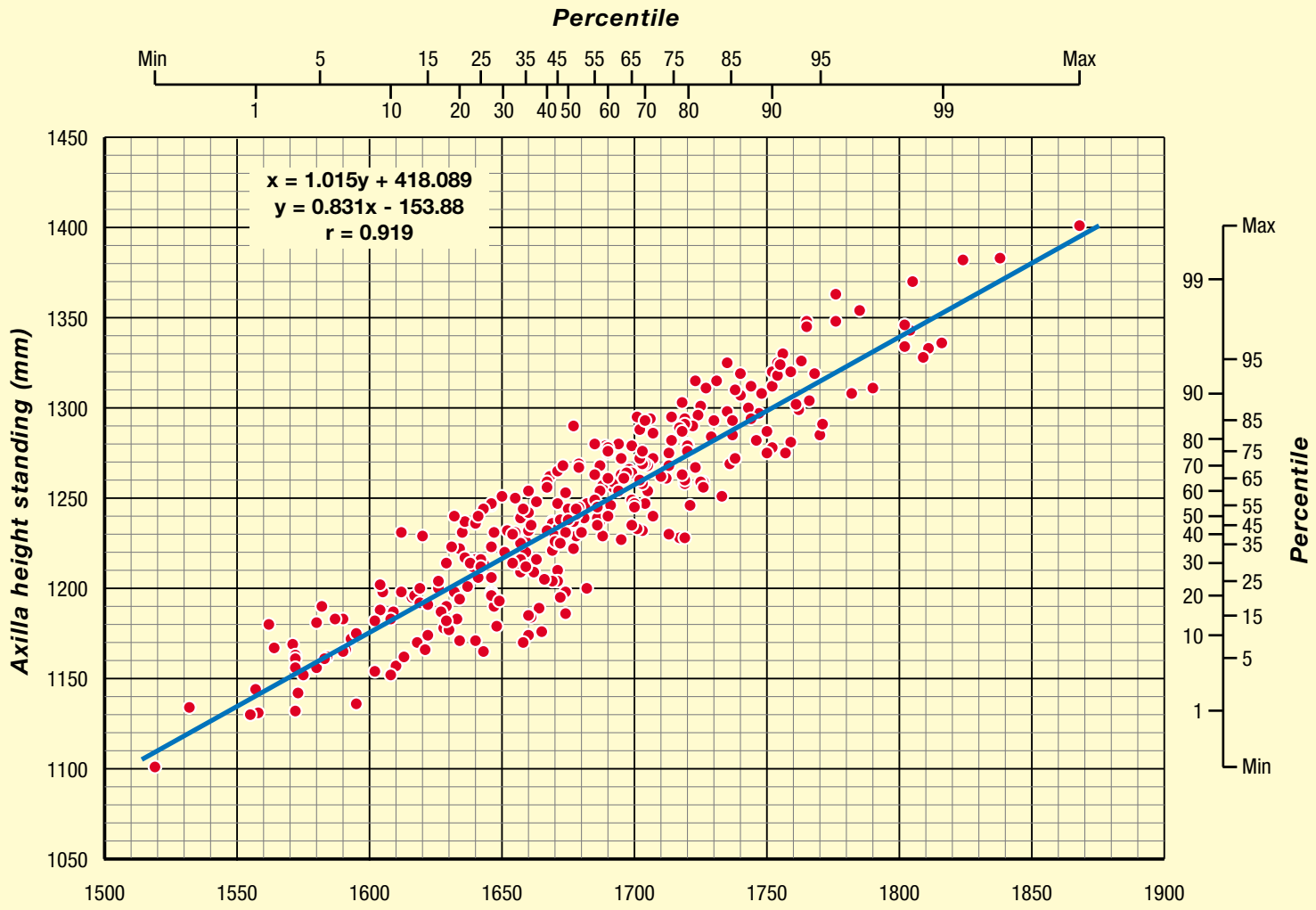
Stature
Acromion to Grip Length

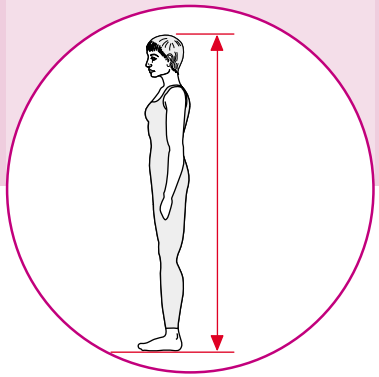


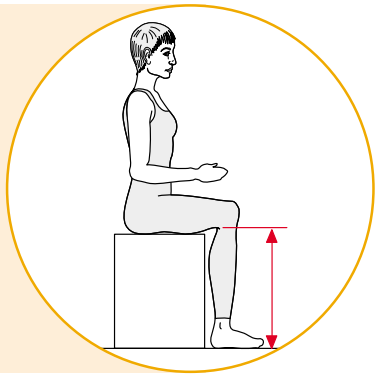
Stature
Axilla Height Standing



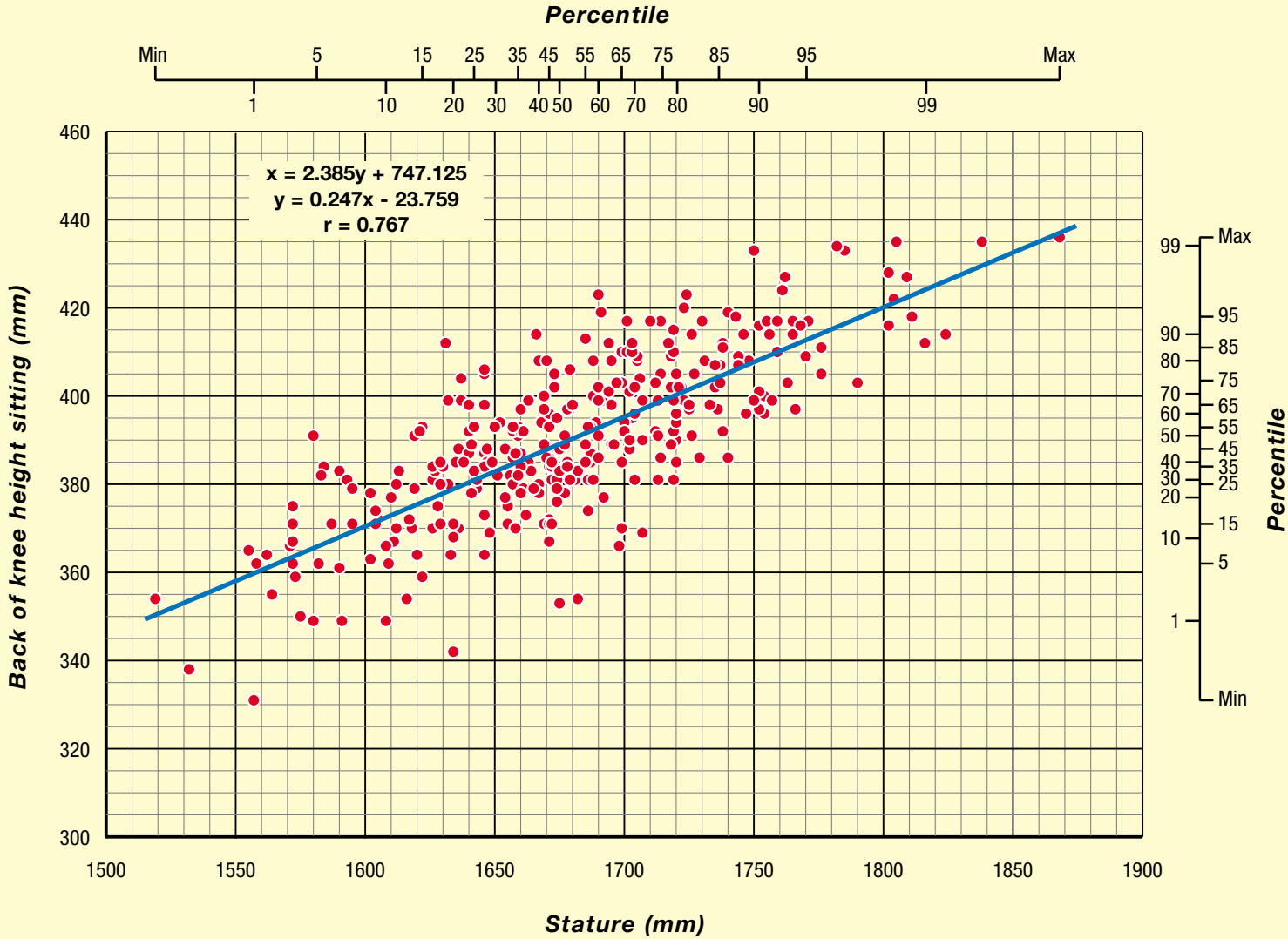




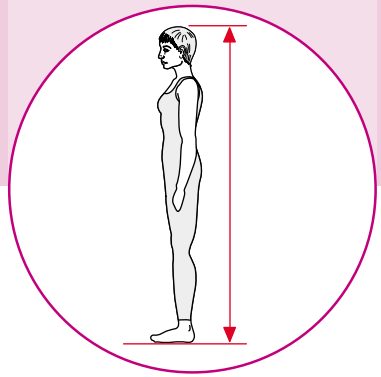


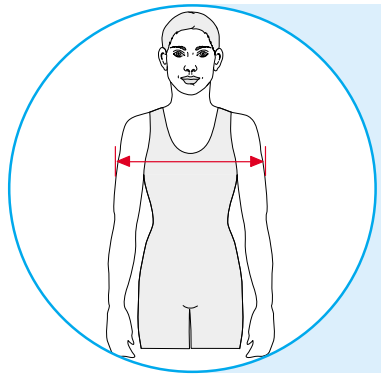


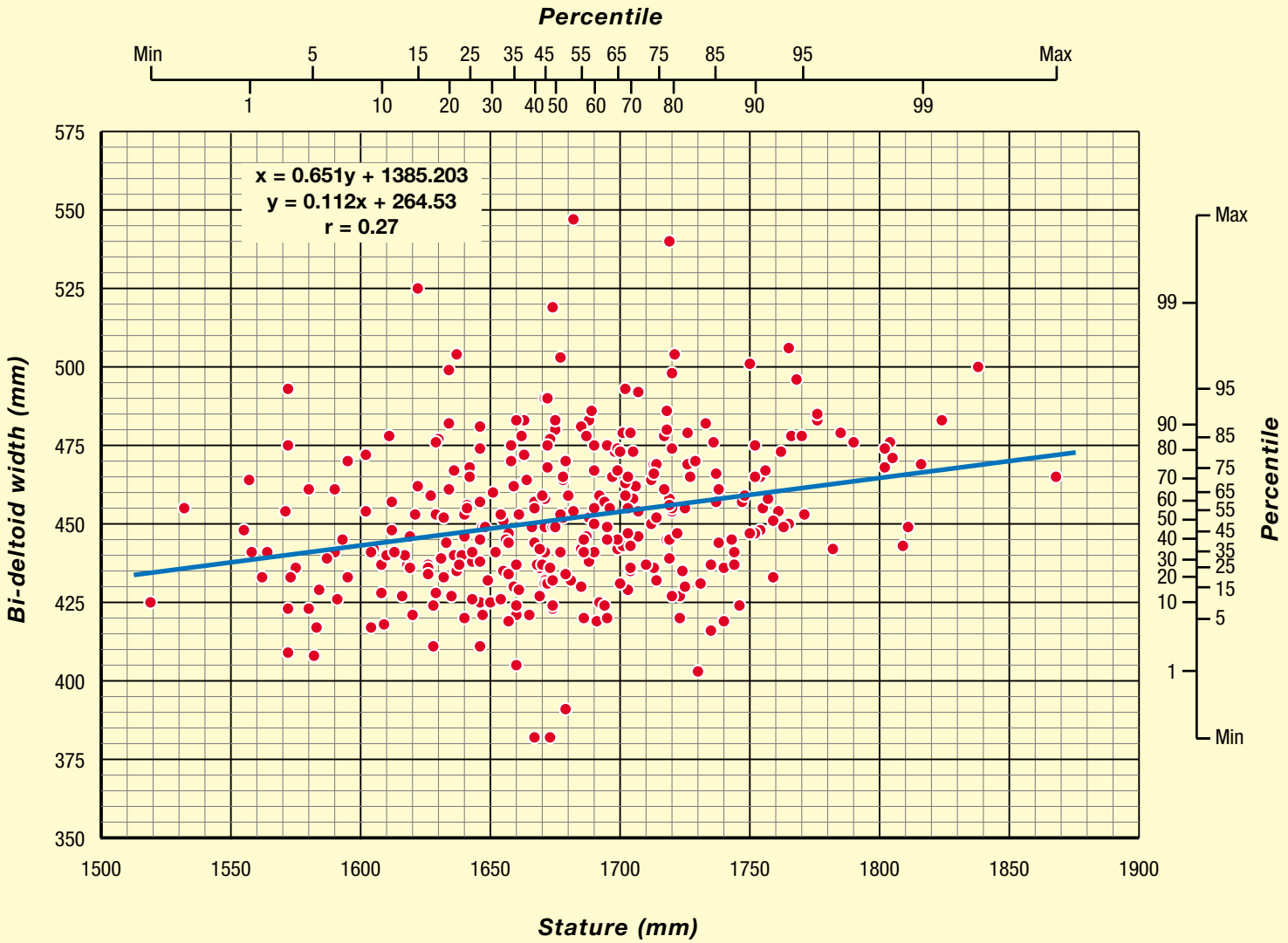
Stature
Back of Knee Height Sitting

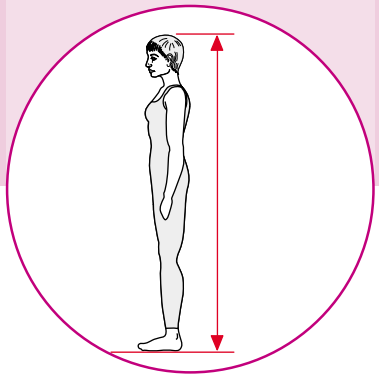


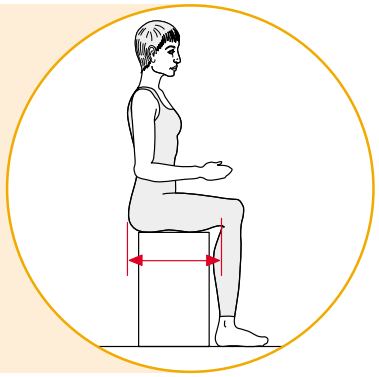
Stature
Bi-deltoid Width



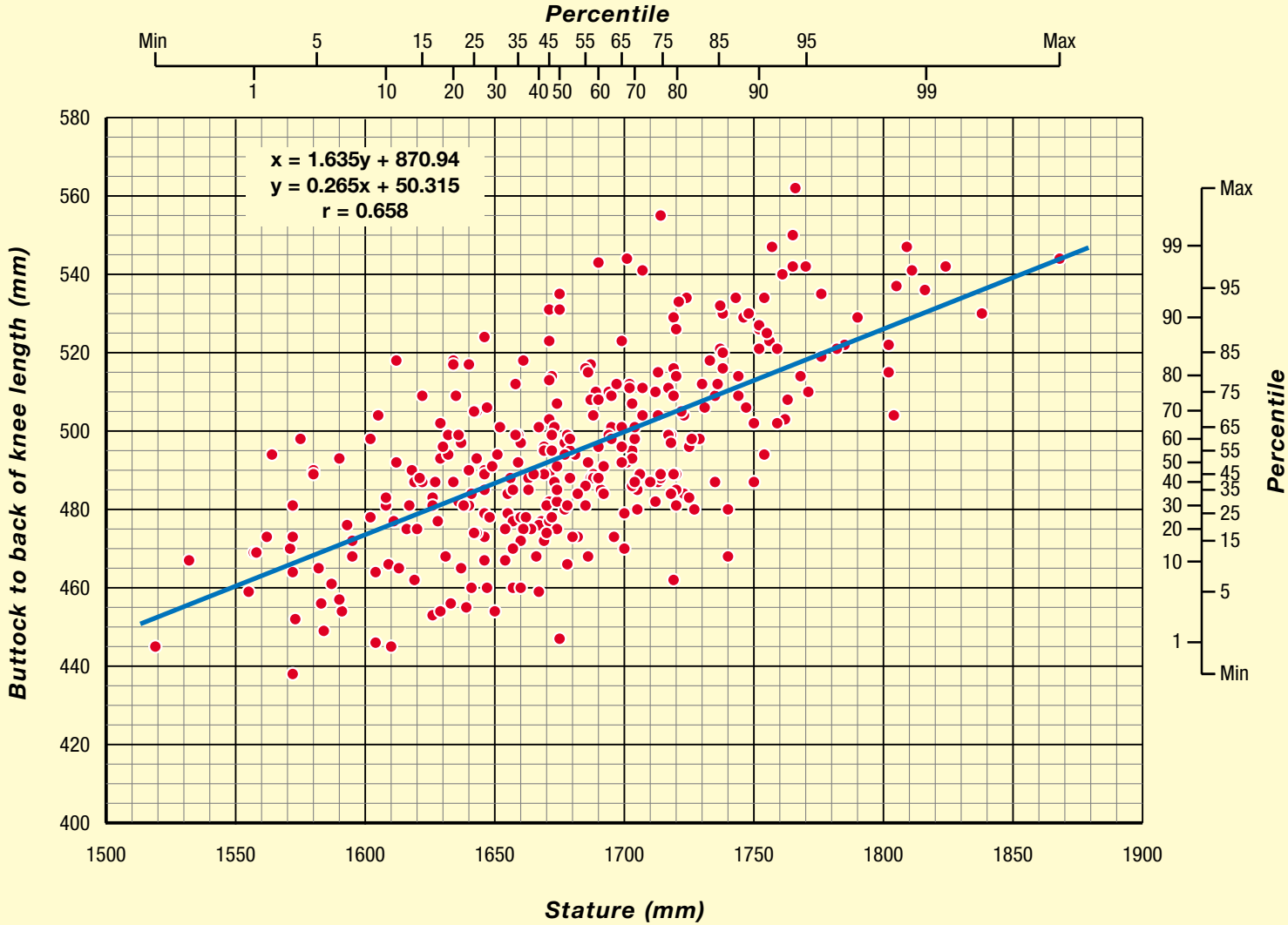




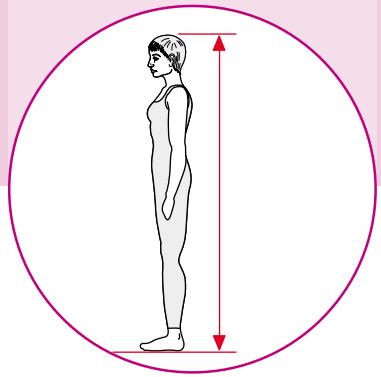


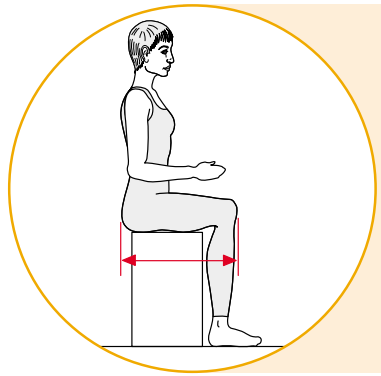


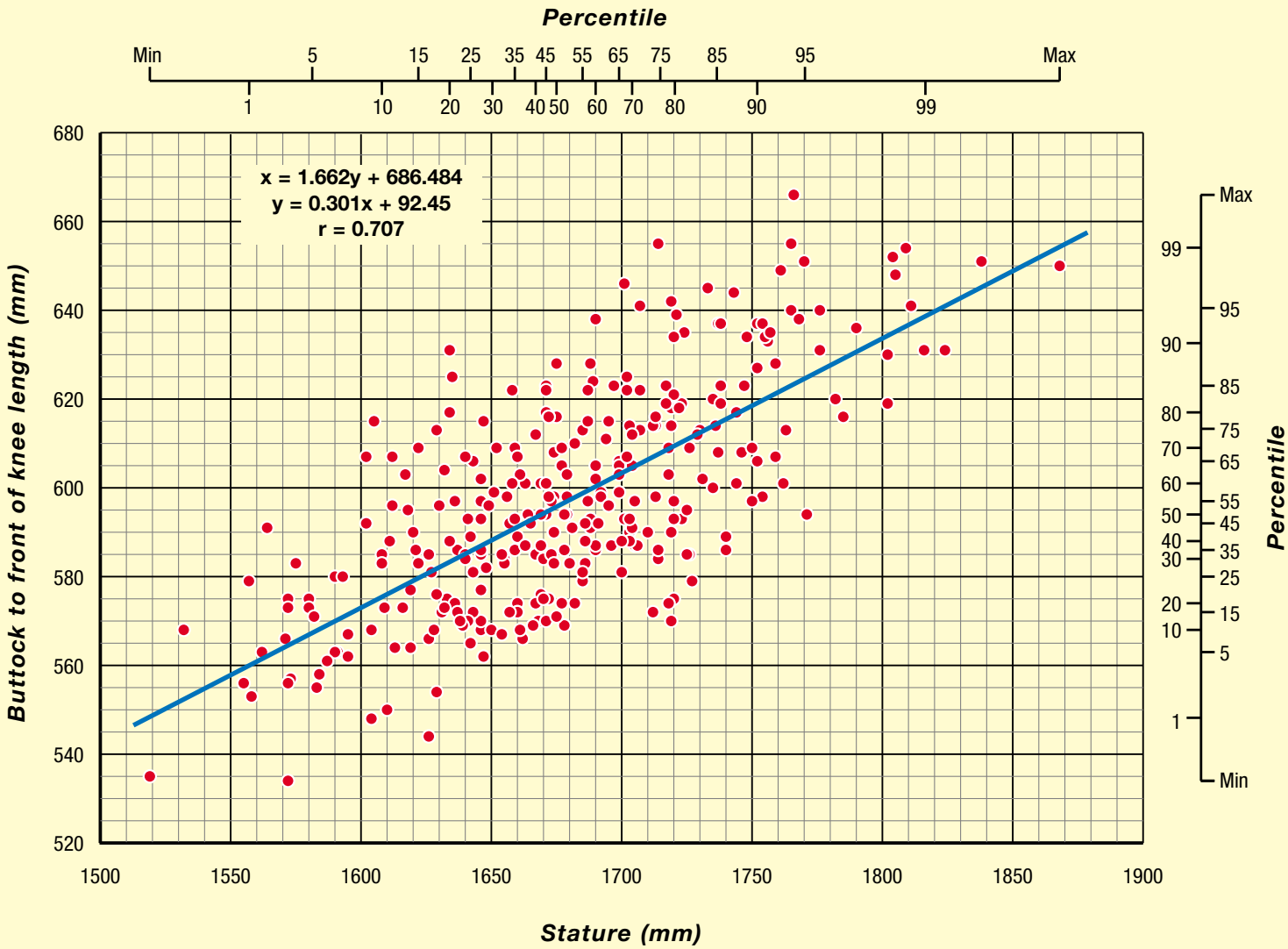
Stature
Buttock to Back of Knee Length

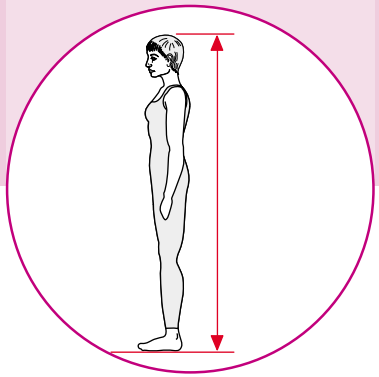


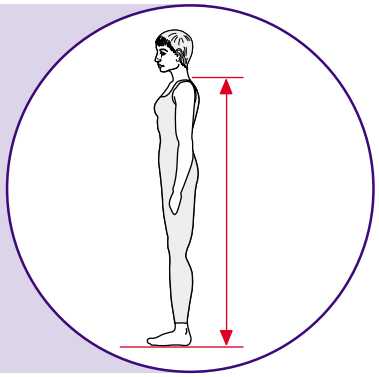
Stature
Buttock to Front of Knee Length



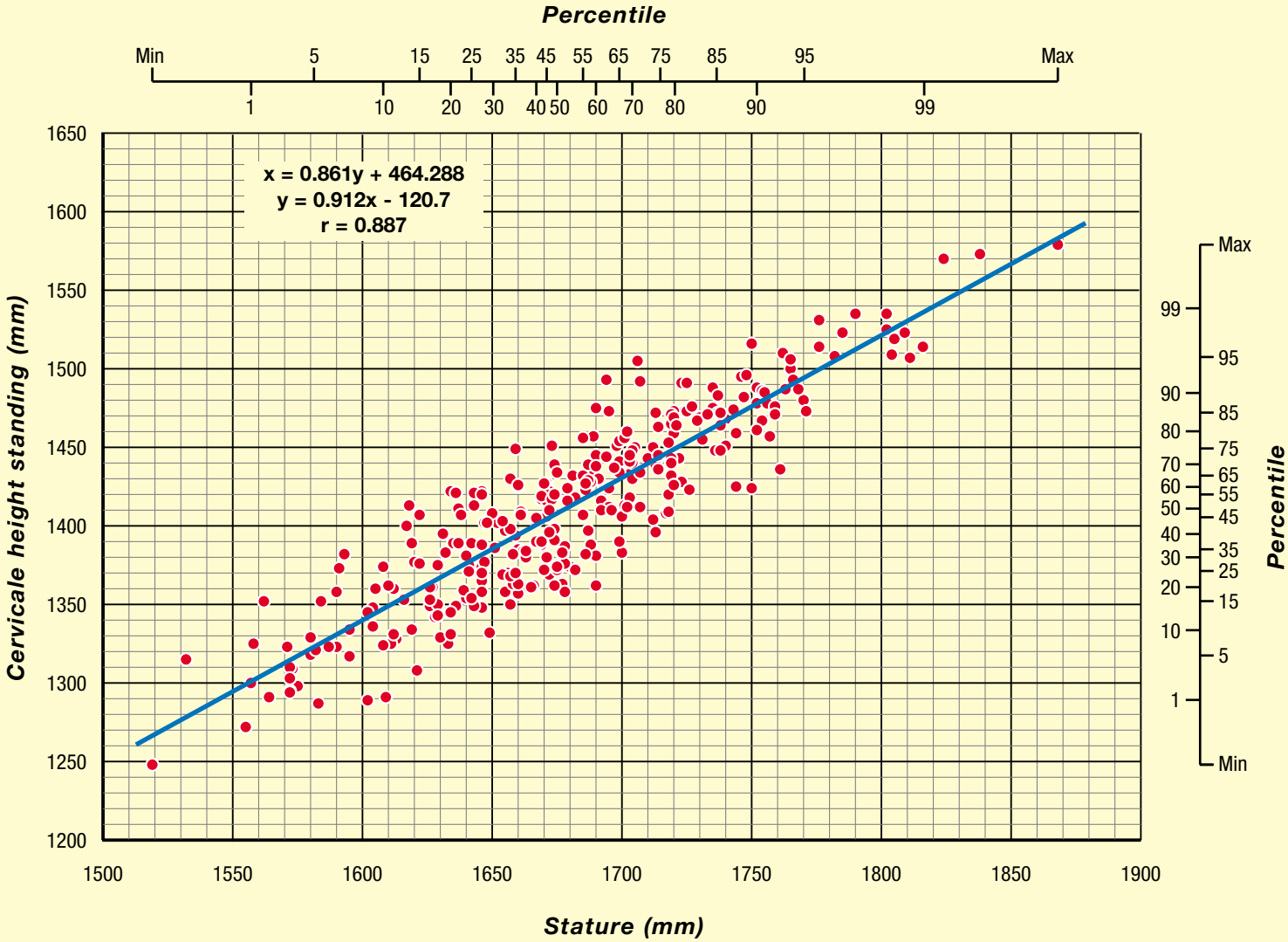




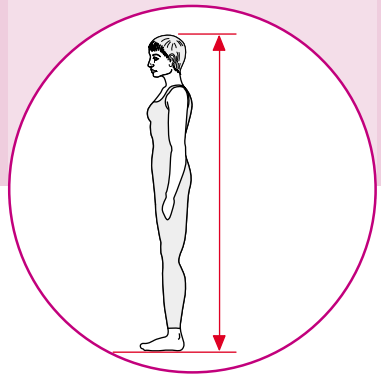


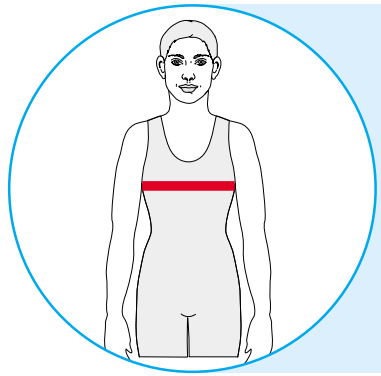


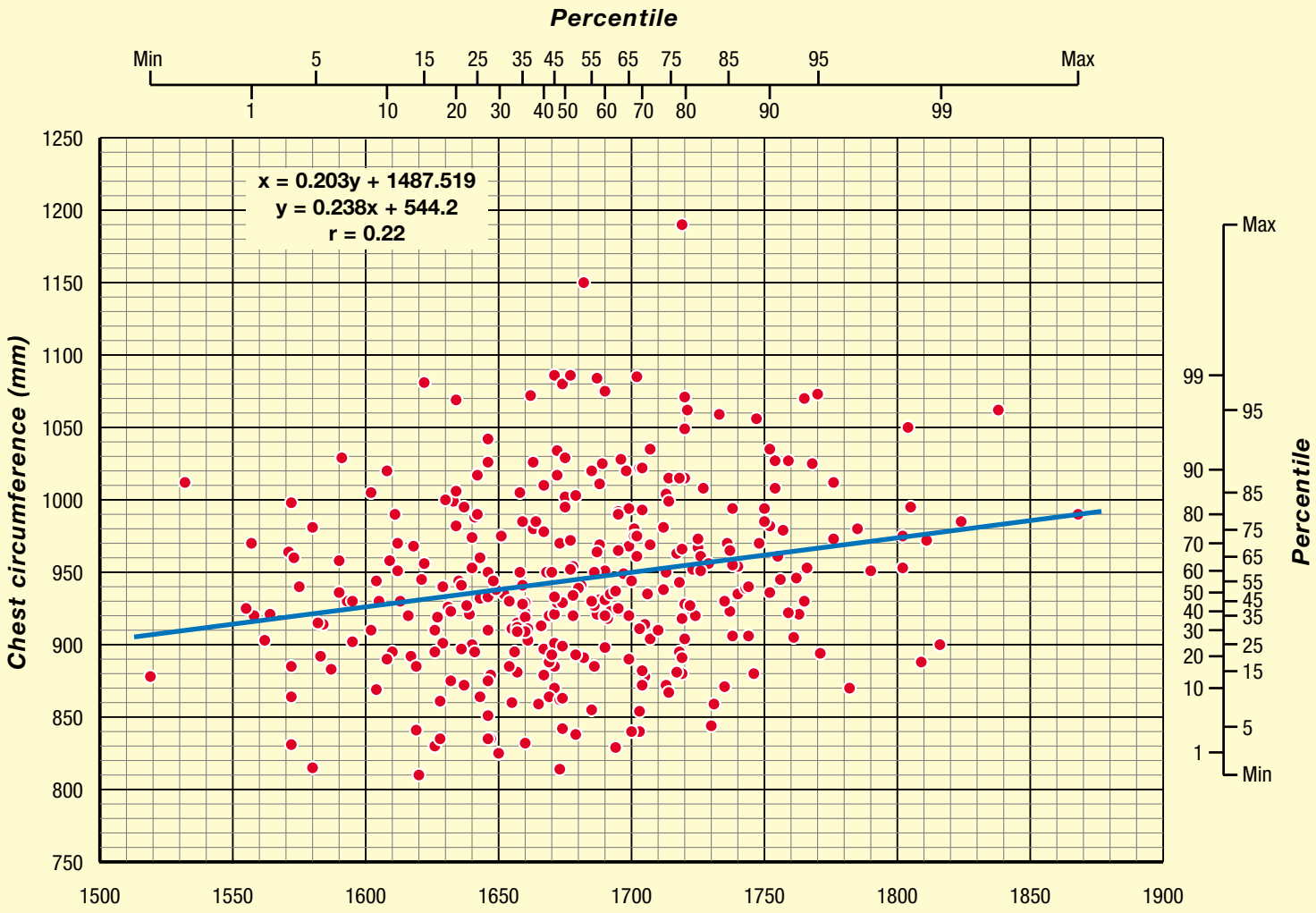
Stature
Cervicale Height Standing

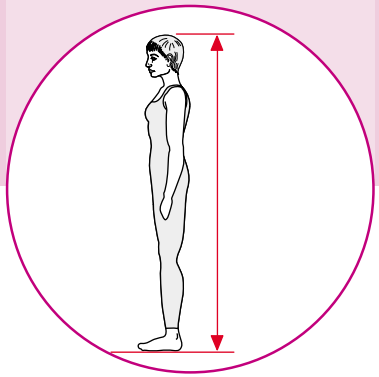


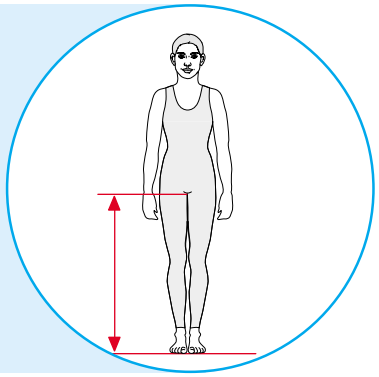
Stature
Chest Circumference



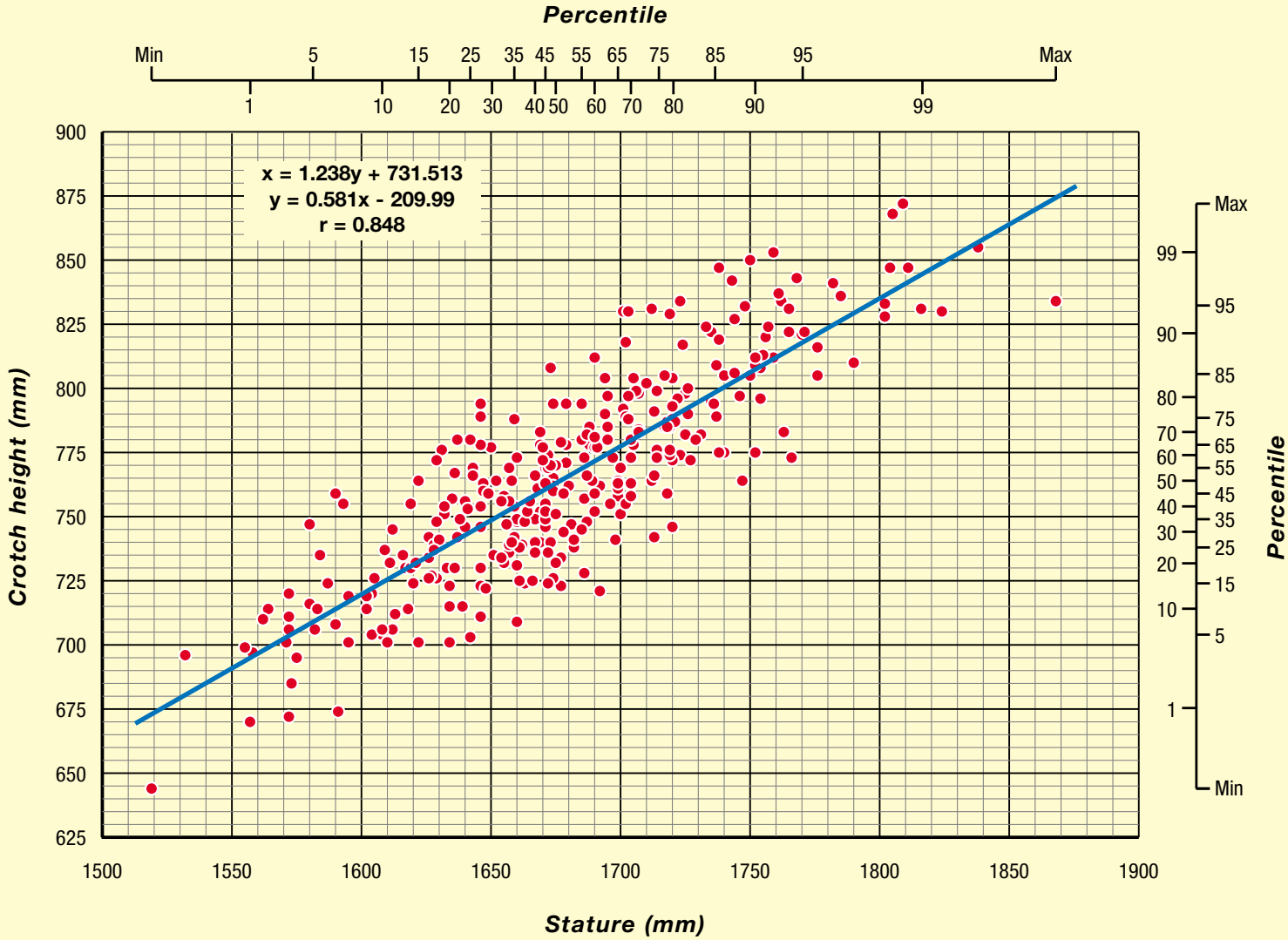




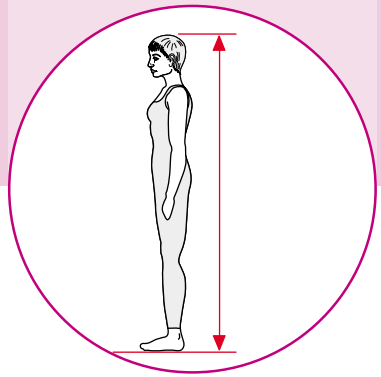


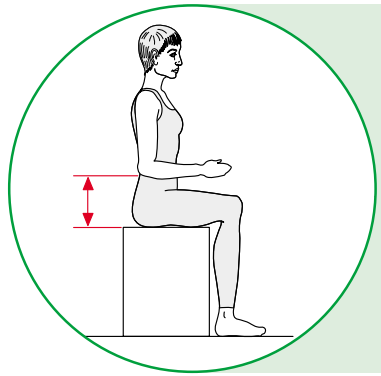


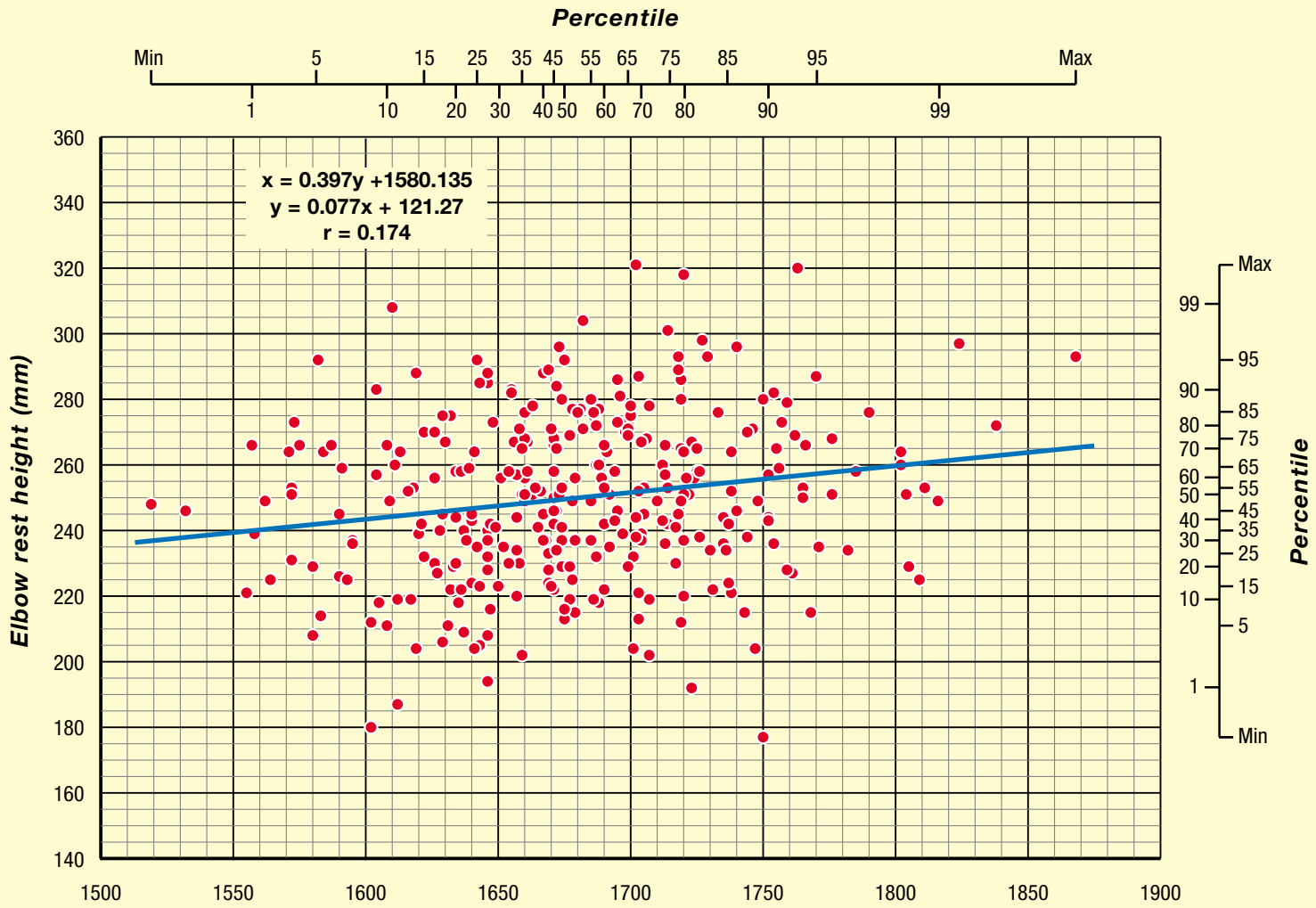
Stature
Crotch Height

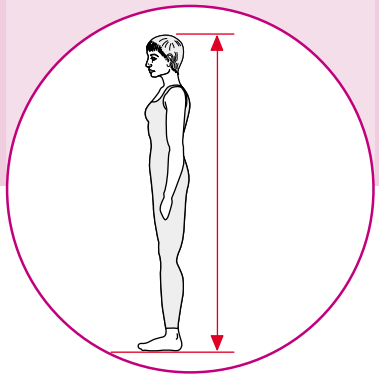


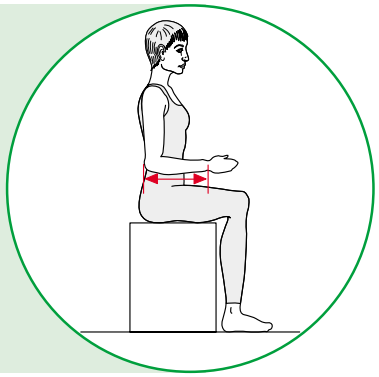
Stature
Elbow Rest Height



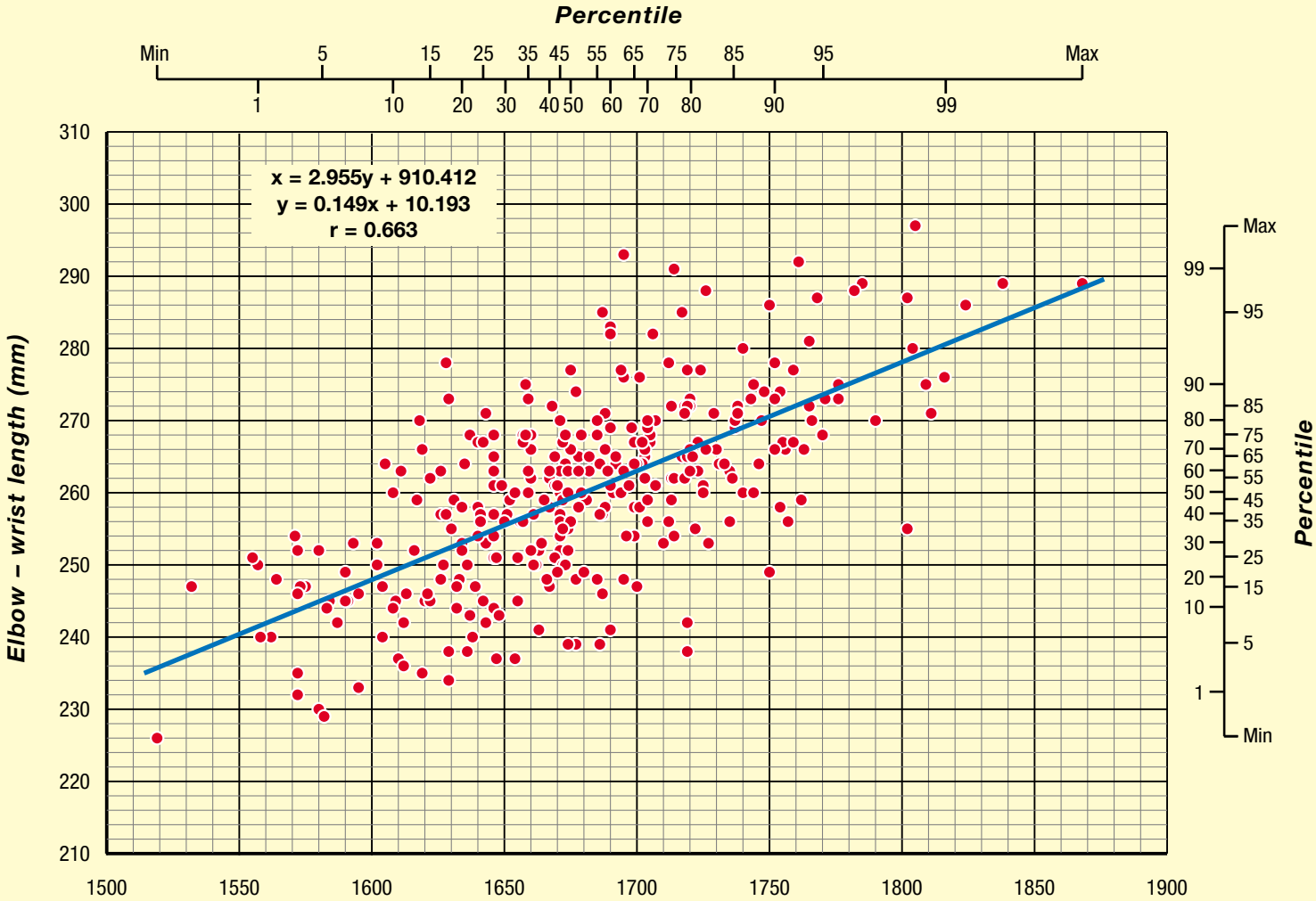




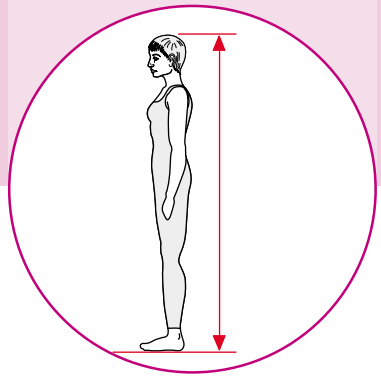


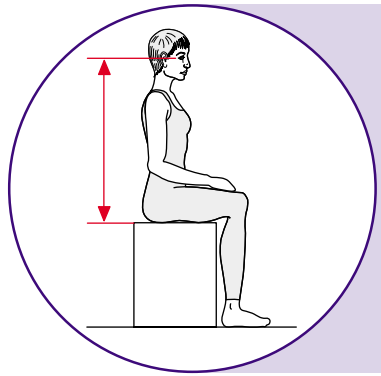


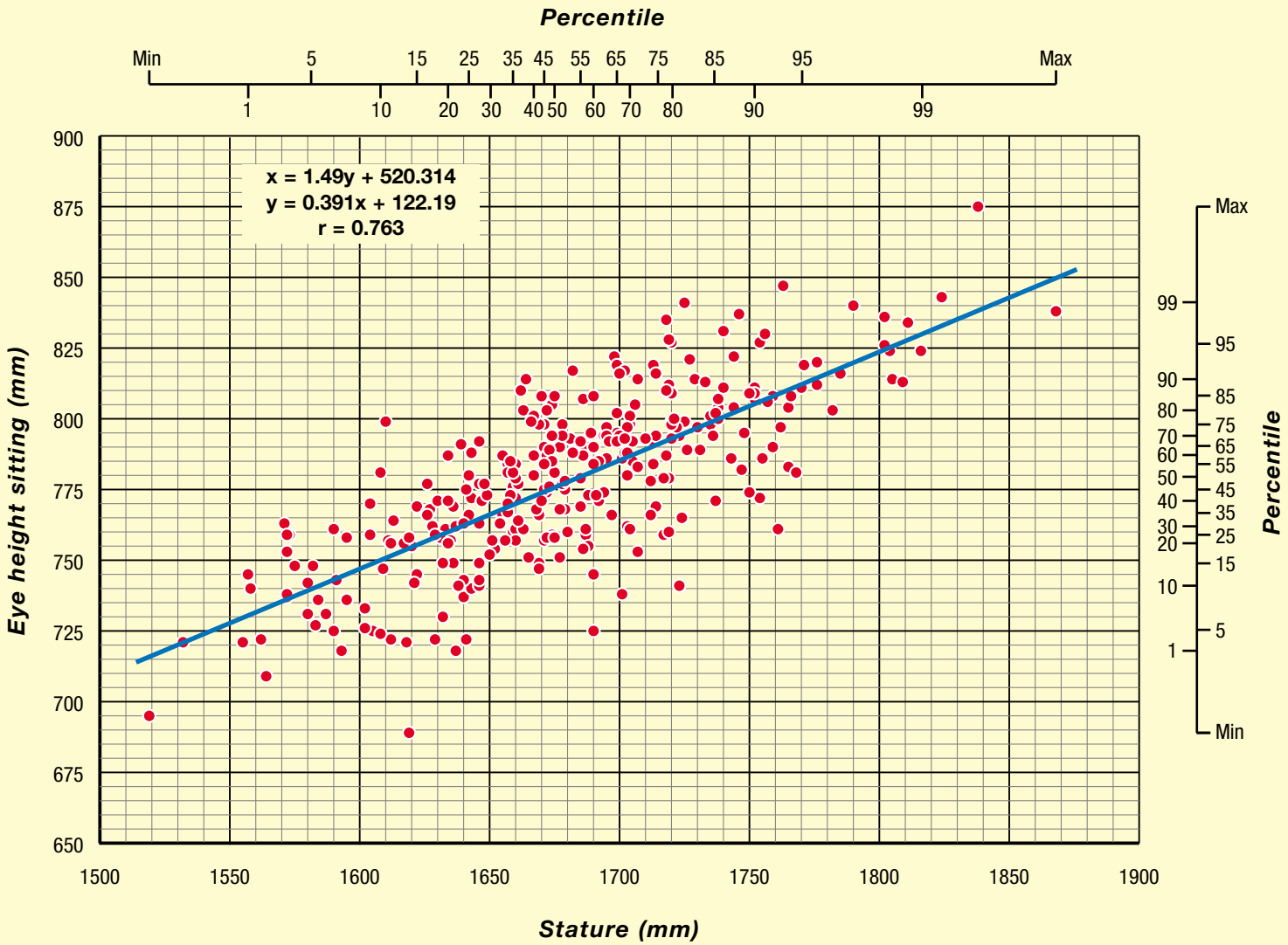
Stature
Elbow – Wrist Length

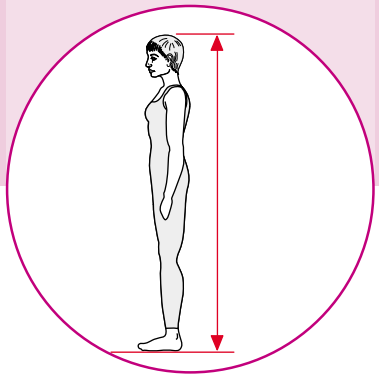


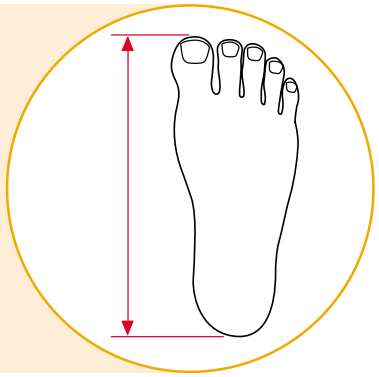
Stature
Eye Height Sitting



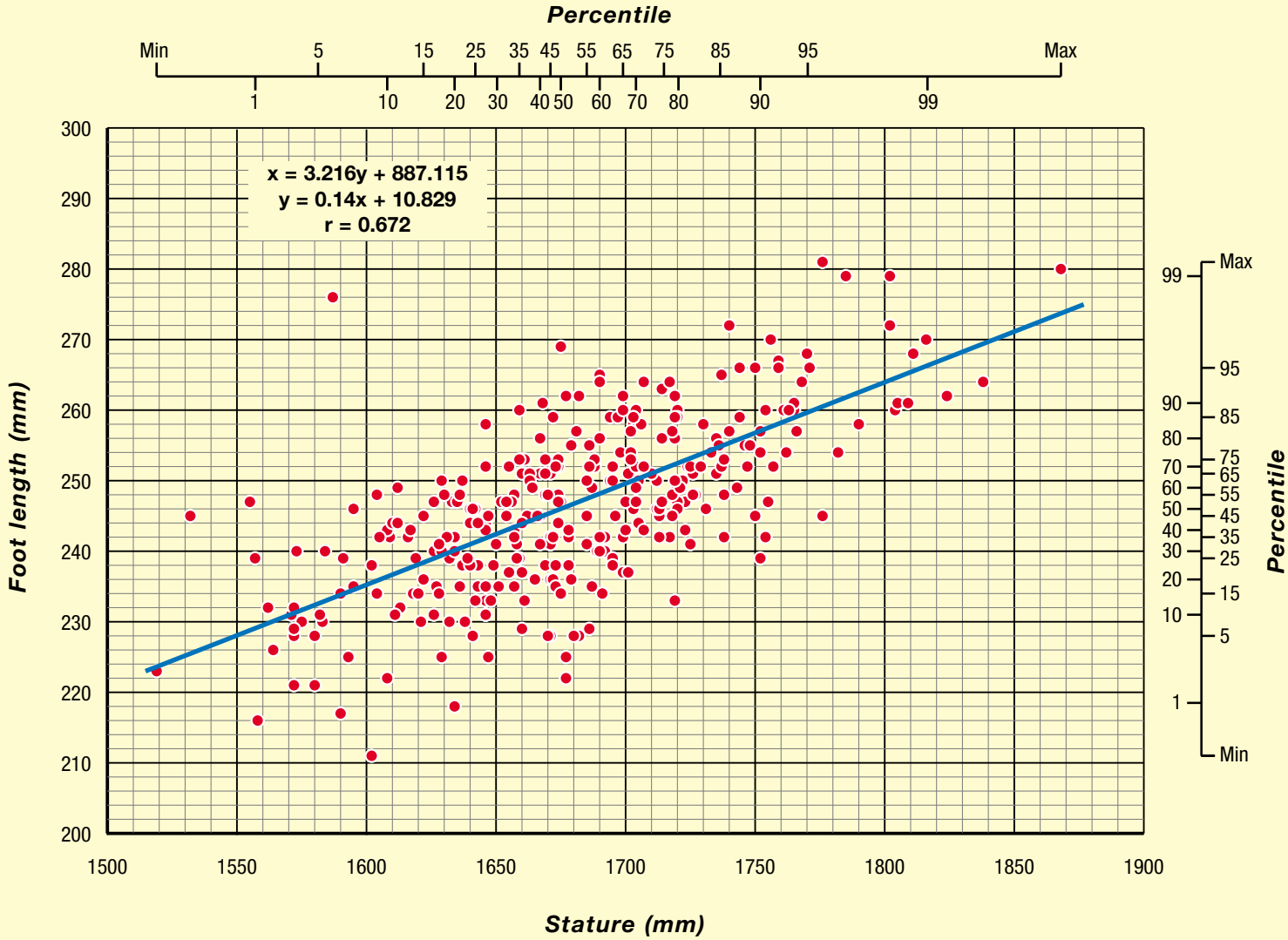




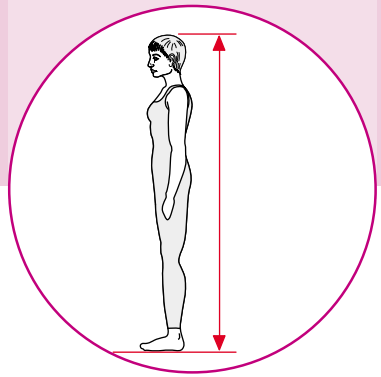


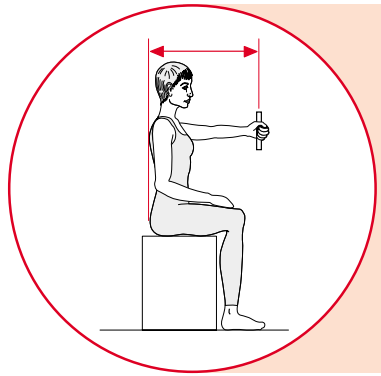


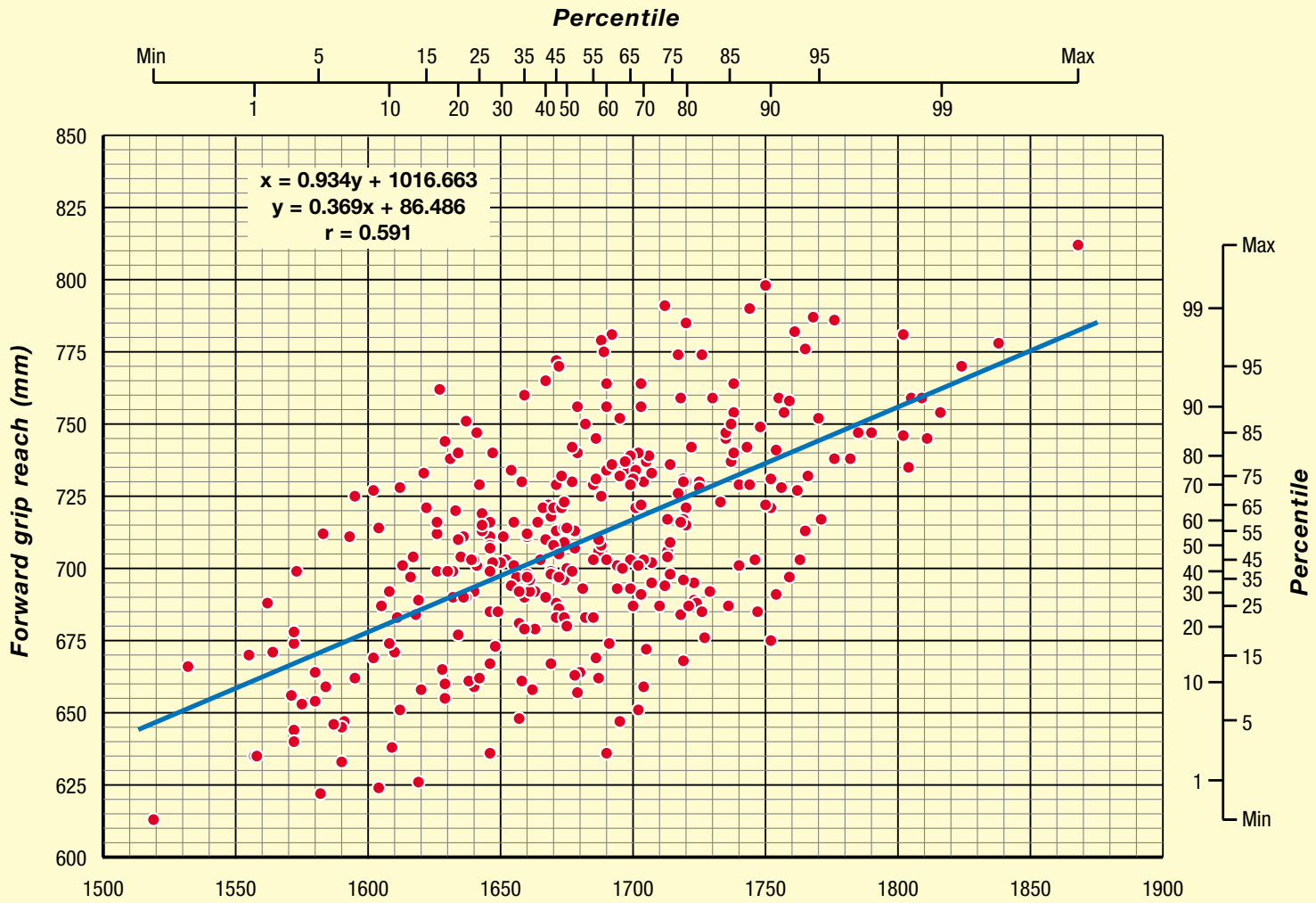
Stature
Foot Length

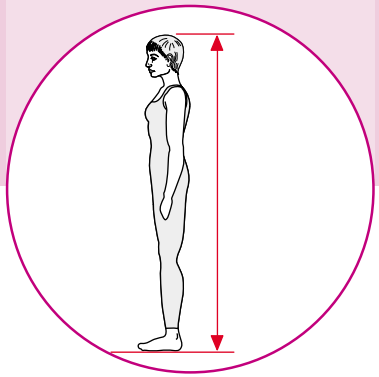


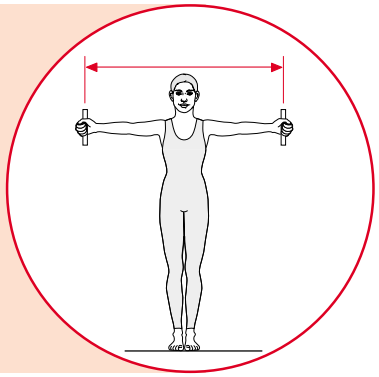
Stature
Forward Grip Reach



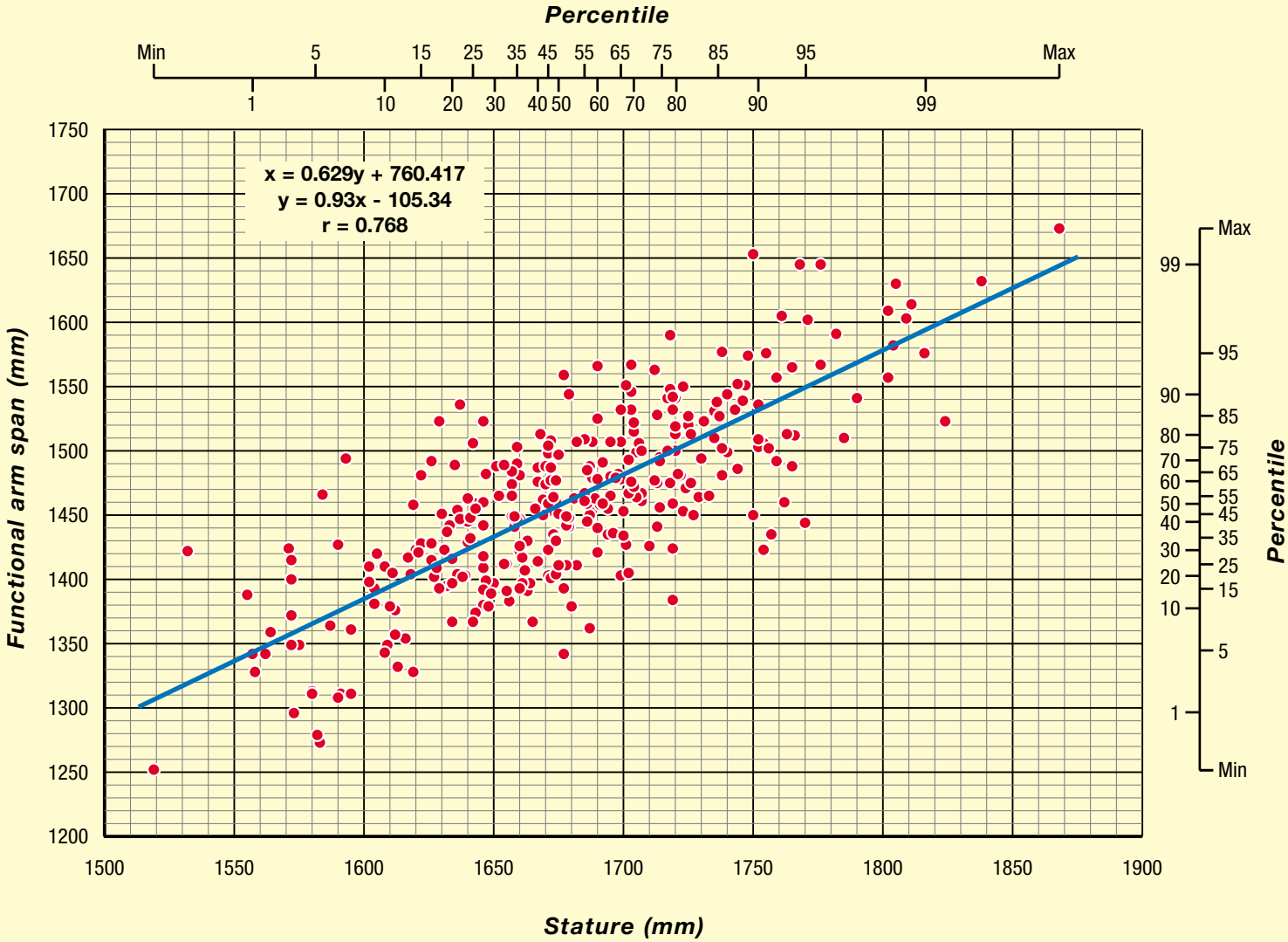




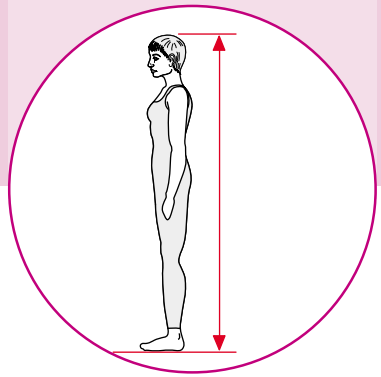


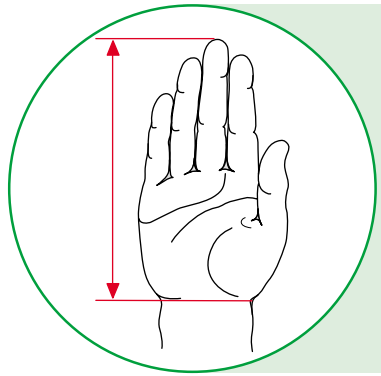


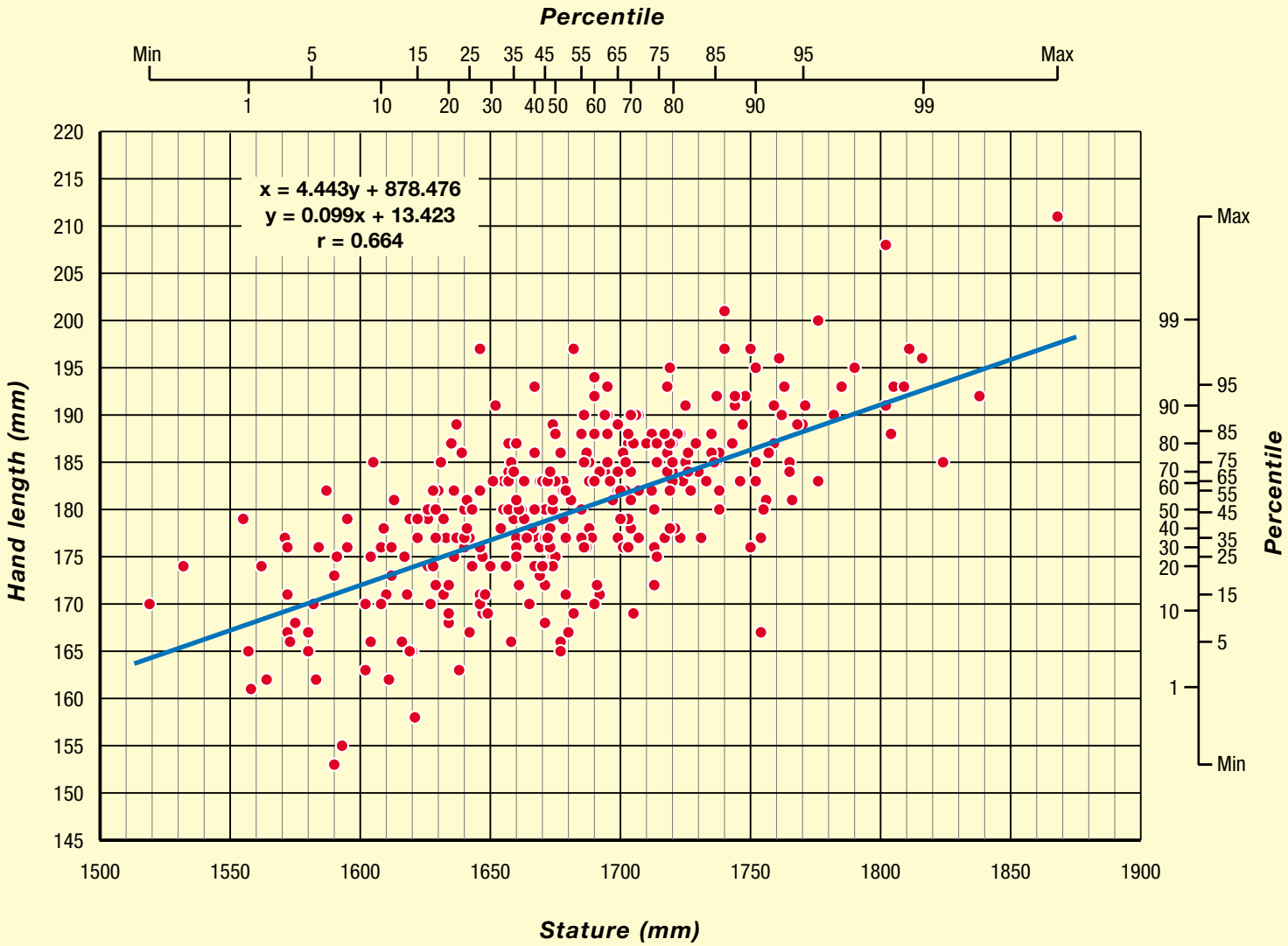
Stature
Functional Arm Span

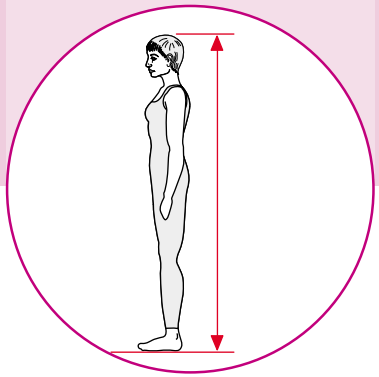


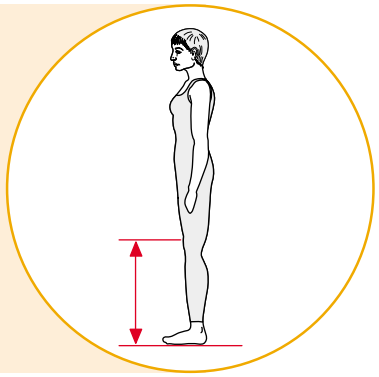
Stature
Hand Length



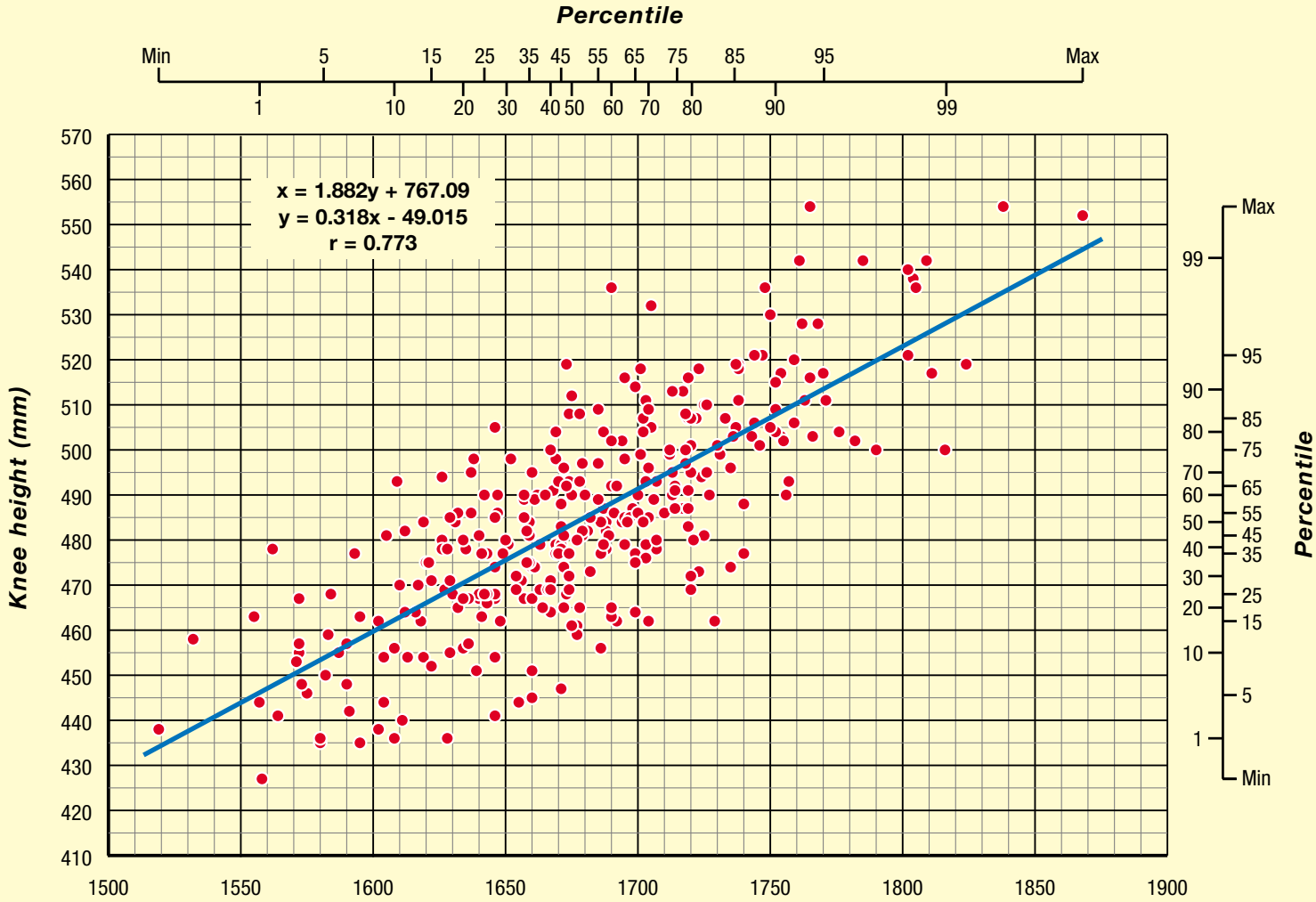




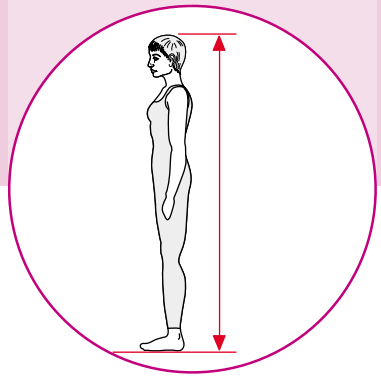


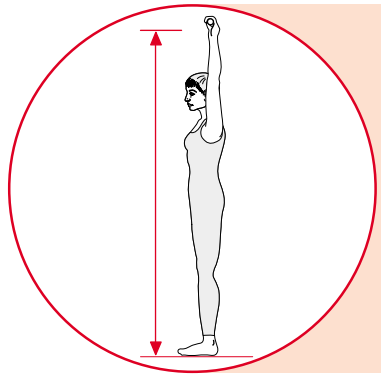


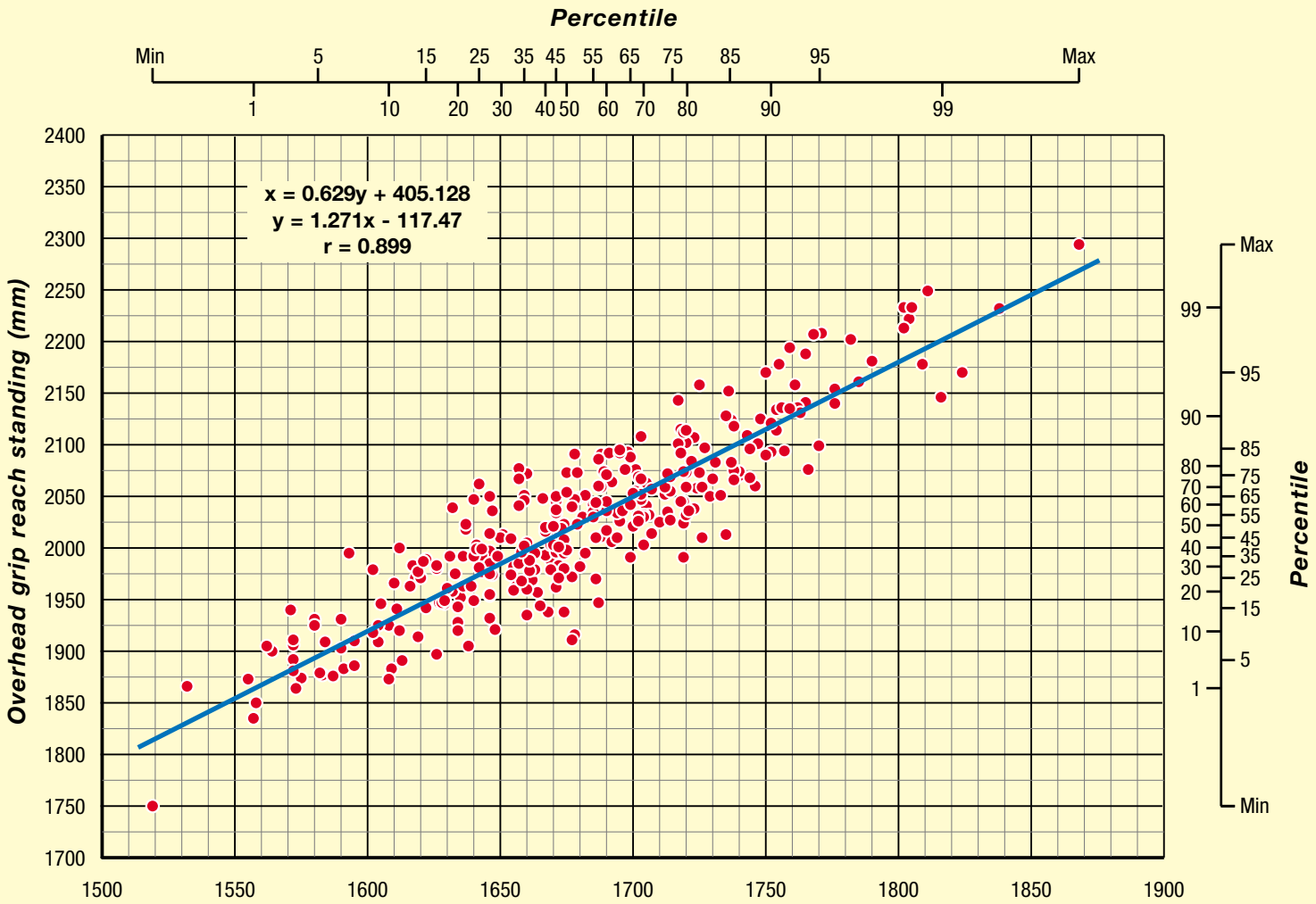
Stature
Knee Height

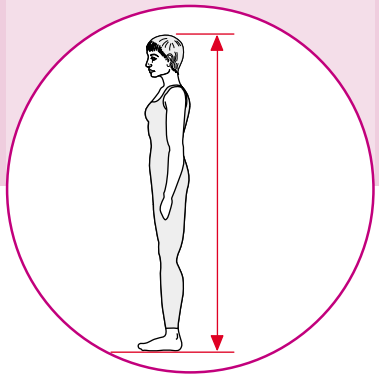


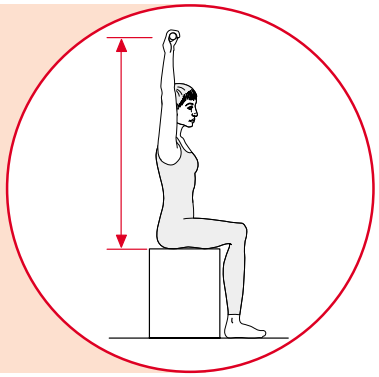
Stature
Overhead Grip Reach Standing



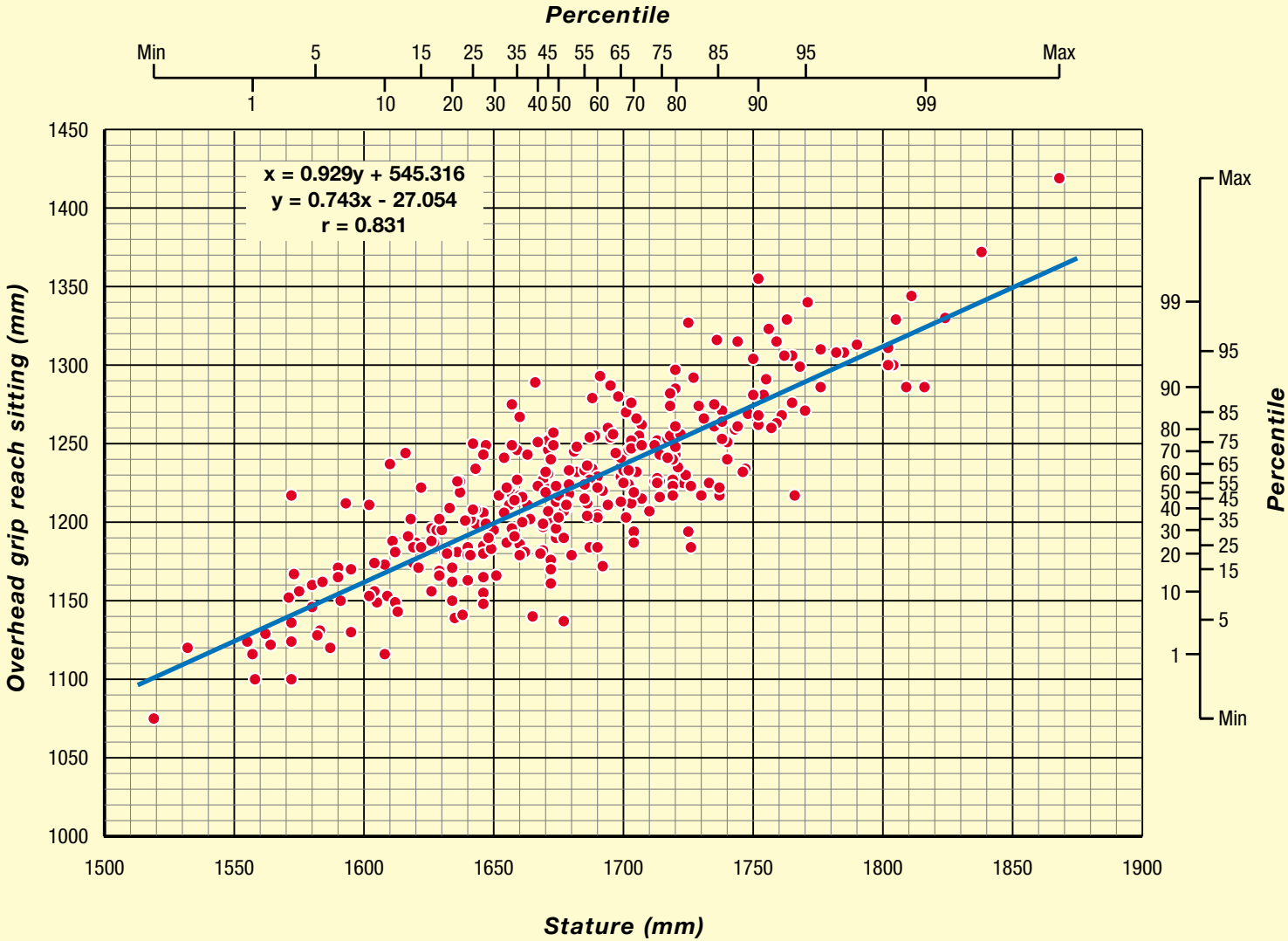




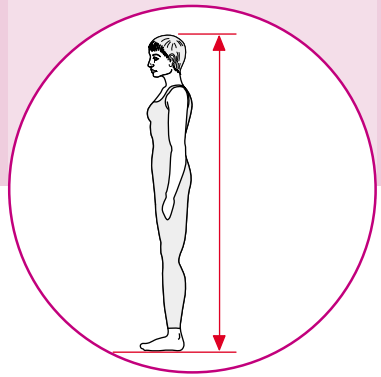


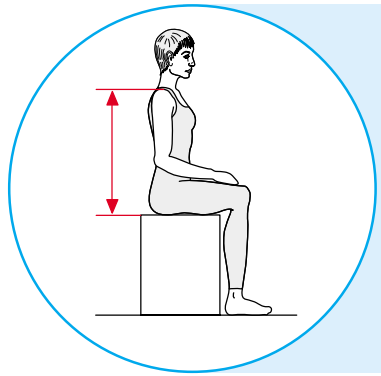


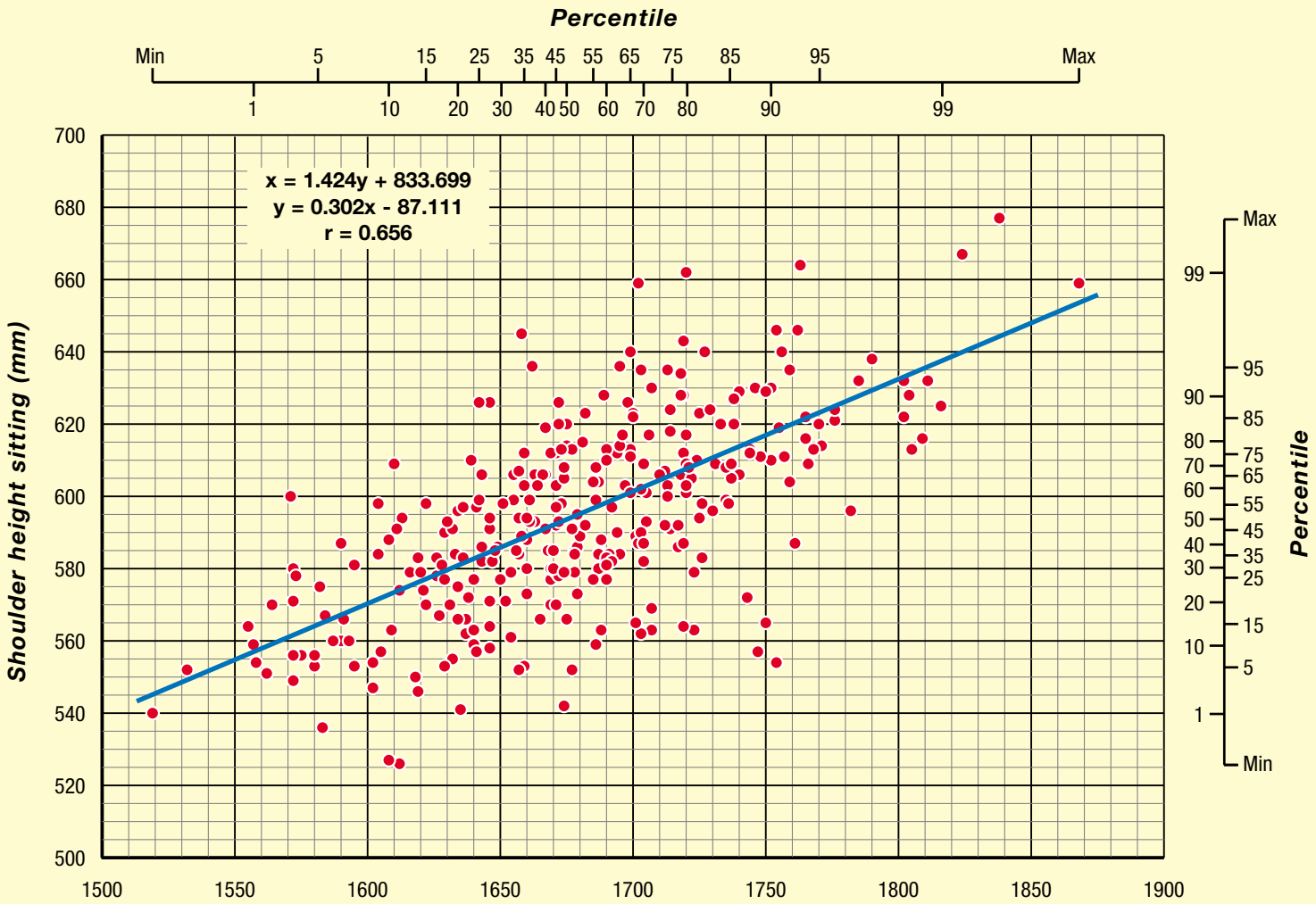
Stature
Overhead Grip Reach Sitting

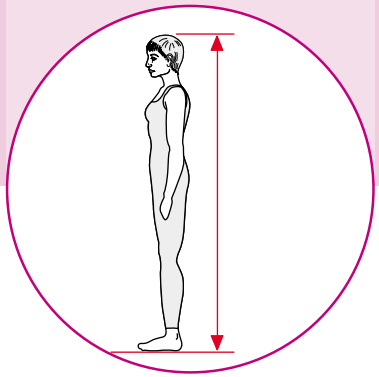


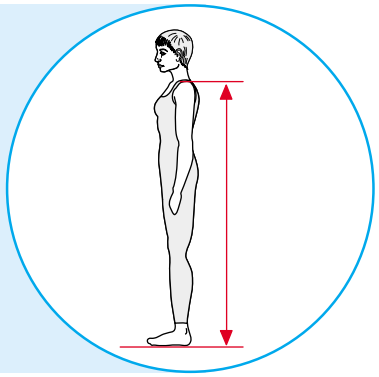
Stature
Shoulder Height Sitting



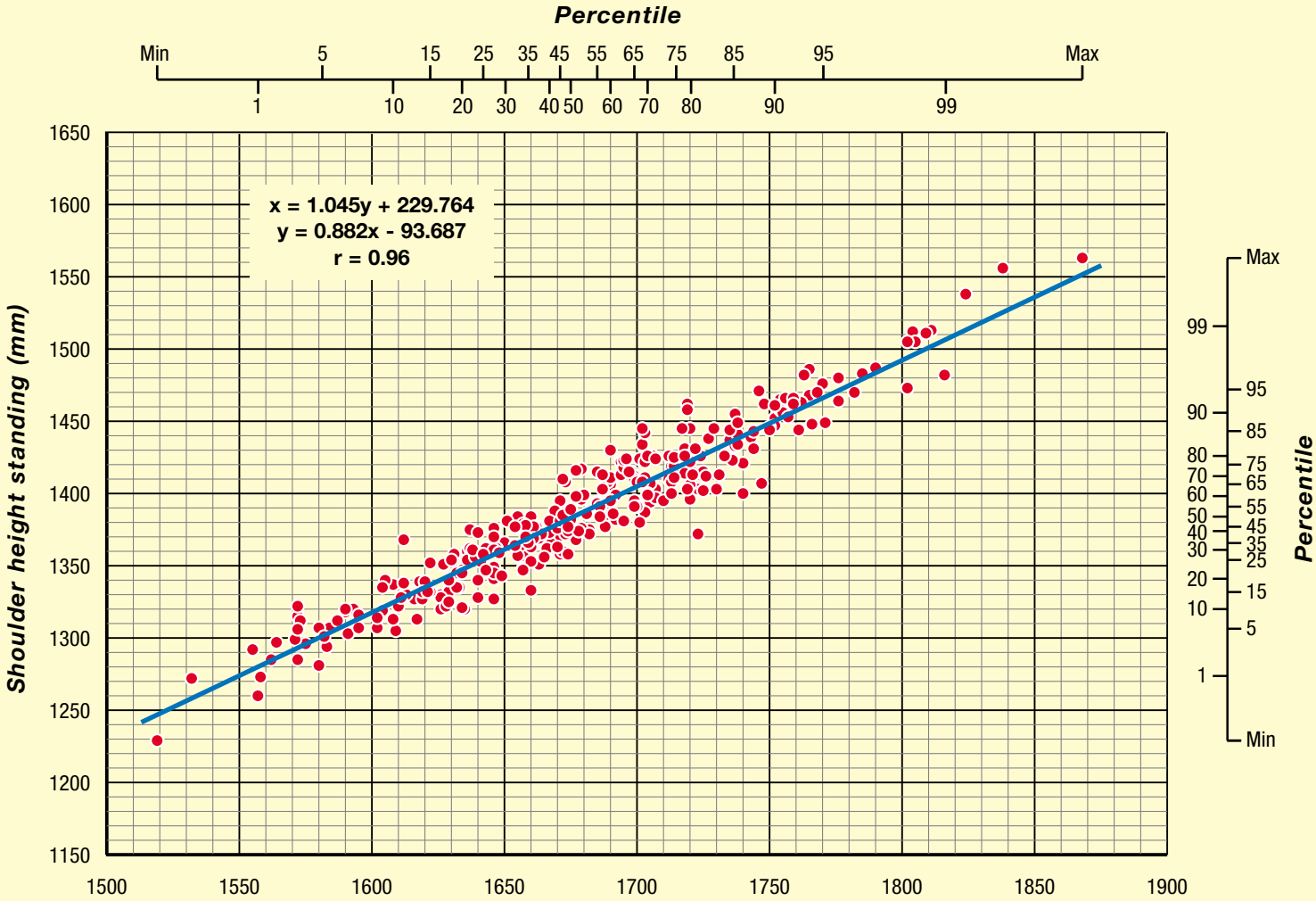




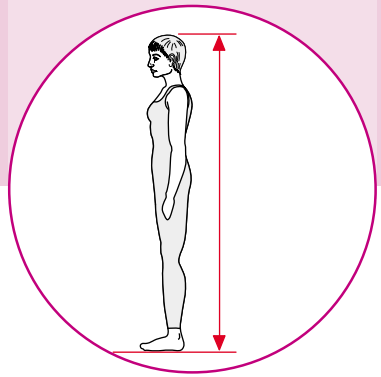


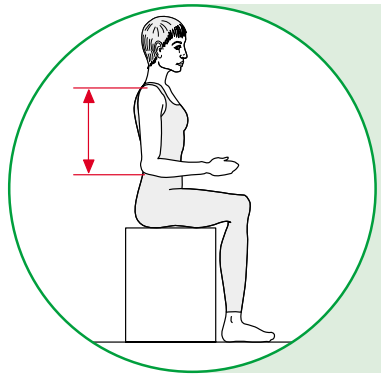


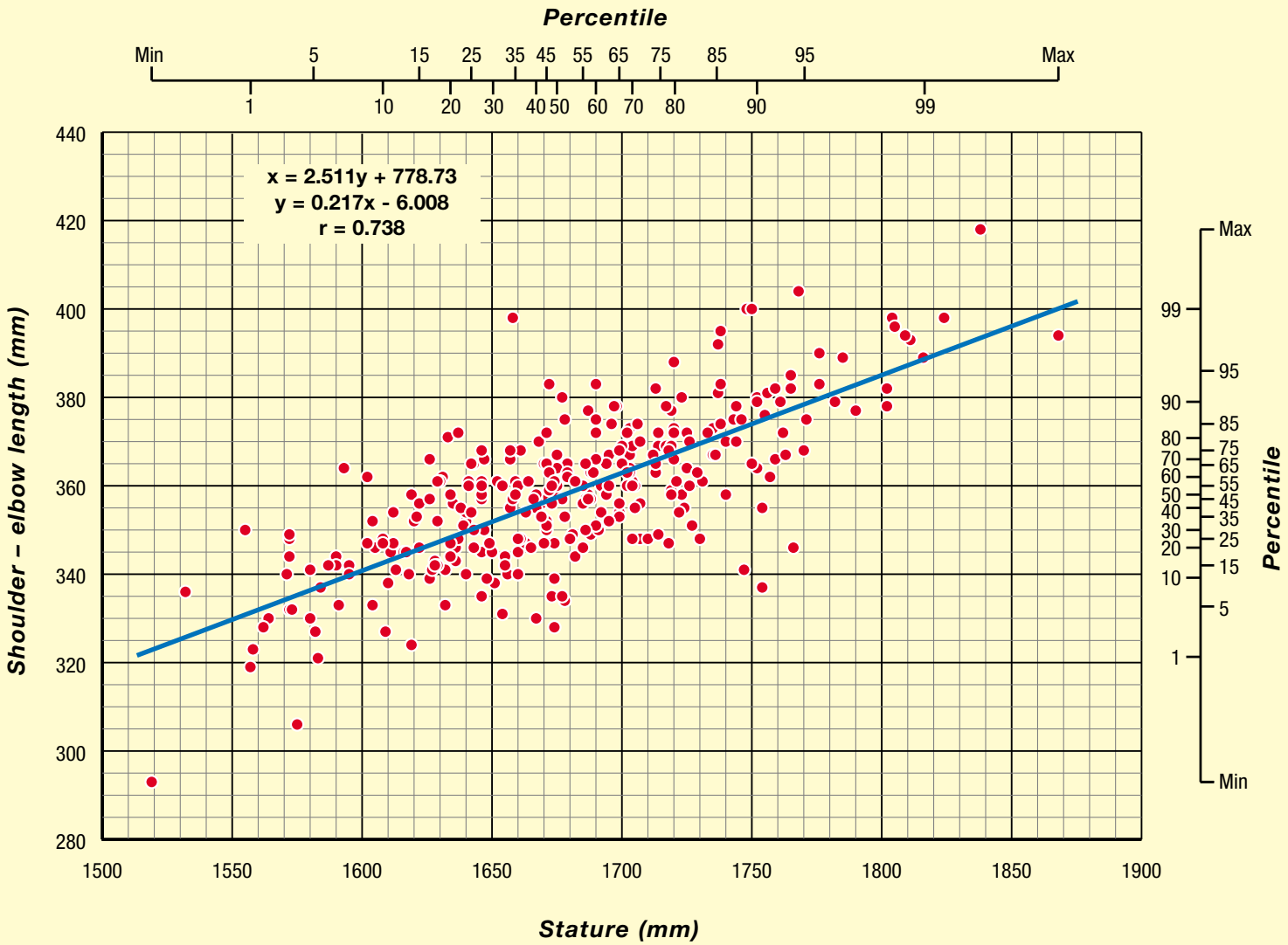
Stature
Shoulder Height Standing

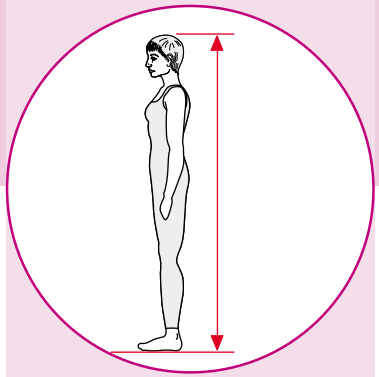


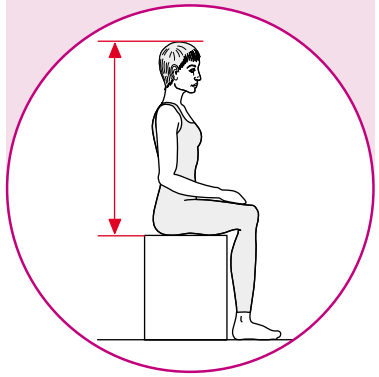
Stature
Shoulder – Elbow Length



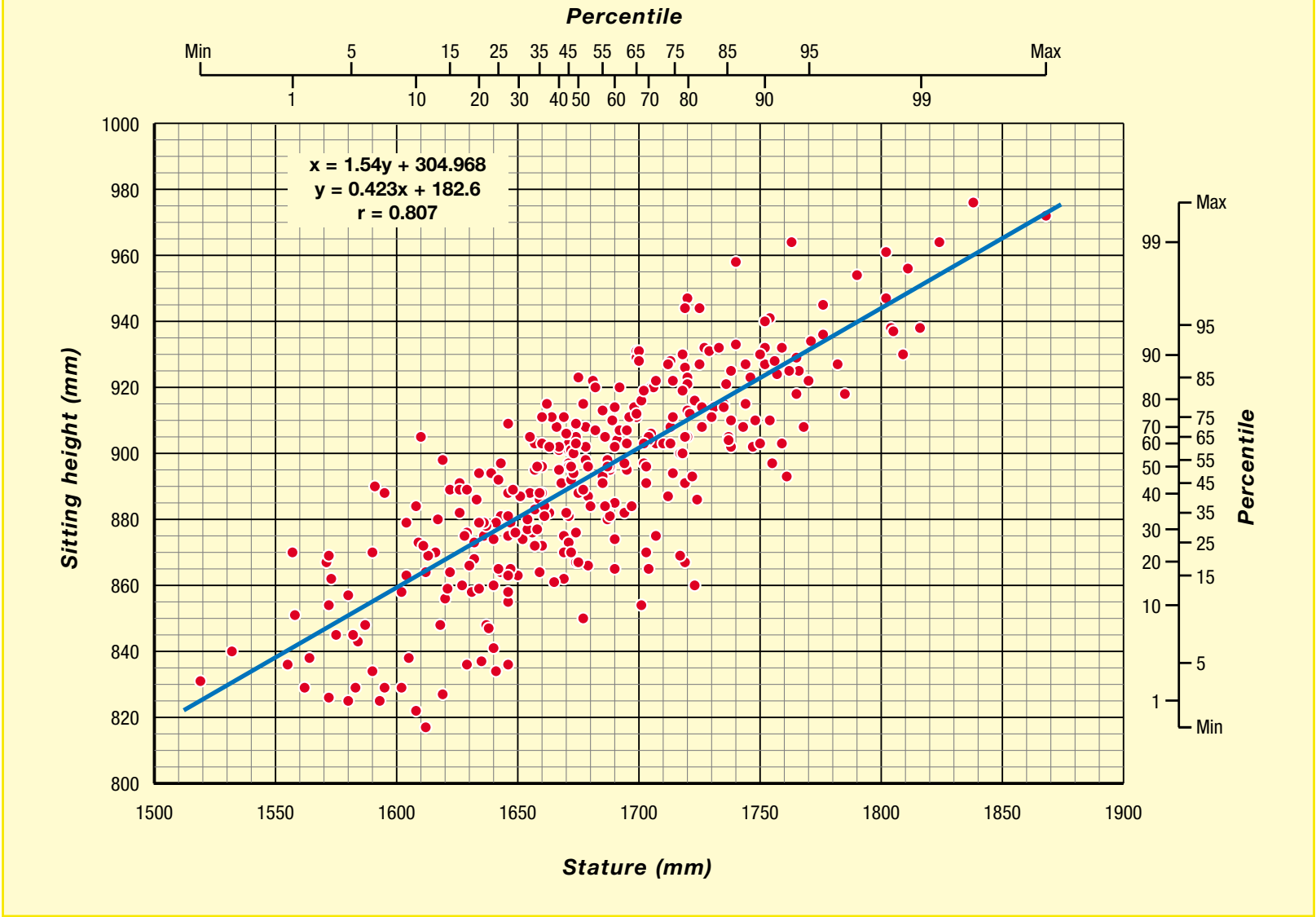




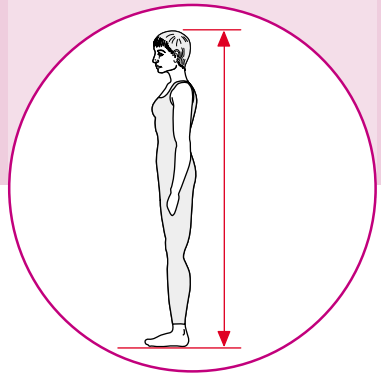


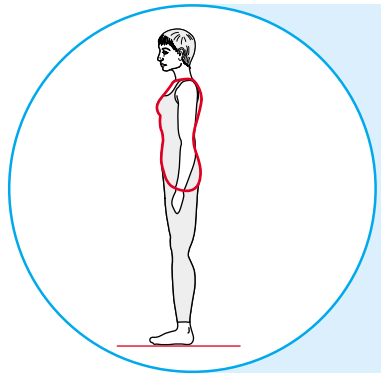


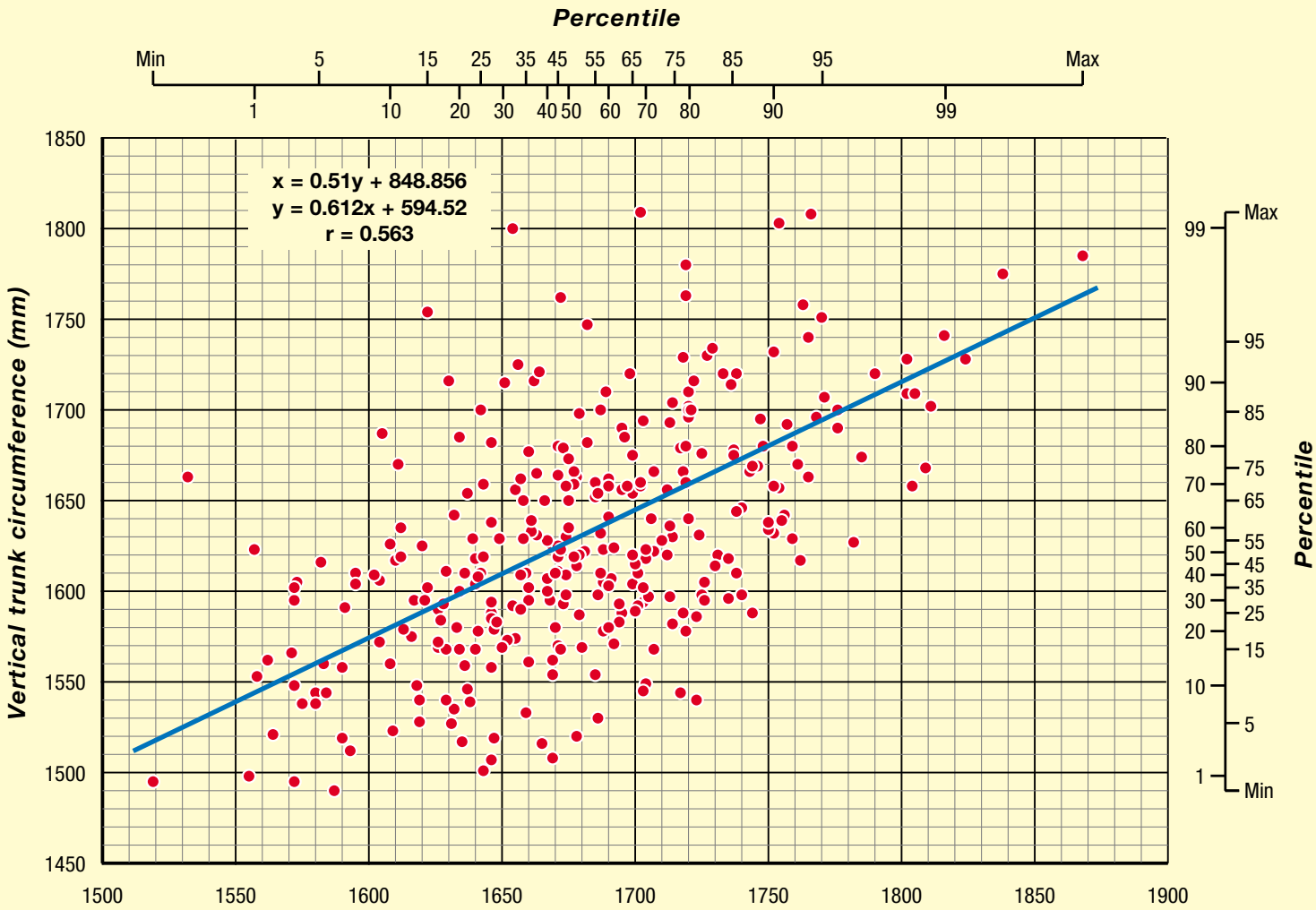
Stature
Sitting Height

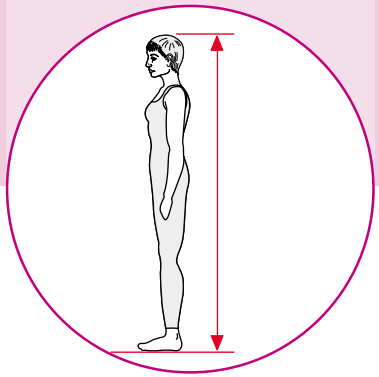


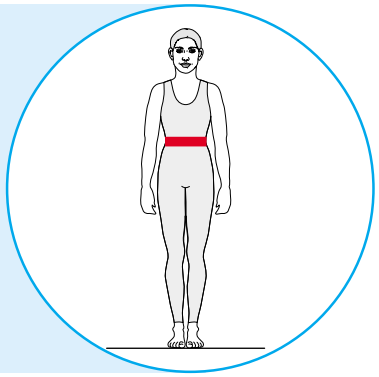
Stature
Vertical Trunk Circumference



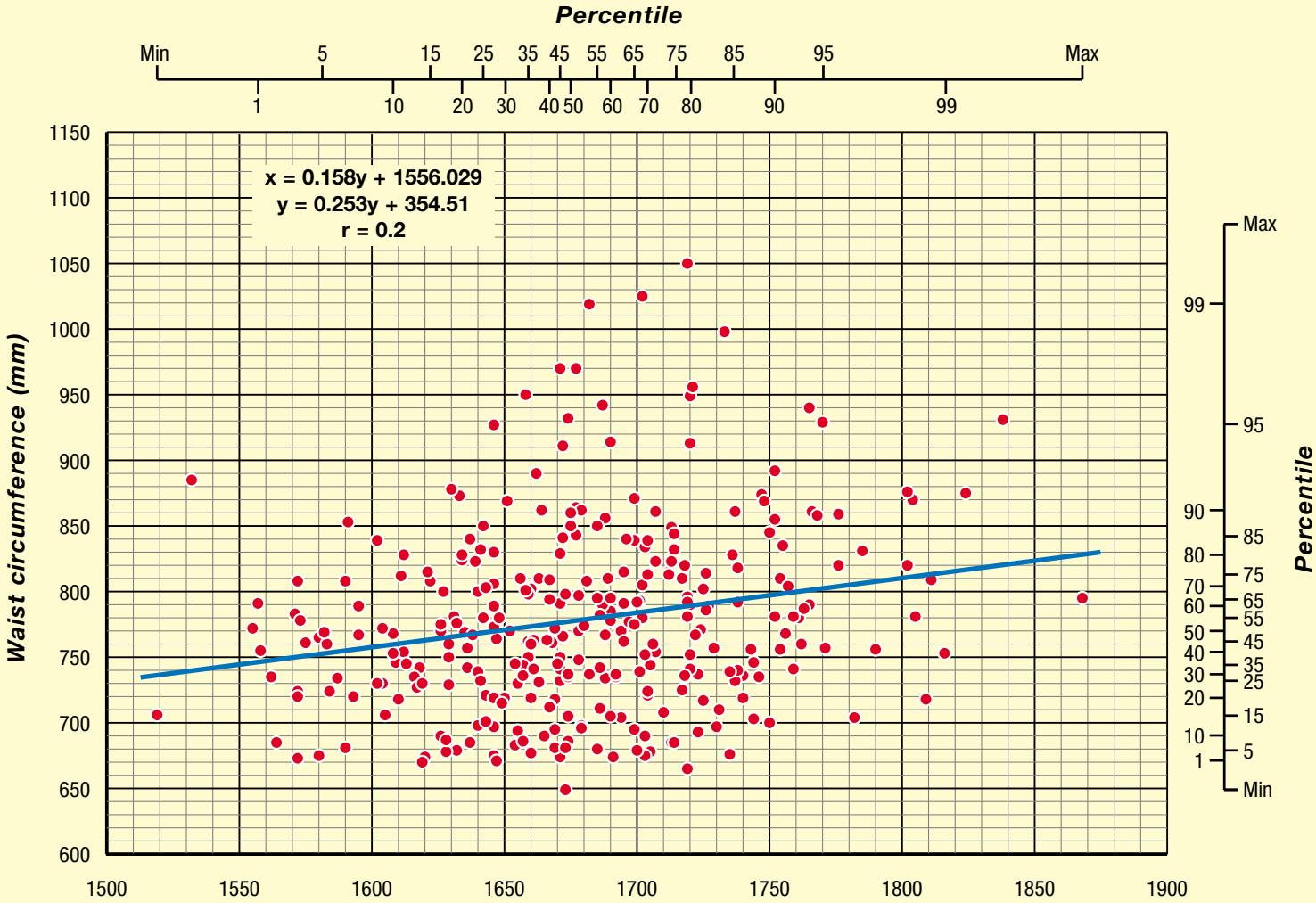




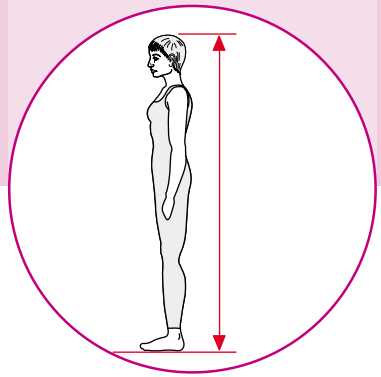


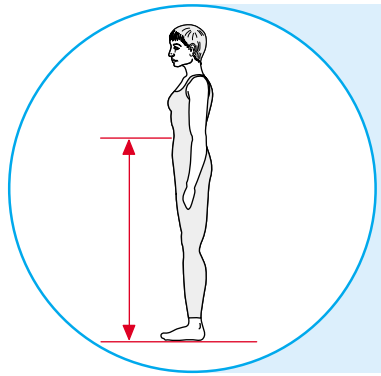


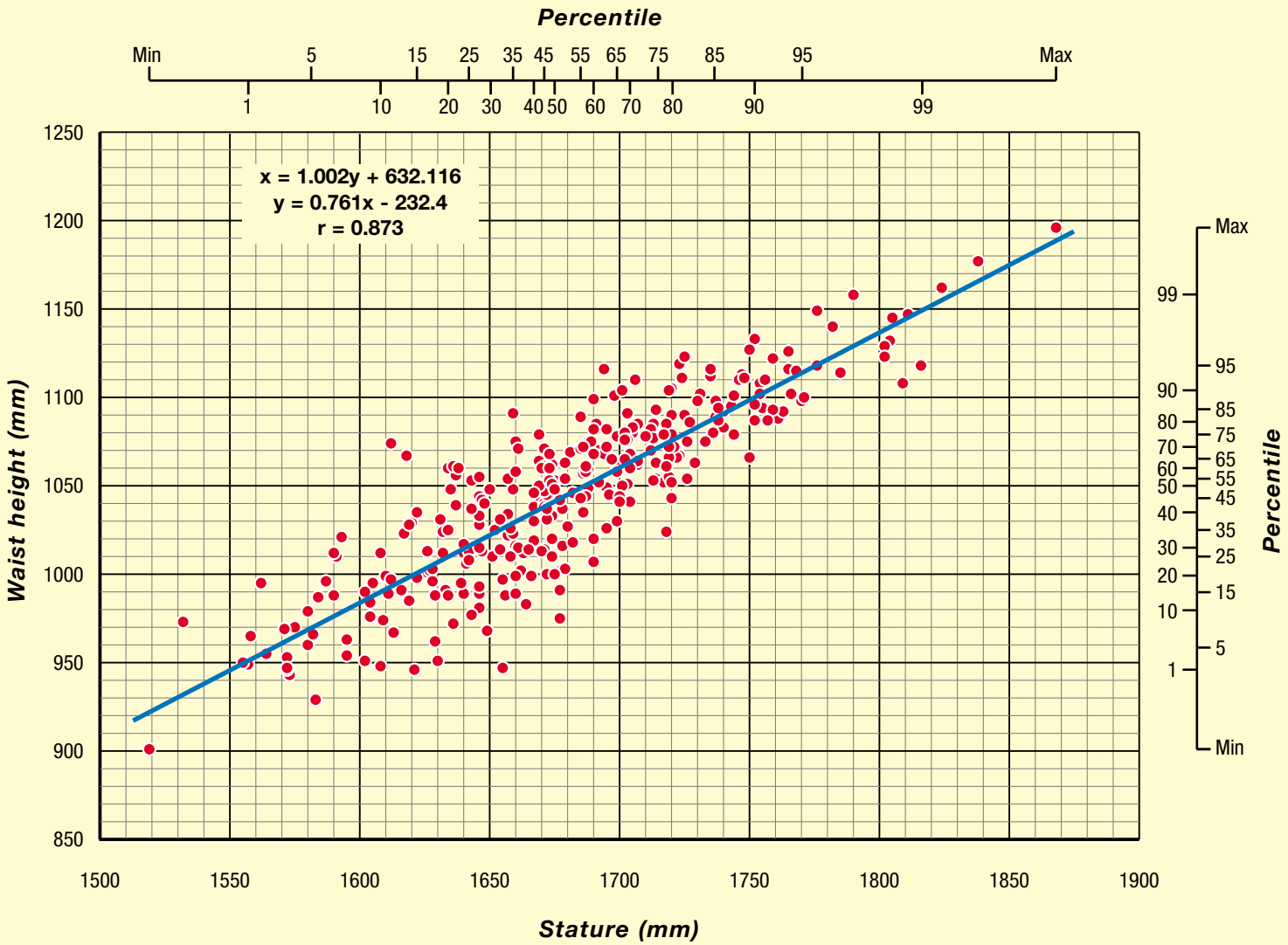
Stature
Waist Circumference

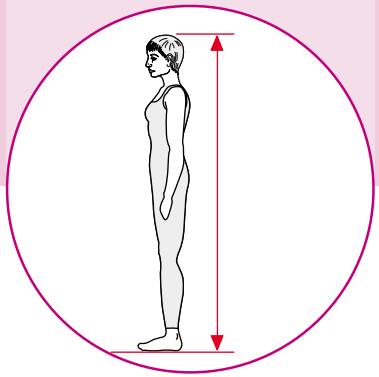


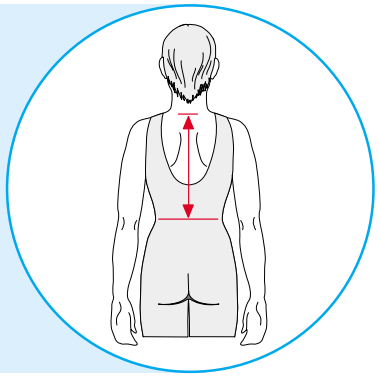
Stature
Waist Height



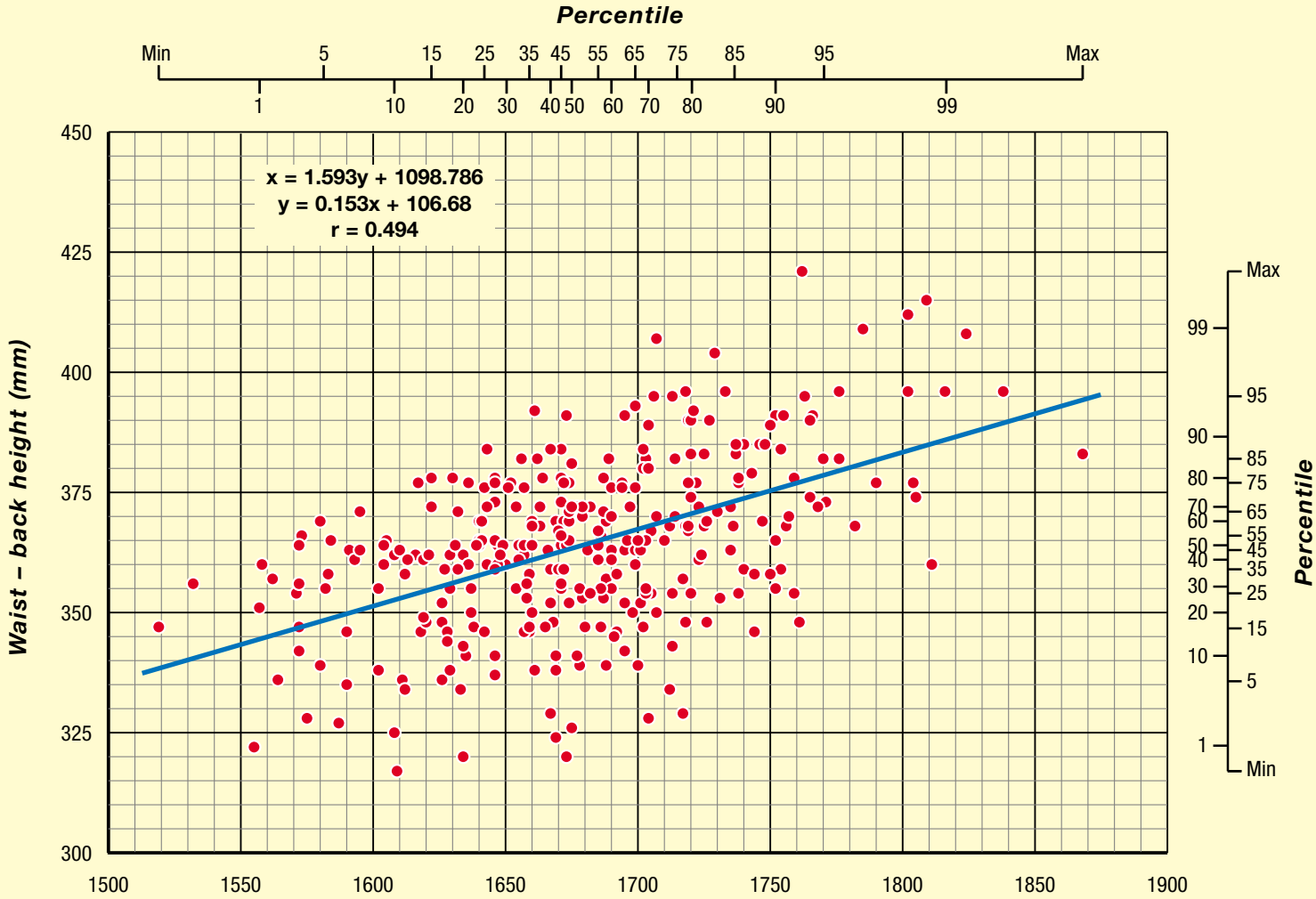




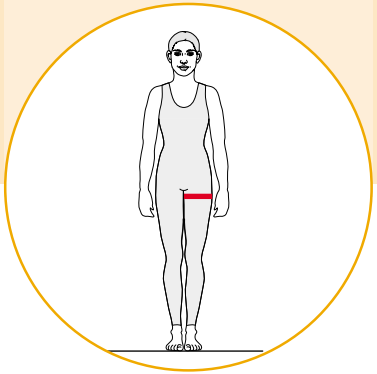


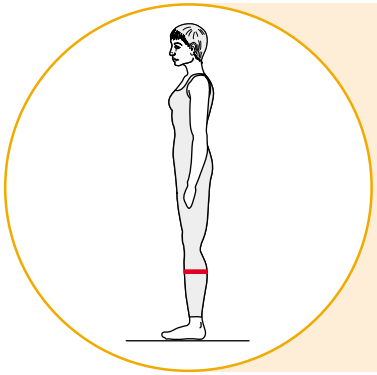


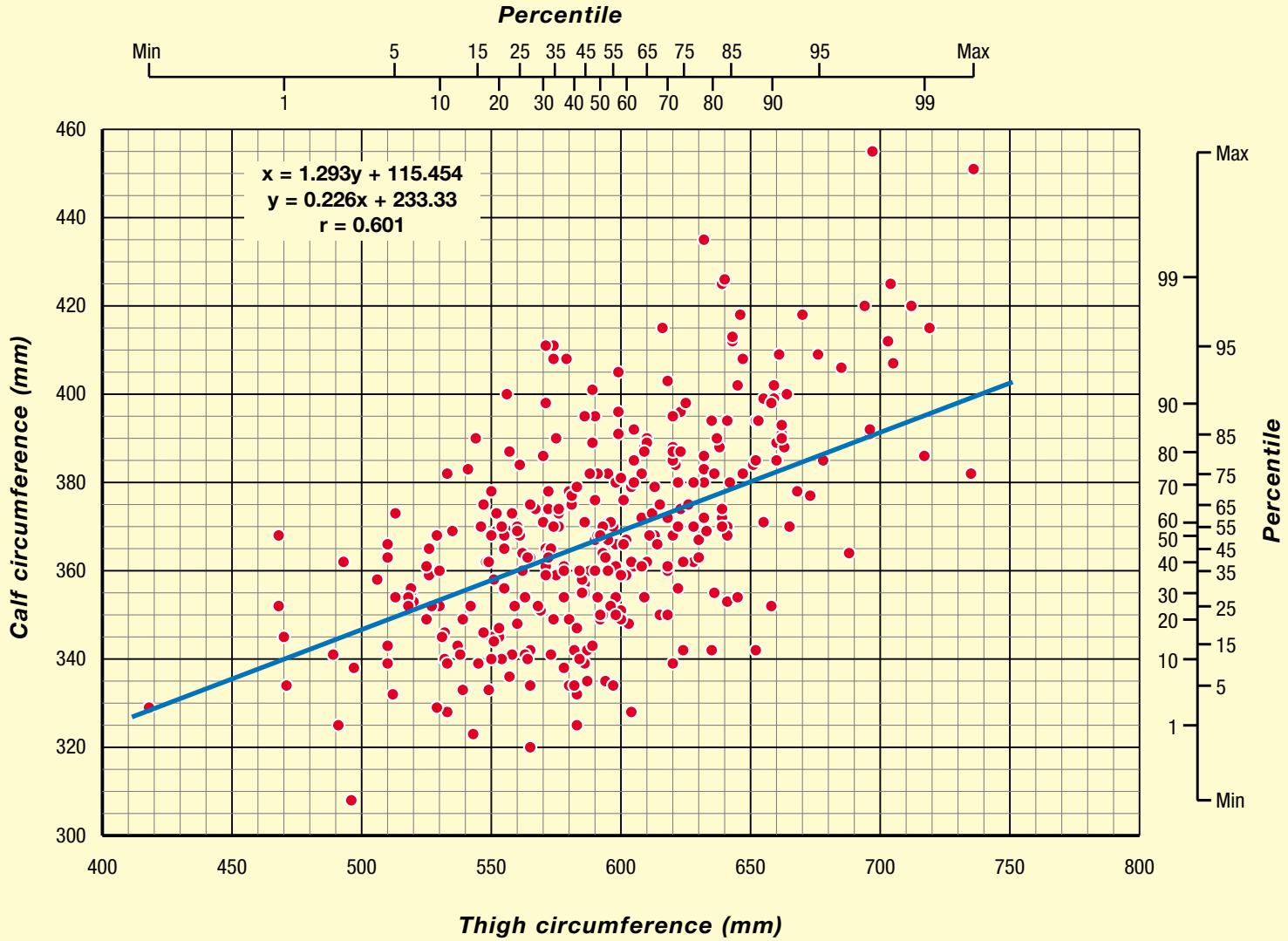
Stature
Waist – Back Height



Thigh Circumference
Calf Circumference







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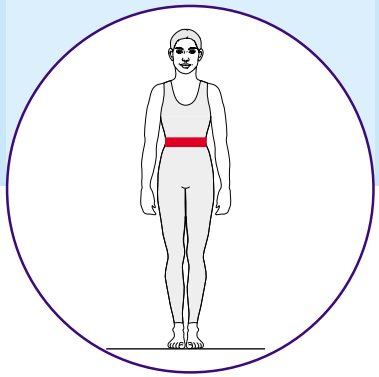
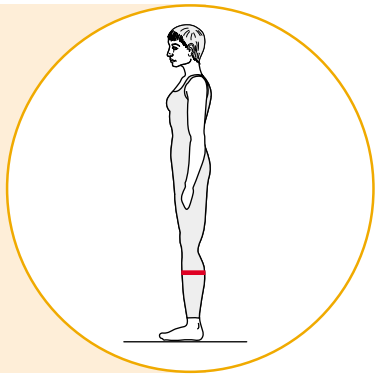
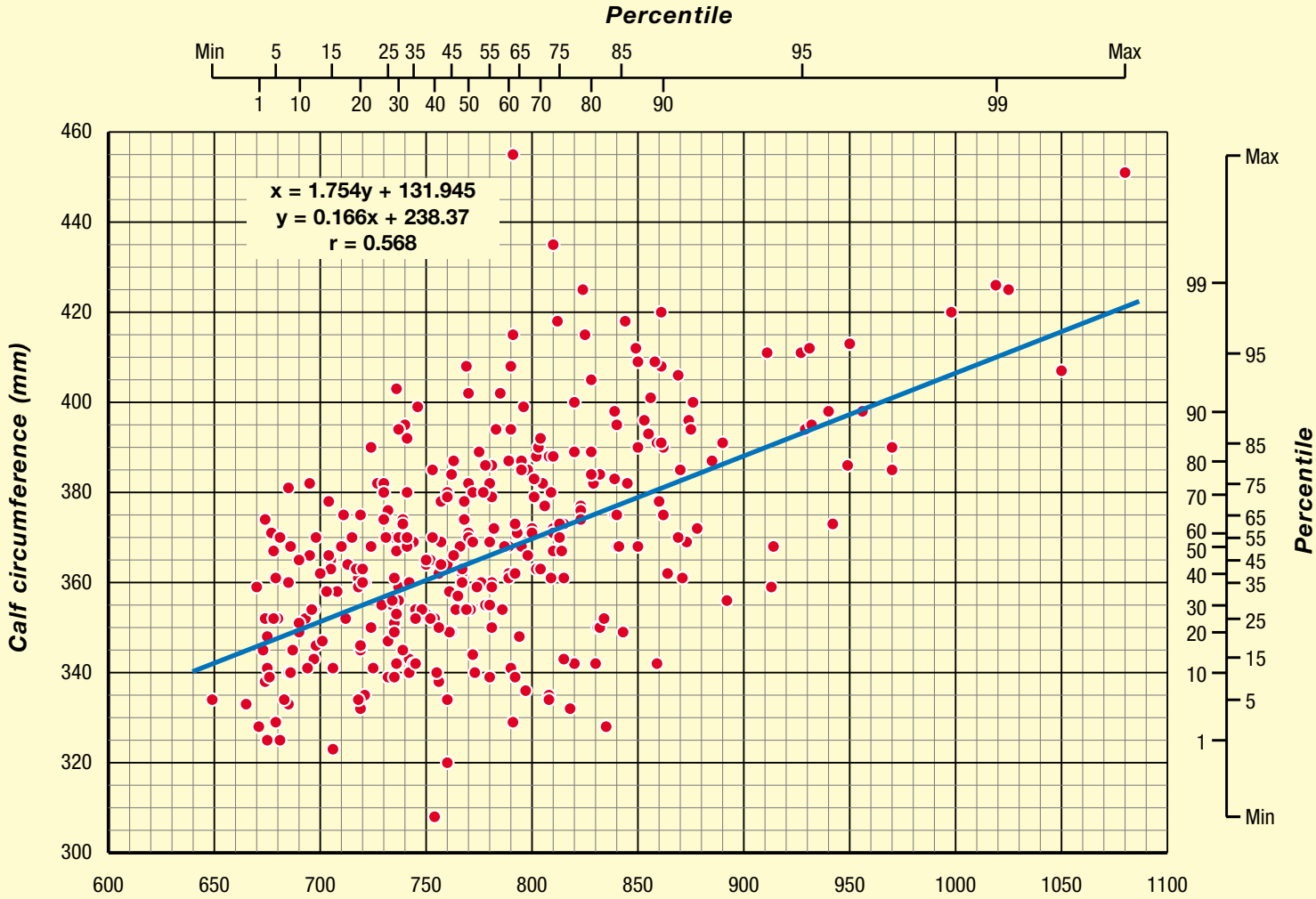
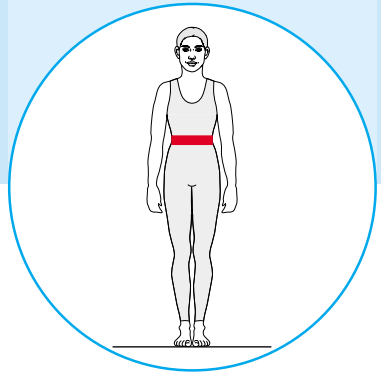


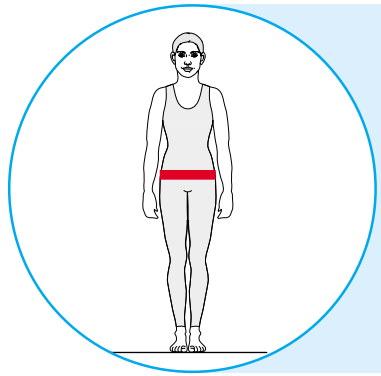


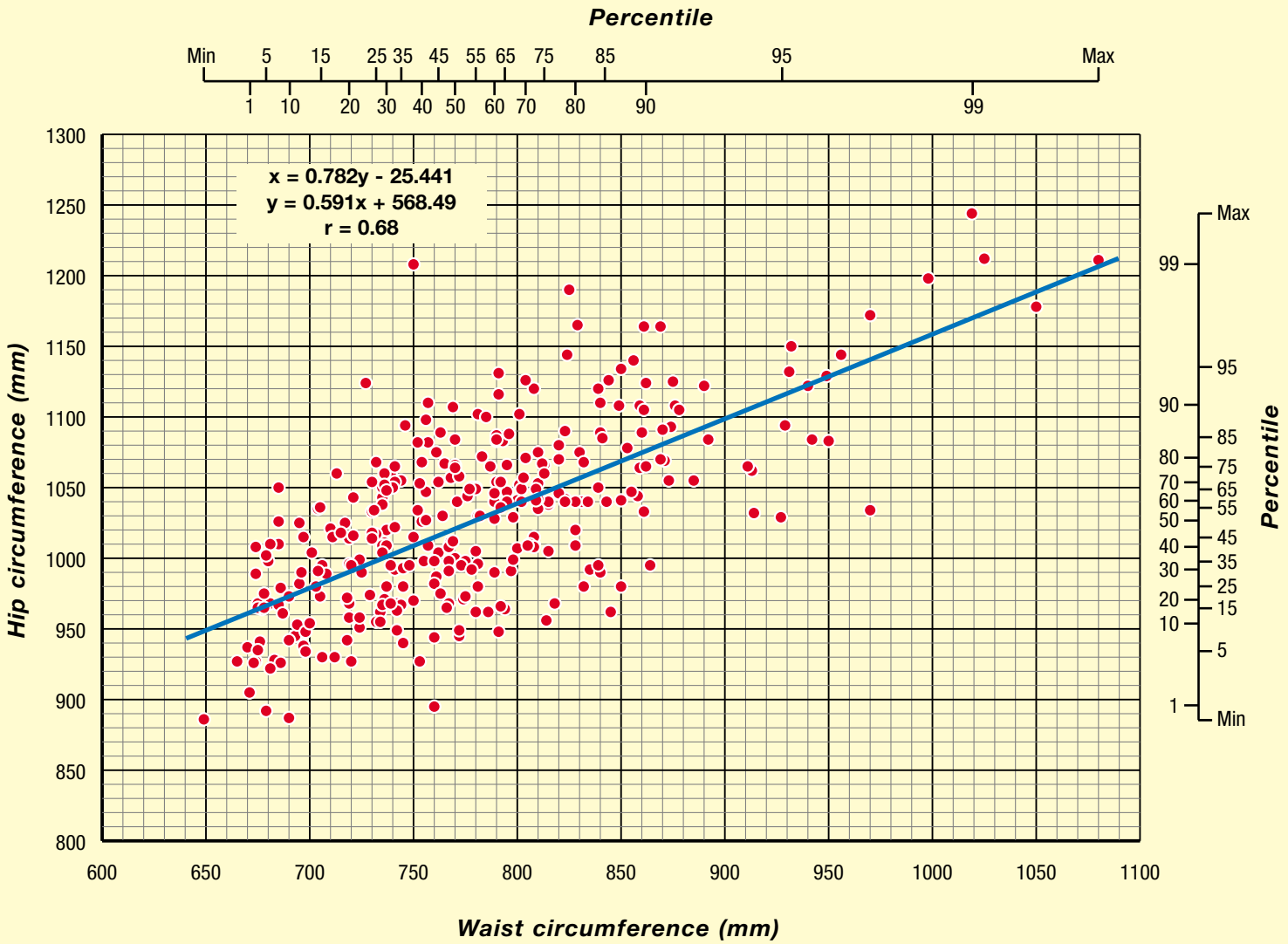
Waist Circumference
Calf Circumference

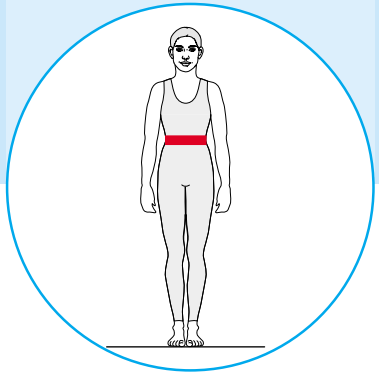


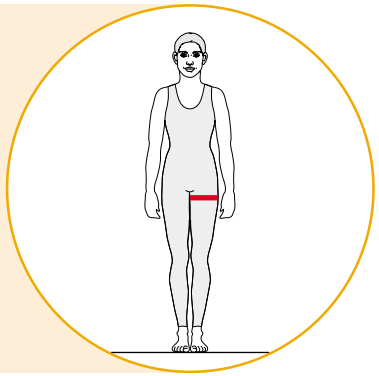
Waist Circumference
Hip Circumference



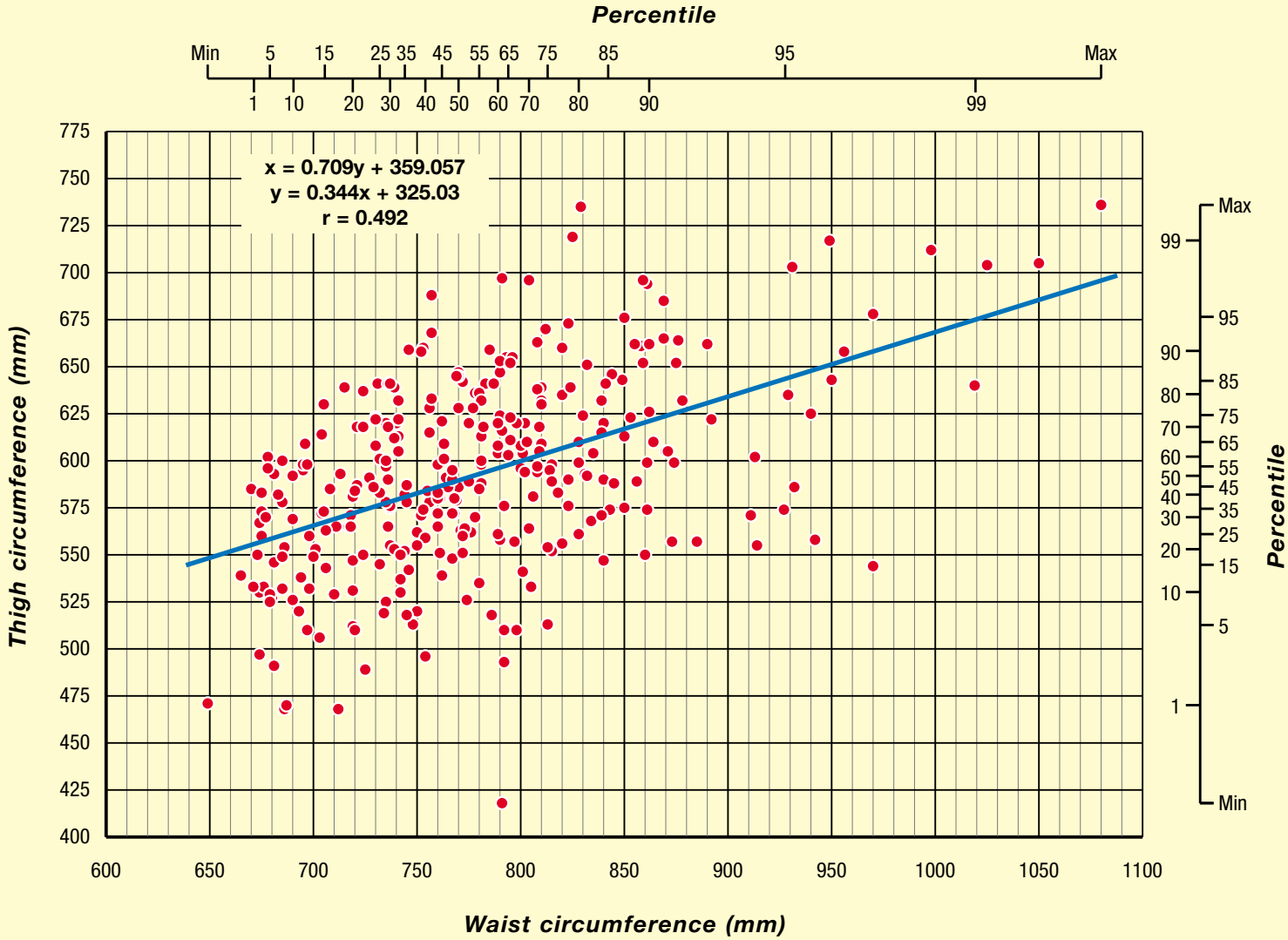




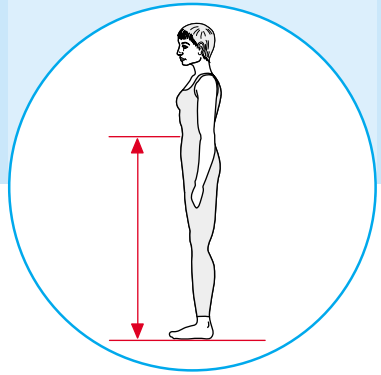


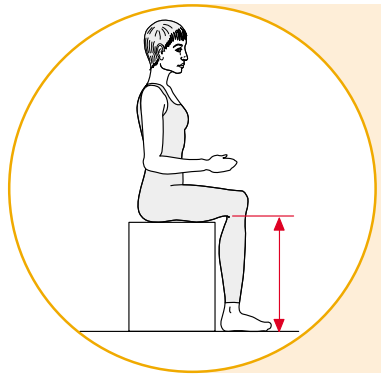


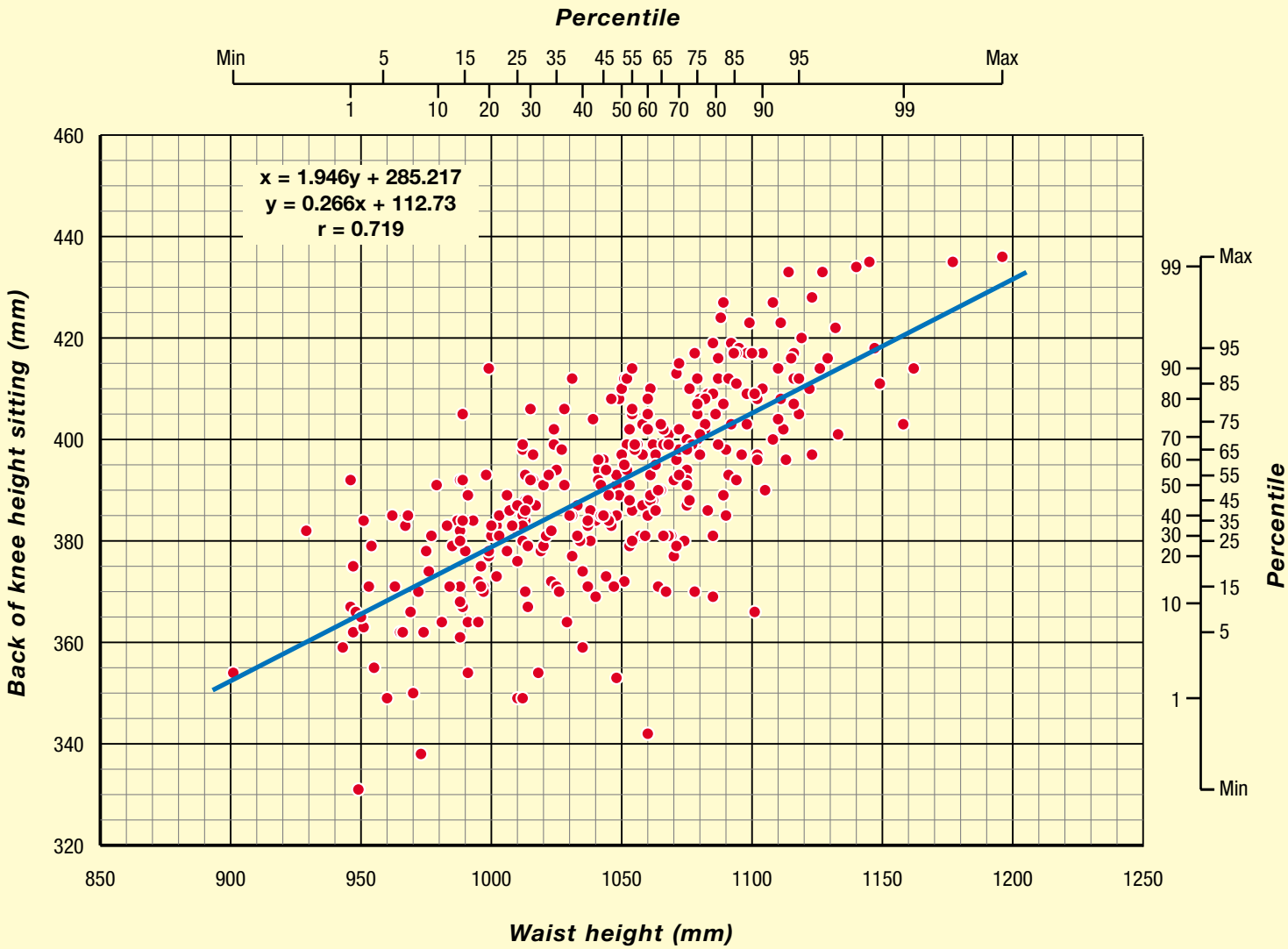
Waist Circumference
Thigh Circumference

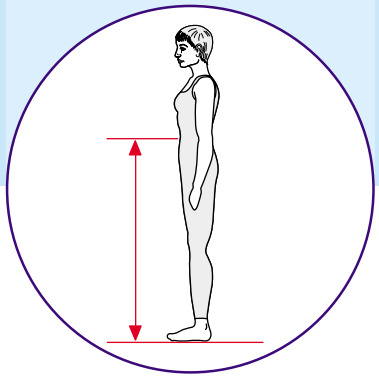


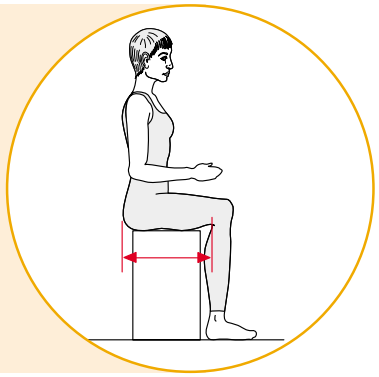
Waist Height
Back of Knee Height Sitting



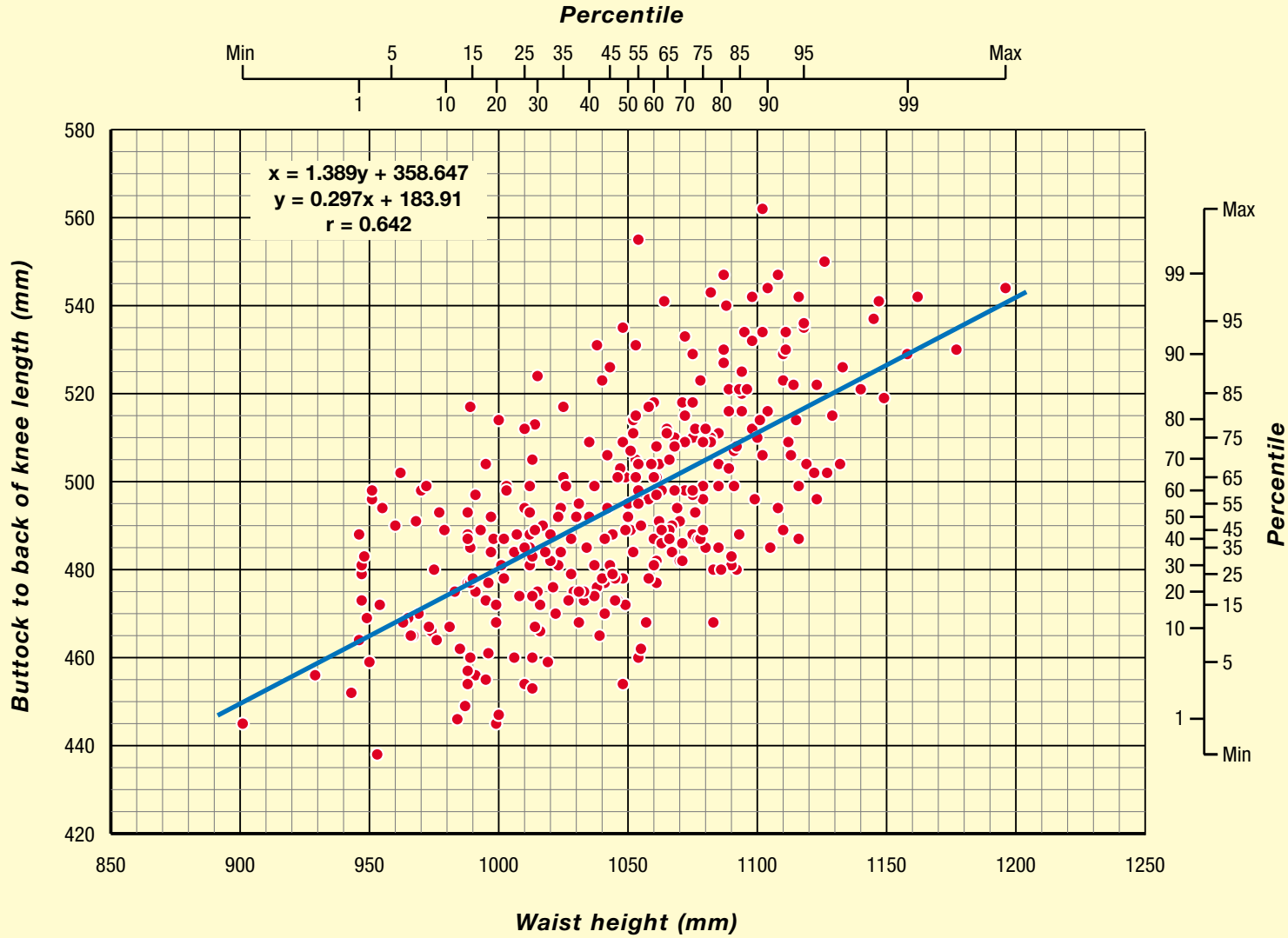




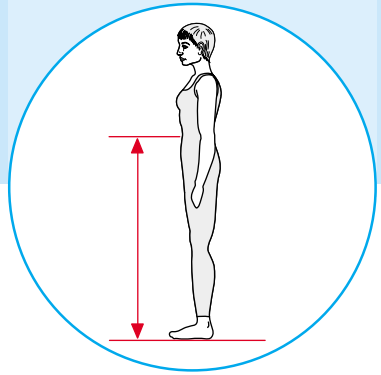


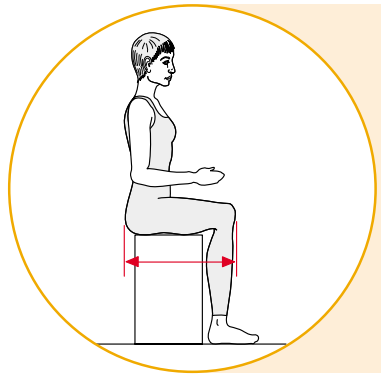


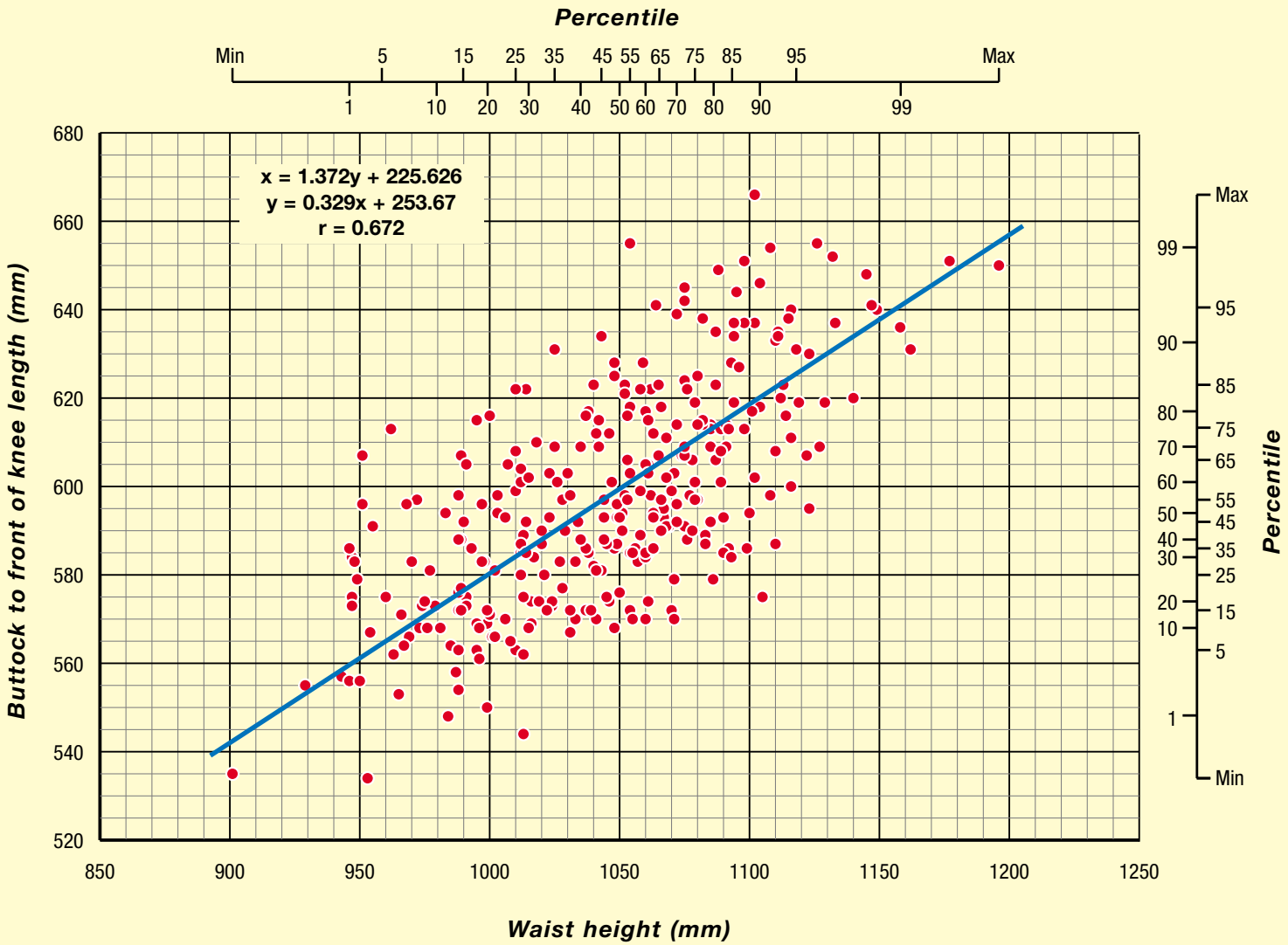
Waist Height
Buttock to Back of Knee Length

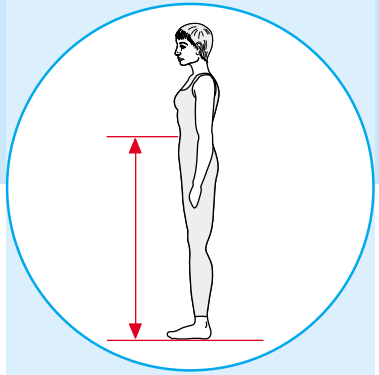


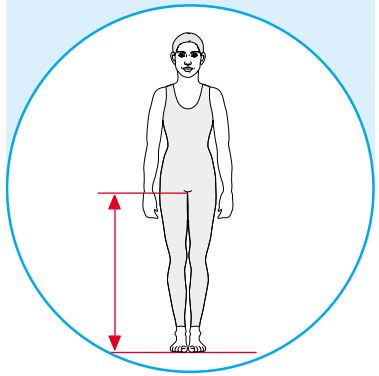
Waist Height
Buttock to Front of Knee Length



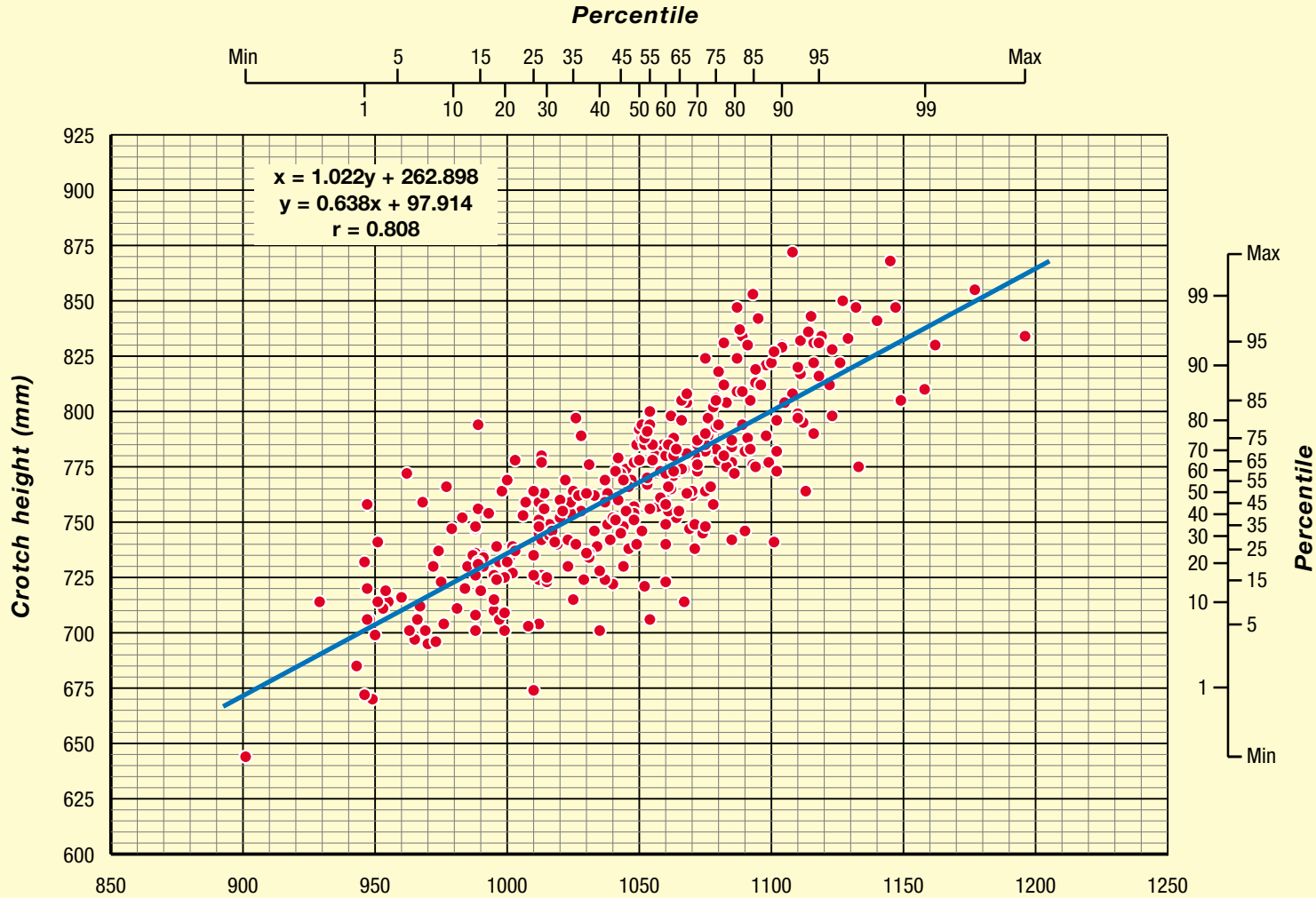




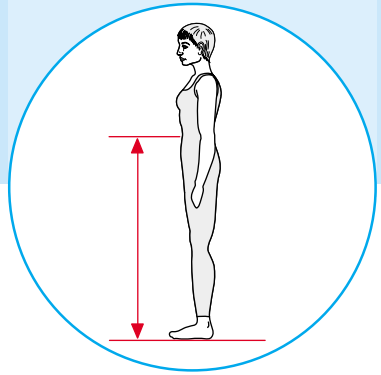


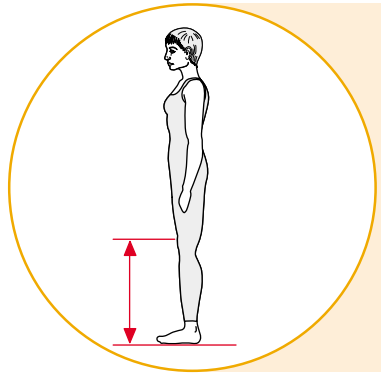


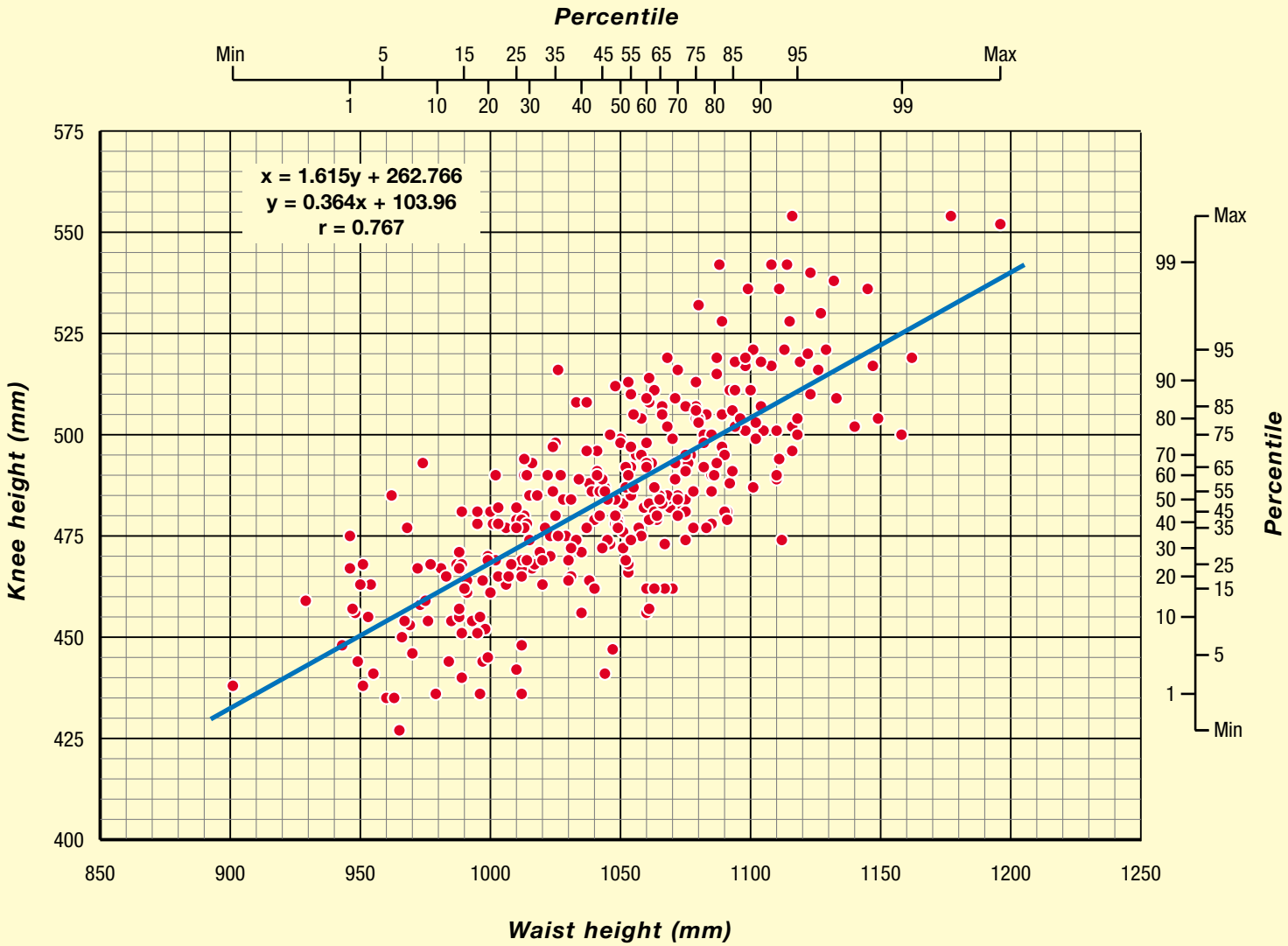
Waist Height
Crotch Height



Waist Height
Knee Height







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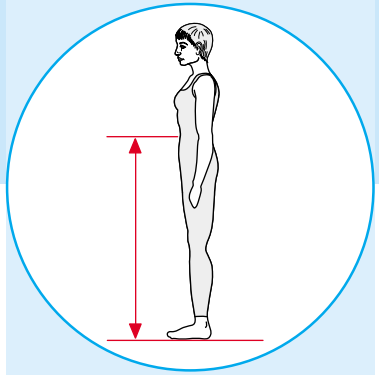
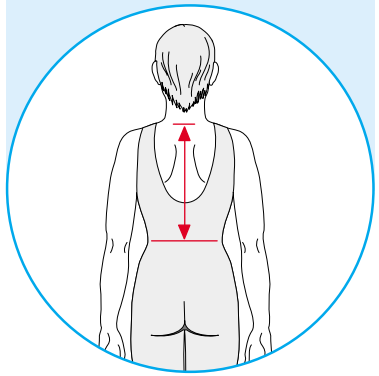
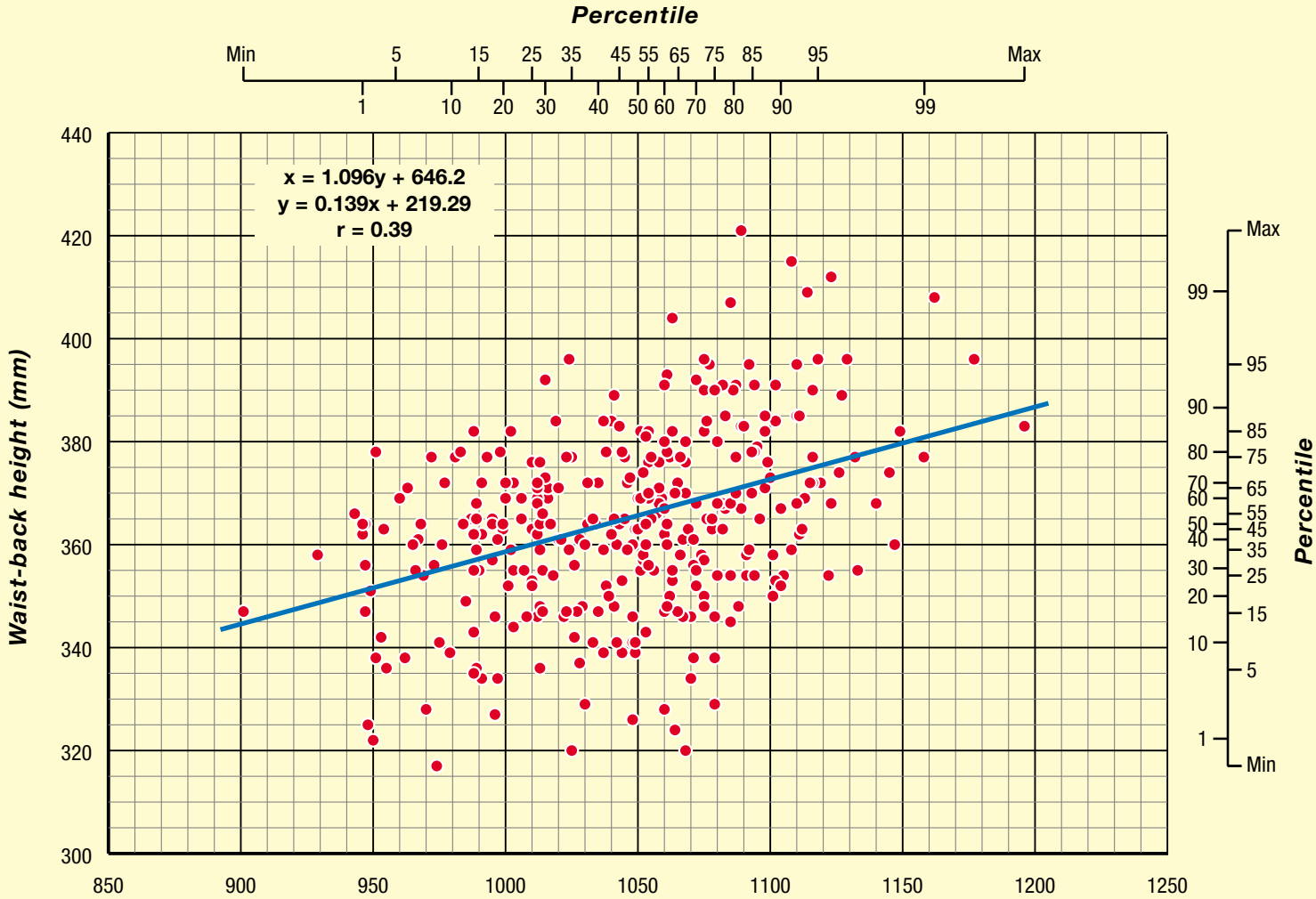
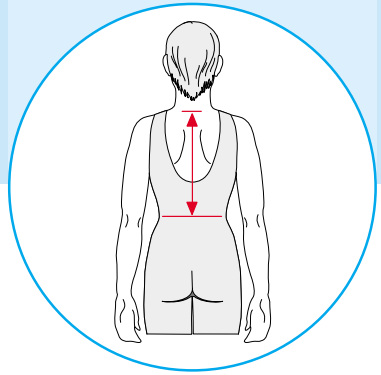


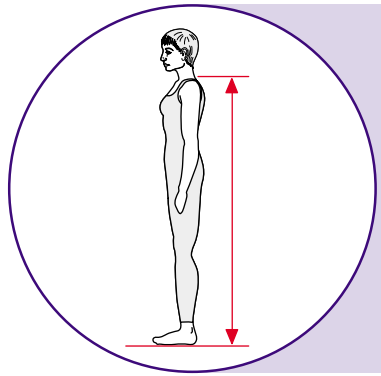


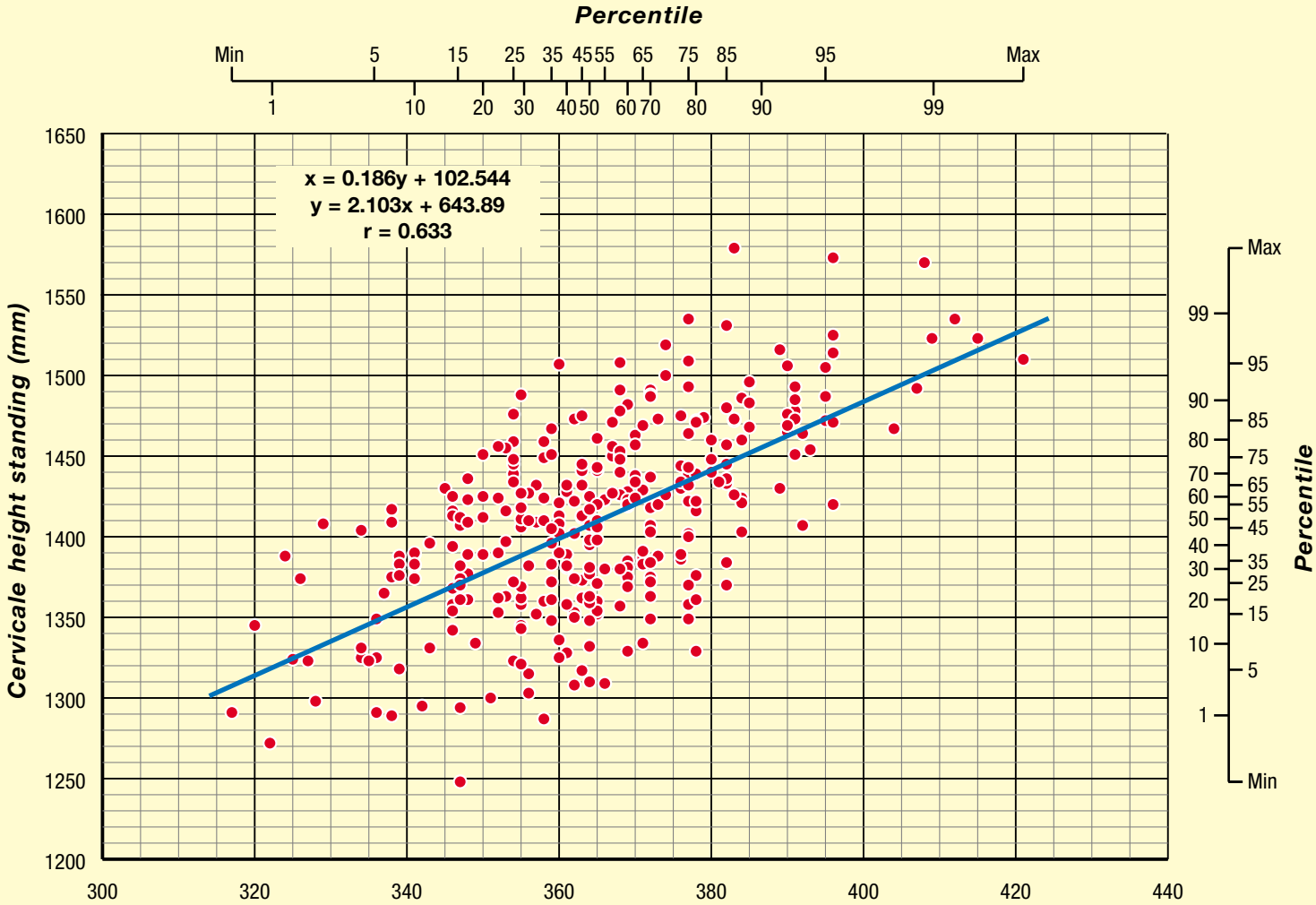
Waist Height
Waist-Back Height

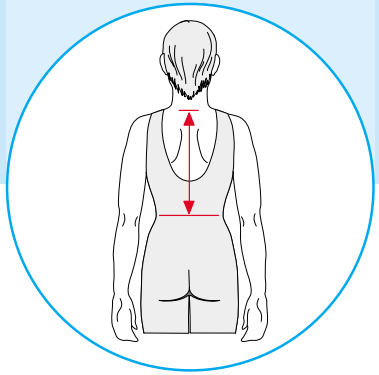


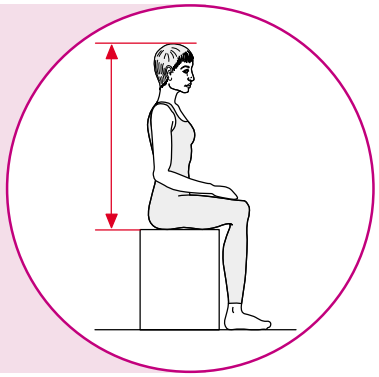
Waist-back Height
Cervicale Height Standing



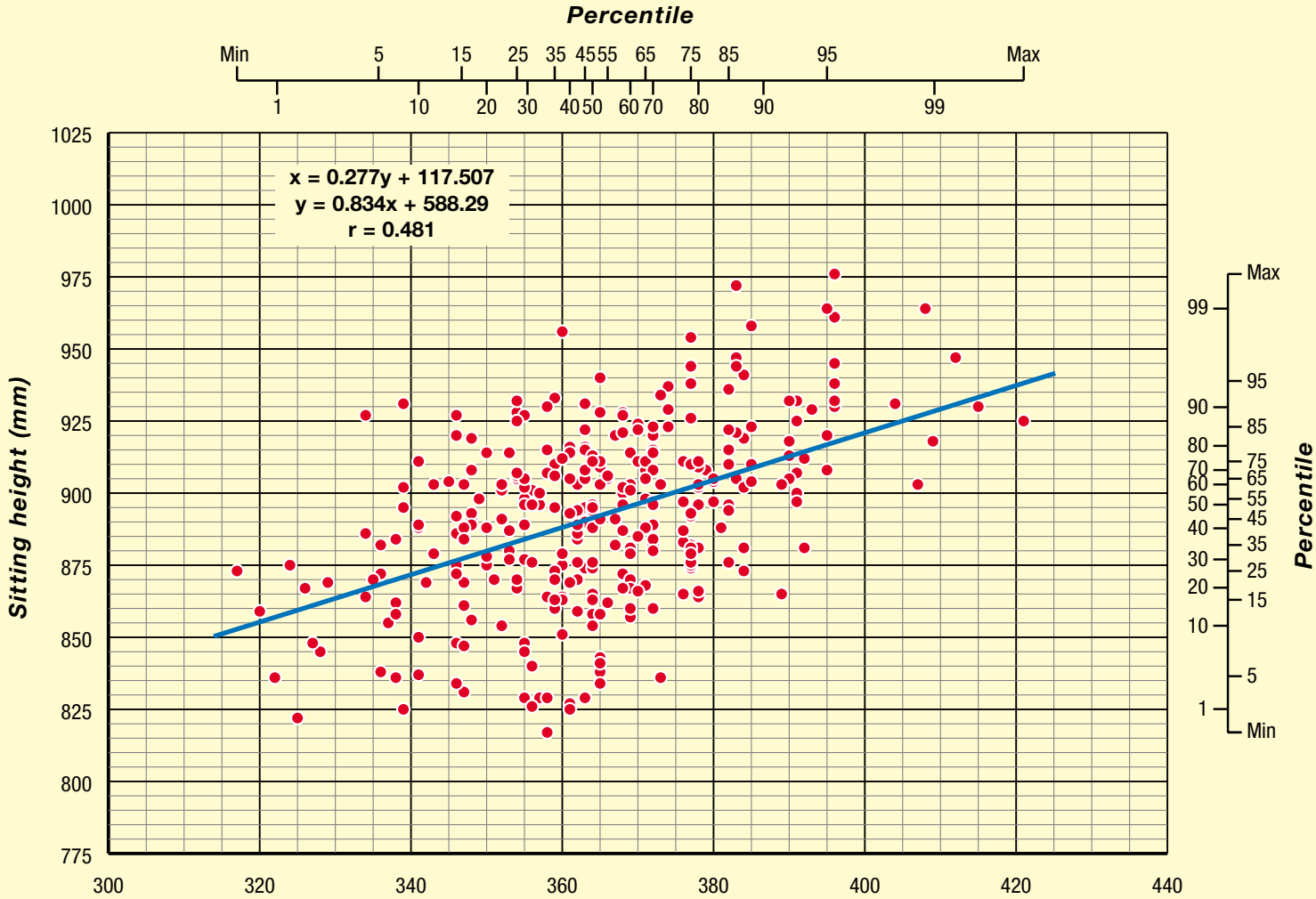








Waist-back Height
Sitting Height



6. Worked Examples

6.1 Zones of convenient reach

The zone of convenient reach (ZCR) may be defined as the zone or space in which an object may be reached conveniently, that is without undue exertion (5). The parameters of the ZCR are defined by the sweeping movements of the arm, measured from the shoulder to the fingertip or the centre of a grip, which form a series of arcs for each hand (see Figure 6.1.1). It is the radius of these arcs that provides useful design information.

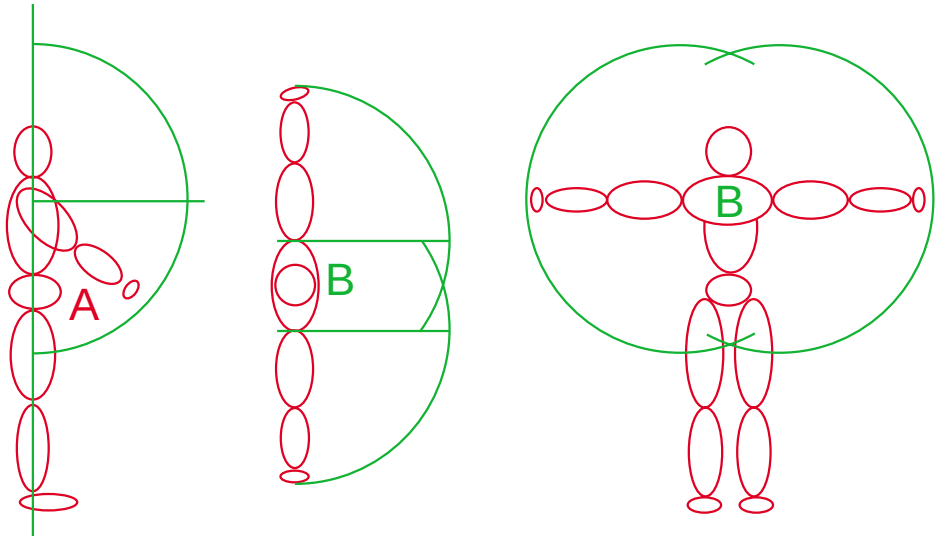


Figure 6.1.1: The arcs of the arms that form zones of convenient reach

Zones of convenient reach can be used to solve design problems where a range of users must access controls or objects. As an example, we will consider the location of lockers used for stowage on the side of an appliance so that they might be conveniently accessed by a standing person. To do this we must calculate the ZCR for a 5th percentile female and a 95th percentile male. In order to draw the circle that each arm would create over the side of the appliance, we need to work out the radius of that circle. This can be done using Pythagoras' theorem:

$$r = \sqrt{a_2 - d_2}$$

where r is the radius of the circle on the side of the appliance, a is the acromium to grip length and d is the horizontal distance between the shoulder and the side of the appliance.

So, for a 5th percentile female (see measure 56 for acromion to grip length data) standing 300 mm away from the side of the appliance, the radius of the circle would be:

$$\sqrt{591.4_2 - 300_2} = 509.7$$

Since equivalent male firefighter data is not yet available, we shall use the 95th percentile value provided in the most recent UK civilian anthropometry report (3). The radius of the circle would be:

$$\sqrt{717.8_2 - 300_2} = 652.1$$

To construct the ZCR in the vertical plane on the side of the appliance, 300 mm in front of the shoulders, we must draw 2 circles of radius 509.7 mm for the 5th percentile female and 2 circles of radius 652.1 mm for the 95th percentile male. The centres of the circles are defined by shoulder height standing and bi-acromial width (measures 17 and 19 respectively for 5th percentile female). Again, the data for the 95th percentile male must be provided from civilian data. A summary of the data points required to construct the ZCR is shown in Table 6.1.1. The resulting zone is shown in Figure 6.1.2.

Table 6.1.1: Data to construct ZCR for handgrip at a distance of 300 mm (mm)

	5th percentile female	95th percentile male
Radius (r)	509.7	652.1
Standing shoulder height	1306.4	1559.5
Bi-acromial width	320.4	447.2

In Figure 6.1.2 the area common to both ZCR's has been shaded, and suggests where lockers should be placed for convenient access by most of the user population. Obviously, some items may have to be stored outside the ZCR, and where this is the case, consideration should be given to the weight and shape of objects. Account should be taken for drawers that pull out and how far back items can be stowed on them.

Zones of convenient reach can be calculated for any plane parallel or perpendicular to the line that joins the shoulders. Some radii are presented in Table 6.1.2, calculated using the same sources of data; these can be used in conjunction with the appropriate bi-acromial widths and shoulder heights.

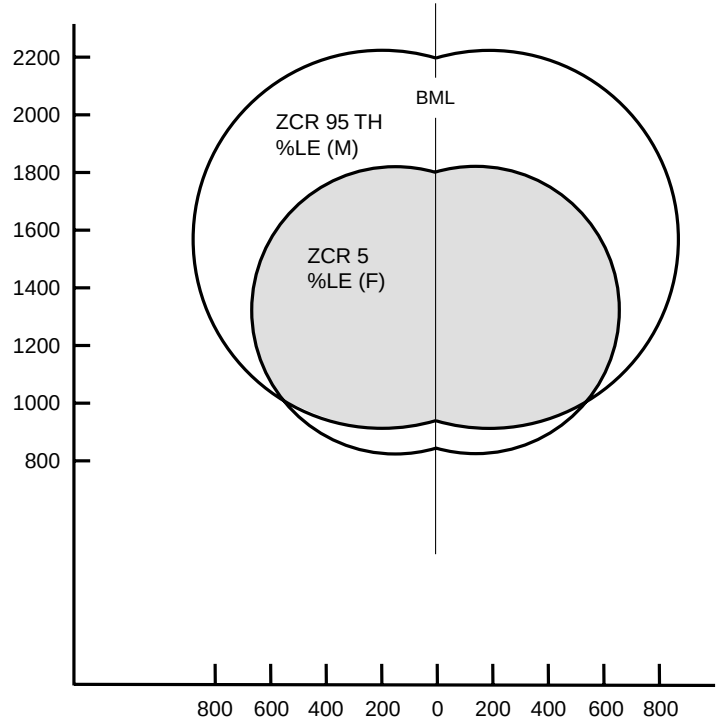


Figure 6.1.2: Zone of convenient reach on a vertical surface 300 mm in front of the shoulders for a 5th percentile female (F) and a 95th percentile male (M). BML is body mid line. Adapted from (4)

Table 6.1.2: Examples of radii for zones of convenient reach (grip reach) (mm)

Distance to surface (d)	Female Percentiles 5th	Female Percentiles 50th	Female Percentiles 95th	Male Percentiles 5th	Male Percentiles 50th	Male Percentiles 95th
50	589.3	630.0	683.2	605.1	660.6	716.1
100	582.9	624.0	677.7	598.9	654.9	710.8
200	556.6	599.5	655.2	573.3	631.6	689.4
300	509.7	556.3	615.8	527.9	590.7	652.1
400	435.6	489.3	673.2	456.8	528.1	596.0
500	315.8	386.6	468.2	344.5	434.6	515.0
600	-	198.6	330.5	93.2	280.9	394.0
700	-	-	-	-	-	158.9

The data in this example can be substituted for different design issues. For example, shoulder height standing can be replaced by shoulder height sitting plus seat height (ensure correction is made if feet do not touch the floor), or different plane of operation may be used.

6.2 PPE sizing charts

Most manufacturers of PPE will have extensive experience in creating size rolls/ options. However, the data and graphs in this report will provide a more accurate picture of the national female firefighting population that may aid in improving the fit and performance of PPE. Below are some useful points that may complement manufacturers' existing knowledge when developing the sizing and fit of items of PPE.

- The use of scatter diagrams illustrates the 'spread' of data points for a particular measure. When one measure is plotted against another we can see the relationship, or correlation, between those two measures. When developing a sizing system, the first step is to choose which is the most critical dimension or the 'key measurement'. For example, when considering a glove this is likely to be hand length (Figure 6.2.1).

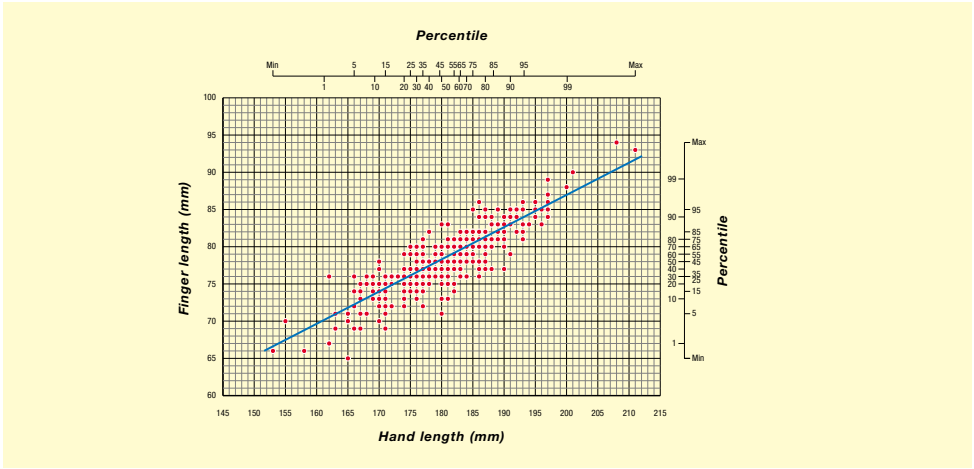


Figure 6.2.1: Scatter diagram of hand length vs finger length

Secondly, how does this relate to a 'tailoring dimension'? For example, what are the type and number of layers to be included in the gloves, will anything be worn underneath (such as examination gloves) and should the glove have an extended cuff?

The third step is to determine how many subdivisions there should be within this measure. Hand length vs finger length, for example, may have 10 mm increments for hand length and 5 mm increments for finger length. It should be noted that increments do not necessarily have to begin and end on a *0 or a *5, as these figures have only been used for illustrative purposes. For example, a hand length increment on Figure 6.2.1 could be 177 – 187 mm instead of 175 – 185 mm. Also, increments of 5 and 10 mm may not necessarily be appropriate.

The process is then repeated by selecting the second key measure for the item of PPE in question (for gloves, this may be finger length), again considering tailoring dimensions and the number of subdivisions in each measure.

- For any item of PPE the third step (above) will be affected by the closeness of fit required (for example, face masks will require a close fit) and the cost implications where a greater range of sizes are offered. However, where two key measures correlate well, there is less spread of data points, and therefore all possible sizes need not be provided. For example, in Figure 6.2.1, a glove to fit a person with a hand length of 165-175 mm and a finger length of 80-85 mm need not be provided.

- Where possible, items of PPE should be adjustable. This not only allows an individual to adjust the item to fit them personally, but also reduces the number of sizes that need to be provided.

- For each size, the item of PPE must fit a person at the top of the range of that size.

- Where possible, try to take into account clothes and other items of PPE that may be worn underneath or over the top of the item of PPE being developed, even when the items are made by different manufacturers. For example, station wear, breathing apparatus, safety glasses, reflective tabards and chemical protection suits.

- Where possible, try to take into account items to be worn in conjunction with the item of PPE being developed in terms of interfacing and overlaps, such as a glove cuff and a tunic sleeve recess (length, thickness).

- Where possible, try to take into account the working environment of the end user. This includes the scenario / conditions in which the item of PPE might be used, the tasks that will be carried out and the equipment that may need to be operated.

- User trials are a very effective way of developing PPE and discovering issues that might have only come to light once many thousands of items have been produced. Appreciably, there is a cost implication in terms of capital and time, but the results are worthwhile, as they make PPE more acceptable to the user, safer and easier to use.

User trials can be conducted with subjects who are carrying out their job as normal, or subjects can take part in a controlled simulated work situation. The former provides realism but lacks control, and the latter provides control but lacks realism. Ideally, both types of trial would be carried out for several reasons: 1) Operational use of PPE is often different to a textbook method or the way a manufacturer intended it to be used. Feedback of realistic use may help prevent accidents. 2) Operational evaluation of PPE tends to be subjective and opinions may be swayed by inappropriate influences, whereas controlled evaluation can include objective tests that accurately determine the performance of an item of PPE, such as timed dexterity tests. 3) Using a standard format during controlled testing will allow comparison between items of PPE that are tested in the future or that are produced by different manufacturers. An example of this is firefighting tunics and leggings being tested to EN 469 (8) at a test house, although controlled testing can be carried out in-house (manufacturer or brigade) using a well-designed method.

Guidance on conducting user trials can be found in a publication entitled Designing Safety into Products- Making ergonomics evaluation a part of the design process **(AVAILABLE FREE OF CHARGE) (14).** Examples of developing sizing systems for firefighting garments can be found in two reports carried out for the United States Navy (15, 16) **(AVAILABLE FREE OF CHARGE by contacting the author of the reports).**

7. Glossary of Terms

Body parts

Basic description (anatomical description)

Acromion: the bony tip of the shoulder (the highest point on the lateral edge of the scapular)

Axilla: the muscle that borders the front of the armpit (the small depression inferior to the proximal end of the arm)

Bicep muscle: (the large muscle that lies in front of the bone of the upper arm, which is the humerus)

Buttocks: (the fleshy protrusions on the posterior aspect of the body at the junction of the lower back and upper part of the legs)

Cervicale: the level of the prominent neck vertebra (the protrusion of the spinal column at the base of the neck, caused by the dorsal tip of the spine of the 7th cervical vertebra)

Chest: (the region of the upper torso bordered by the rib cage and the diaphragm)

Deltoid muscle: the muscle on the upper, outer border of the arm and shoulder (the muscle that lies over the lateral surface of the shoulder joint and the bone of the upper arm, which is the humerus)

Ectocanthus: the outer border of the eye socket (the lateral corner of the eye)

Finger tip: the tip of the middle finger (the distal point on digit three that is not on the fingernail)

Glabella: the brow ridge (the most anterior part of the forehead between the brow ridges in the mid-sagittal plane)

Gluteal fold: (the furrow between the buttocks above and the back of the thigh below)

Hip: either side of the body below the waist and above the thigh (the proximal end of the femur and the pelvis form the hip joint, also known as the iliac crest)

Interscye: surface distance across the back from the fleshy fold of one armpit to the other (surface distance across the back between the posterior axillary folds)

Knee: (the knee joint is formed by the distal end of the femur, the proximal end of the tibia or shinbone, and the patella)

Menton: the bony tip of the chin (the lower edge of the tip of the chin in the mid-sagittal plane)

Metacarpal bones: (the long bones of the palm of the hand)

Metatarsal bones: (the long bones of the mid-foot)

Naison: the depression at the top of the nose (the point of maximum depression in the mid-sagittal plane at the junction of the nose and the forehead)

Occiput: the bony prominence at the back of the head (the prominence at the posterior aspect of the skull)

Olecranon: (the most posterior region on the bony tip of the elbow)

Patella: the knee cap (the triangular bone on the anterior aspect of the knee)

Phalanges: the finger and toe bones- there are three phalanges in each digit, except the thumb and the big toe which only have two (the distal bones of the hands and feet)

Popliteal fossa / point: the hollowed out region of the leg directly behind the knee involving both the bottom of the thigh and the top of the calf (when the leg is flexed the popliteal point is defined as the point where the underside of the tendon of the lateral biceps femoris muscle meets the calf)

Radial styloid process: the bony protrusion at the base of the back of the hand, on the same side of the hand as the little finger (the lateral downward projection of the distal end of the radius)

Radius: (the lateral bone of the two bones of the forearm when the palm of the hand is facing forward)

Sternum: the breastbone (a long flat vertical bone in front of the thorax, to which are attached the collar bone and the first seven pairs of ribs)

Thenar eminence: the fleshy area of the palm at the base of the thumb (the pad of the muscle at the base of the thumb on the lateral part of the hand when the palm of the hand is facing forward)

Tragion: (the notch in the cartilage of the ear just above and immediately in front of the earhole)

Triceps: (the muscle that lies behind the bone of the upper arm, which is the humerus)

Ulna: (the medial bone of the two bones of the forearm when the palm of the hand is facing forward)

Vertex: the top of the head (the most superior point on the head)

Descriptive terms

Anterior: towards or to the front of the body

Coronal plane: any vertical plane passing from side to side and dividing the body into anterior and posterior segments

Distal: referring to limbs farther or distant from the trunk

Inferior: lower or below

Lateral: away from the midline of the body

Medial: towards the midline of the body

Posterior: toward or at the back of the body

Proximal: referring to limbs closer to the trunk

Sagittal plane: any vertical plane passing from front to back and dividing the body into right and left segments

Superior: higher or above

Transverse plane: a horizontal plane cutting across the long axis of the body at right angles to both coronal and sagittal planes

8. Statistical Terms

Mean (m)

The mean (also called the arithmetic mean or average) refers to the value that results when all the values in a data set are added together and the total is divided by the number of values in the data set, expressed as:

$$m = \frac{\sum x}{n}$$

where x is an individual value and n is the total number of values.

Standard deviation (SD)

The standard deviation is a measure of variability of a set of measurements, ie. how spread out numbers are from the mean. It is calculated by taking the square root of the arithmetic mean of the squares of the deviations from the mean in a set of measurements and is expressed:

$$SD = \sqrt{\frac{\sum(x - m)^2}{n}}$$

Where x is the individual measurement, m the mean value of the set of measurements and n the number of measurements.

Percentile

The value below which fall a specific percentage of a large number of statistical units arranged in order from the smallest to the largest. For example, 45% of the population being measured are smaller than the 45th percentile stature measurement.

Coefficient of variation (CV)

The coefficient of variation is the standard deviation (SD) expressed as a percentage of the mean (m). This is given by:

$$CV = \frac{100 \times SD}{m}$$

Standard error of the mean (SEM)

The standard error of the mean is an estimate of the sampling error of the mean. When a sample of individuals who are deemed to be representative of the population in question are measured, the true mean and standard deviation cannot really be known (unless every member of a population is measured); instead they are inferred or estimated from that population. The SEM tells us that if we repeated the same set of measurements many times and calculated the SEM each time, the real mean would lie within the confidence interval calculated (sample mean ± 2SEM) in 95 out of 100 cases (95% chance that the real mean is within the calculated confidence interval for our sample mean).

The SE can be calculated as follows:

$$SEM = \frac{SD}{\sqrt{n}}$$

The equation shows that as the number of subjects measured increases, the SE will decrease and the predictions will be more accurate.

Correlation coefficient (r)

The correlation coefficient is an indication of how closely two variables (such as body dimensions) are related to one another. Its value ranges from –1.00 to +1.00 with –1.00 representing a perfect negative linear relationship (y decreasing as x increases), 0.00 representing a total lack of linear relationship, and +1.00 representing a perfect positive linear relationship (y increasing as x increases) between the variables. For example, one might correlate waist circumference with hip circumference. The correlation coefficient is given by:

$$r = \frac{\sum (x - mx)(y - my)}{\sqrt{\sum (x - mx)^2 (y - my)^2}}$$

where x is the individual variant on the x axis, mx is the mean of the values on the x axis, y is the individual variant on the y axis, and my is the mean of the values on the y axis.

The correlation (r value) between waist circumference and hip circumference is shown on the scatter diagram on page 165. The r value is + 0.68, which shows a reasonable (positive) correlation between the two measures. An example of a very good correlation between two measures is that of stature with shoulder height standing, which has an r value of + 0.96 (page 156).

Regression equations

Regression means the linear relationship between a dependent (y axis) and an independent variable (x axis) giving the best estimate of the dependent variable. Put more simply, a regression equation allows us make a good estimate of a particular measure using its relationship with another measure. Regression equations are expressed as follows:

$y = ax + b$ *Equation 1*

$x = cy + d$ *Equation 2*

Equation 1 is the regression of y on x. y is the dependent variable for a chosen x, a is the regression coefficient or slope, and b is the regression constant or intercept identifying the value of y when x equals zero.

Equation 2 is the regression of x on y. x is the dependent variable for a chosen y, c is the regression coefficient or slope, and d is the regression constant or intercept identifying the value of x when y equals zero.

When x and y are perfectly correlated Equations 1 and 2 are identical. When there is no correlation the two regression equations represent lines at right angle passing through (mx,my).

The regression coefficients (a and c) are calculated thus:

$$a = \frac{\sum (x - mx)(y - my)}{\sum (x - mx)^2}$$

$$c = \frac{\sum (x - mx)(y - my)}{\sum (y - my)^2}$$

The regression constants are calculated as:

$b = my - b\,mx$

$d = mx - d\,my$

where x is the individual variant on the x axis, mx is the mean of the values on the x axis, y is the individual variant on the y axis, and my is the mean of the values on the y axis.

A straightforward example of how a regression equation can be used:
The only equations you need are Equations 1 and 2 above (usually only one at once), but since the regression equations have been provided on each scatter diagram, all we need to do is substitute some values. For example, look at the scatter diagram that correlates chest circumference (measure 21) with bi-deltoid width (measure 20) on page 83. The regression equations provided on the scatter diagram are as follows:

x = 1.896y + 87

y = 0.279x + 188.89

The horizontal axis is always labelled the x axis (which has the independent variable on it) and the vertical axis is always labelled the y axis (which has the dependent variable on it). In this case, chest circumference is on the x axis and therefore the independent variable, and bi-deltoid width is on the y axis and therefore the dependent variable.

If we knew that a person had a certain chest circumference, say 950 mm, we could make a good estimate of what their bi-deltoid width would be. Since bi-deltoid width is the variable we want to determine and it is on the y axis, we use the second equation from above and substitute in the chest circumference value:
y = 0.279 (950) + 188.89
therefore, y = 453.94, a good estimate of bi-deltoid width for this person.

9. References, recommended reading and useful contacts

References

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(2) Norton, K., & Olds, T. (2000). *Anthropometrica*, University of New South Wales Press.

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Wilson, J.R. and Corlett, E.N. (1995) *Evaluation of Human Work* (2nd Edition), Taylor & Francis, London.

Useful contacts

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British Standards Institute,
389 Chiswick High Road, London, W4 4AL,
0208 996 9000

Department of Trade and Industry,
I Victoria Street, London, SW1H 0ET,
Tel: 0207 215 0383

Department of Trade and Industry Publications Orderline,
ADMAIL 528, London SW1W 8YT, Tel: 0870 1502 500, Fax: 0870 1502 333,
e-mail: dtipubs@eclogistics.co.uk.
The following anthropometric data sources are available *FREE OF CHARGE:*
ADULTDATA (quote URN 98/736) and Strength Data for Design Safety
(quote URN 00/1070)

Design Council,
34 Bow Street, London, WC2E 7DL
Tel: 0207 420 5200, Fax: 020 7420 5300,
Web pages: www.design-council.org.uk/ www.sharinginnovation.org.uk

The Design Council is a government (DTI) funded organisation, which encourages the best use of design by businesses in order to improve their competitive edge. It also aims to improve design in the fields of education and government.

Ergonomics Information Analysis Centre,
The University of Birmingham, School of Manufacturing and Mechanical Engineering,
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The Ergonomics Society,
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Tel: 01509 234904

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Open Ergonomics,
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Thank you for your time

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