ATLAS OF ROENTGENOGRAPHIC MEASUREMENT

Lee B. Lusted
Theodore E. Keats

FOURTH EDITION

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Roentgenographic Measurement

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LEE B. LUSTED, M.D.
Professor of Radiology
The University of Chicago

THEODORE E. KEATS, M.D.
Professor and Chairman
Department of Radiology
University of Virginia School of Medicine

YEAR BOOK MEDICAL PUBLISHERS, INC.
Chicago • London

First edition, 1959
Second edition, 1967
Third edition, 1972
Fourth edition, 1978
Reprinted, March 1981

Library of Congress Catalog Card Number: 78-54028

International Standard Book Number: 0-8151-5655-3

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Other books by Theodore E. Keats:

An Atlas of Normal Roentgen Variants That May Stimulate Disease, 2d edition

An Atlas of Normal Developmental Roentgen Anatomy, with Thomas H. Smith, M.D.

TO
HOWARD L. STEINBACH

Foreword

Since the conception of radiology as a medical science, the growth of this field has been truly remarkable. The early pioneers in the field had little or no knowledge of the normal anatomy or physiology of the living human and, of necessity, relied on morbid anatomy and existing texts. The early radiologic literature was based on empiric observation. These observations, when correlated with what was considered normal in the cadaver, led to erroneous concepts of normal anatomy and physiology.

It soon became apparent that a thorough knowledge of the normal roentgenologic anatomy was necessary before the physician could reliably detect the pathologic state. As a result of intensive studies of normal subjects, a great body of statistics has been accumulated representing the wide range in size and form of normal structures. However, the great number and relative inaccessibility of these observations has precluded their routine use by the busy practitioner of radiology.

This book should be of value to the physician because it provides him, in one volume, the most useful roentgenographic measurements in the medical literature. It should point the way to further studies of a statistical nature in those fields in which there is a lack of information or a conflict of observations.

The selection of the most pertinent information to be included in a book such as this is a difficult task. The authors have done their job well; and it is hoped that they will continue to collect new data, as they become available, for future editions.

HOWARD L. STEINBACH

Preface to Fourth Edition

Almost 20 years ago the *Atlas of Roentgenographic Measurement* appeared in its first edition. Many changes in imaging techniques and procedures have occurred since that edition, particularly in the fields of nuclear medicine, ultrasound and computed tomography. These changes are reflected in the present text with the addition of more than 50 new entries, including 24 from pediatric radiology and 2 each from computed tomography, neuroradiology, nuclear medicine and ultrasound. Other additions cover a wide range of topics in adult roentgenography from the measurements of coronary arteries to the size of renal transplants.

Radiologists from several countries have published roentgenographic measurement studies since the third edition of this book appeared. The international interest in roentgenographic measurements and in the development of new imaging modalities has been responsible for three topics which are emphasized in this edition: (1) new roentgenographic measurements from several countries around the world; (2) measurements of the same organ by two imaging modalities; and (3) the importance of presenting normal anatomic measurements in ratio relationships.

Normal roentgenographic measurements reflect the anatomic characteristics of the population studied. Diverse human races show certain anatomic differences, and we have attempted to encourage radiologists around the world to help us compile normal roentgenographic measurements so that the *Atlas* may be more useful internationally. For instance, in this edition normal lateral measurements of the adult nasopharynx for Chinese, Japanese and United States populations are presented in adjacent columns of a single table. We hope future editions of the *Atlas* will reflect continued interest in measurements from various populations.

A notable occurrence since the publication of the third edition of the *Atlas* is the progress in new imaging modalities which enable the physician to measure some structures by two or more techniques. Cerebral ventricle dimensions may be obtained by pneumoencephalography and computed tomography; the pancreas may be measured by ultrasound and computed tomography, fetal maturity may be determined by roentgenography and ultrasound. For purposes of illustration and comparison, we have placed such measurements in sequence in the text.

Future imaging developments will enable the physician to measure particular anatomic structures with two or more modalities. The physician will be challenged to apply the modality which is most likely to optimize the expected diagnosis information.

With the interest in new imaging modalities and in normal organ measurements for various populations, it is appropriate to emphasize the determination of normal standards of mensuration by use of ratio relationships. We referred to this subject in the Preface to the second edition of the *Atlas*. The subject deserves further discussion because ultrasound and computed tomography images come in a variety of sizes which are measured by reference to a calibrated scale. A uniform medium size format for radiographic film, nuclear medicine, ultrasound and computed tomography* would help to standardize the image size of a particular organ. The lack of such an image format and the interest in studying roentgenographic measurements of diverse populations argue for the presentation of normal anatomic measurements in terms of body ratio relationships. For instance, early studies with cranial computed tomography and ultrasound showed that the ratio of cerebral ventricle size to skull width (Evans' Index) agreed well with the measurements obtained by pneumoencephalogram.

*Loop, J. W.: Am. J. Roentgenol. 129:355, 1977.

Ratio relationships of body measurements are best understood in the context of two types of norms used for describing standard man: the descriptive or absolute norm and the analytic or proportionality norm. Descriptive, absolute standards are only valid within the population on which they are established. A preferable method uses analytical proportional norms in which any one body part is measured in terms of any other part or of the whole body (allometry).

The analytical approach to a determination of normal anatomic measurements in the various racial populations emphasizes the use of ratios. Proponents maintain that, despite the absolute change in human size, the individual parts remain related in harmonious proportions according to the principle of optimal design. In other words, the validity of allometric norms is largely independent of the absolute size of an adult. Use of the analytical approach results in a simplification of several concepts to the point where the only plausible working hypothesis is that the internal structures of healthy adults are proportional in size to external body measurements and to body surface area estimated from these measurements.

Allometric relationships have been the subject of several interesting articles published by von Behrens* since the third edition of the *Atlas* was completed. One frequently employed reference body size parameter used as the denominator in organ size indices is body surface area (BSA;m²). As von Behrens shows, body surface area is readily calculated from height and weight by the equations,

$$BSA;m^2 = 0.176\sqrt{(Wt;kg)\ (Ht;m)}$$

or

$$BSA;m^2 = 0.1053\ (Wt;kg)^{2/3}$$

These calculations are easily performed on the hand-held calculators in common use. In Chapter 6 we use these equations for body surface area to determine liver volume.

As we pointed out in the second edition, the rationale for establishing standards of measurement in ratio relationship form is that the method normalizes for individual variation and when the parameters chosen for measurement are appropriate a large series is not necessarily helpful in establishing normal limits. We encourage more investigators to produce measurements in terms of analytical proportional norms.

We appreciate the continuing interest of readers of the *Atlas*. We hope that the new topics, briefly outlined in this Preface, and the generous inclusion of new illustrations will make this edition especially useful to our colleagues working in computed tomography, nuclear medicine and ultrasound. Our thanks go to the authors and publishers for permission to reproduce the illustrations and data, as well as to our secretaries, Marjorie Pannell and Ann Rutledge, for their assistance in preparing the manuscript.

LEE B. LUSTED
THEODORE E. KEATS

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*Von Behrens, W. E.: Fundamental Principles in Organ Sizing, Australas. Radiol. 16:180, 1972.
———: On estimating areas in radiology and nuclear medicine, Australas. Radiol. 16:325, 1972.
———: Assessment of spleen size in vivo, Australas. Radiol. 17:440, 1973.

Preface to First Edition

With the discovery of roentgen rays it was possible, for the first time, to make accurate measurements of internal anatomic structures in living subjects. The value of such measurement had been firmly established by the anatomists. It is, therefore, not surprising that the accumulation of roentgen-image measurements was begun and that in a relatively short period of time a great wealth of material was collected.

Because of the large volume of measurement information, it is difficult for the busy practitioner of medicine to find specific data and to recognize that which is valid. Also, it is difficult for him to have at hand the reference material which is necessary in his daily work. These are acute problems for the physician whose practice is not confined to a single location and who does not have a conveniently accessible medical library. This atlas has been compiled to help fill these needs. But, needless to say, the limitation of such an atlas should be recognized by the reader, for it is not possible to present all of the measurements which have been reported. We have included the data that are, in our opinion, most reliable and practical. In some cases the data have a questionable statistical value because of the small sample. In these cases, however, the type of measurement selected was thought to be important and to be the best available.

There are several serious limitations to roentgenographic measurements: first, the roentgenologic image is not sharp; second, the anatomic points for the measurements are not always clearly defined, and they are subject to individual interpretation; and third, in many cases the wide range of normal anatomic variation has not been defined.

The interpretation of a roentgenogram remains an art—an art which depends, in part, upon the gestalt which the physician has developed from his study of many similar roentgenograms. To this interpretation the objective evidence of the roentgenographic measurement can make an important contribution.

There are several areas of roentgenographic measurement which need further investigation. This is particularly true in pediatrics. Undoubtedly, more measurement data will be forthcoming as the result of the brisk activity in pediatric roentgenology.

We wish to thank Dr. Howard L. Steinbach for directing our attention to the need for such an atlas and for his critical review of the manuscript, and we are indebted to Dr. John F. Holt for his suggestions concerning improvement of this presentation and to the University of Missouri Research Council for financial assistance which helped to make the project possible.

Mr. William E. Loechel, of the National Institutes of Health, prepared many of the drawings.

We are grateful to the many authors who have allowed us to reproduce their original work in the *Atlas* and to their publishers for kind permission to reproduce the data.

Especially, we thank our secretaries, Lecho Otts, Lillian Worden, Josephyne Corsi and Helena Vatter, for their excellent help in preparing the manuscript.

LEE B. LUSTED
THEODORE E. KEATS

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Geometric Distortion of the Roentgen Image and Its Correction

The roentgen image of an object is larger than the object. This image distortion is caused by the divergence of the roentgen rays, and the amount of distortion is a function of three factors (Fig 1): the object dimension *(O)*, the target-film distance *(D)* and the object-film distance *(d)*.

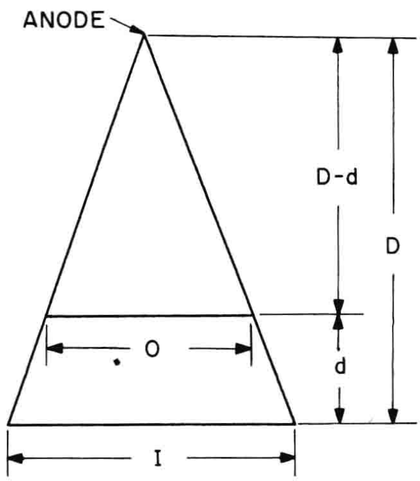


Fig 1. (Courtesy of G. H. Brown, Jr. From Am. J. Roentgenol. 78:1063, 1957.)

To find the true object dimension, the image dimension is multiplied by a number less than one (correction factor, *CF*). This correction factor is obtained by means of the following equation, in which

O = Object dimension (cm)
I = Image dimension on the film (cm)
D = Target-film distance (cm)
d = Object-film distance (cm)

It is important to have all dimensions in the same units. Then, by similar triangles,

$$\frac{O}{I} = \frac{D - d}{D} \quad \text{and} \quad O = \frac{(D - d)}{(D)} I$$

Therefore,

$$CF = \frac{D - d}{D}$$

GEOMETRIC DISTORTION OF THE ROENTGEN IMAGE AND ITS CORRECTION

A number of devices have been constructed which give a fully compensated value of a given object dimension. These devices have usually been made for use in pelvicephalometry.

A nomogram (Fig 2) and a base chart (Fig 3) may be used for finding corrected dimensions and for converting a given target-film distance to another target-film distance.

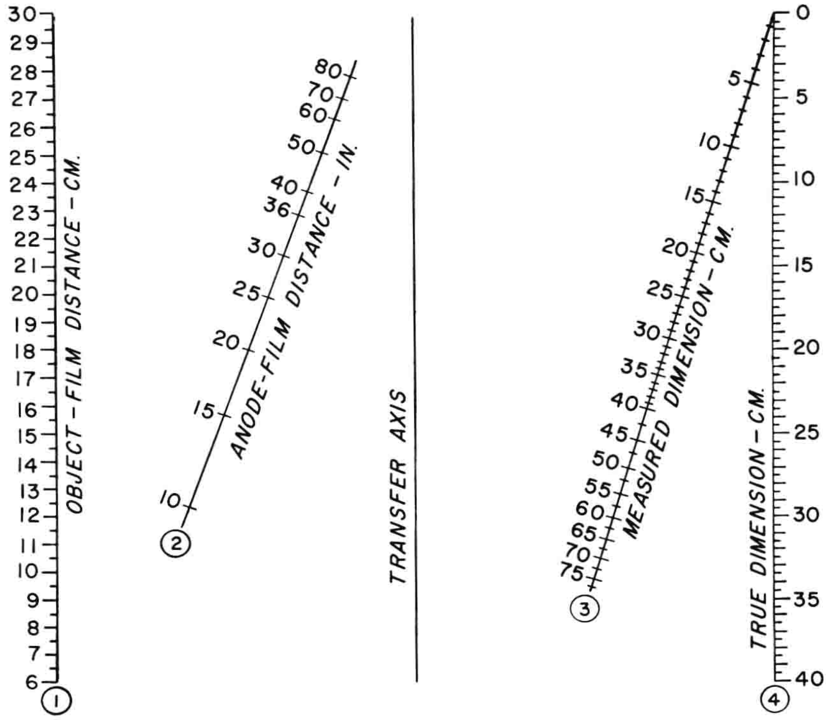


Fig 2. — Nomogram (designed by Holmquist*) for securing corrected dimensions.

1. Draw a straight line from the object-film distance *(1)* through the anode-film distance *(2)* to the transfer axis.

2. Draw a second line from this point on the transfer axis through the measured dimension *(3)* to the true dimension *(4)*.

*Ball, R. P., and Golden, R.: Am. J. Roentgenol. 49:731, 1943, Figure 5.

GEOMETRIC DISTORTION OF THE ROENTGEN IMAGE AND ITS CORRECTION

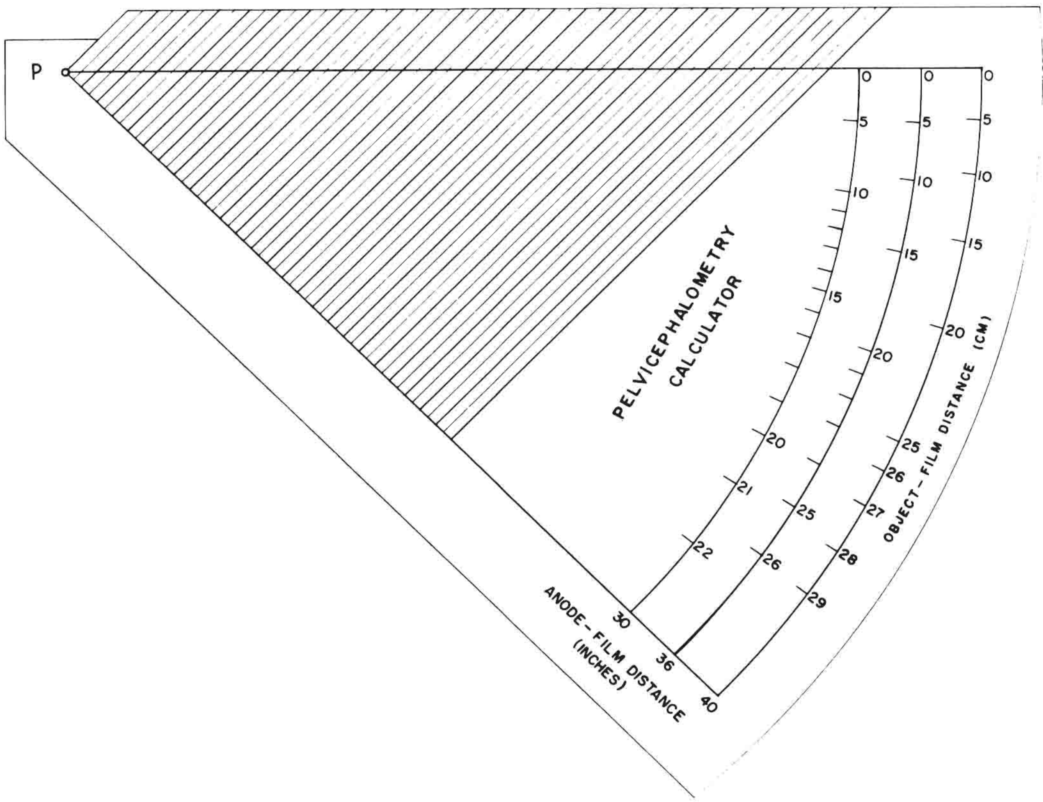


Fig 3.—Base chart* for constructing a roentgen-image distortion calculator. (Approx. × 1/2.) To use the calculator, a centimeter scale, pivoted at *P*, is set for the correct object-film distance value, which is located on the appropriate target-film scale. The image dimension is measured on the centimeter scale at the top of the calculator. From the scale point so obtained, the corresponding oblique guide line is followed down to the pivoted centimeter scale. The compensated dimension is read from the centimeter scale at the intersection of the guide line and the pivoted scale.

*Brown, G. H., Jr.: Am. J. Roentgenol. 78:1063, 1957, Figure 6.

GEOMETRIC DISTORTION OF THE ROENTGEN IMAGE AND ITS CORRECTION

The following tables can be used for converting centimeters to inches, and inches to centimeters:

CM	IN.
1	0.39
2	0.78
3	1.18
4	1.57
5	1.96
6	2.36
7	2.75
8	3.15
9	3.54
10	3.94
15	5.90
20	7.87
25	9.84
30	11.81
35	13.78
40	15.75
45	17.71
50	19.68
55	21.65
60	23.62
65	25.59
70	27.55
75	29.52
80	31.49
85	33.46
90	35.43
95	37.40
100	39.37

IN.	CM
1	2.54
2	5.08
3	7.62
4	10.16
5	12.70
6	15.24
7	17.78
8	20.32
9	22.86
10	25.40
11	27.94
12	30.48
13	33.02
14	35.56
15	38.10
16	40.64
17	43.18
18	45.72
19	48.26
20	50.80
21	53.34
22	55.88
23	58.42
24	60.96
25	63.50
26	66.04
27	68.58
28	71.12
29	73.66
30	76.20
32	81.3
34	86.4
36	91.4
38	96.5
40	101.6
48	121.9
60	152.4
72	182.9

The amount of shift used to obtain stereo radiographs may be calculated as follows:

$$\frac{\text{Target-film distance}}{\left(\dfrac{\text{Film viewing distance}}{\text{Interpupillary distance}}\right)} = \text{Total tube shift}$$

(Half of shift to each side of midline)

Examples:

1) Target-film distance = 40 inches
Film viewing distance = 20 inches
Interpupillary distance = 2.5 inches

$$\frac{40}{20\ /\ 2.5} = 5 \text{ inches}$$

(2.5-inch shift to each side of midline)

2) Target-film distance = 72 inches
Other quantities as above

$$\frac{72}{20\ /\ 2.5} = 9 \text{ inches}$$

(4.5-inch shift to each side of midline)

I. THE CENTRAL NERVOUS SYSTEM

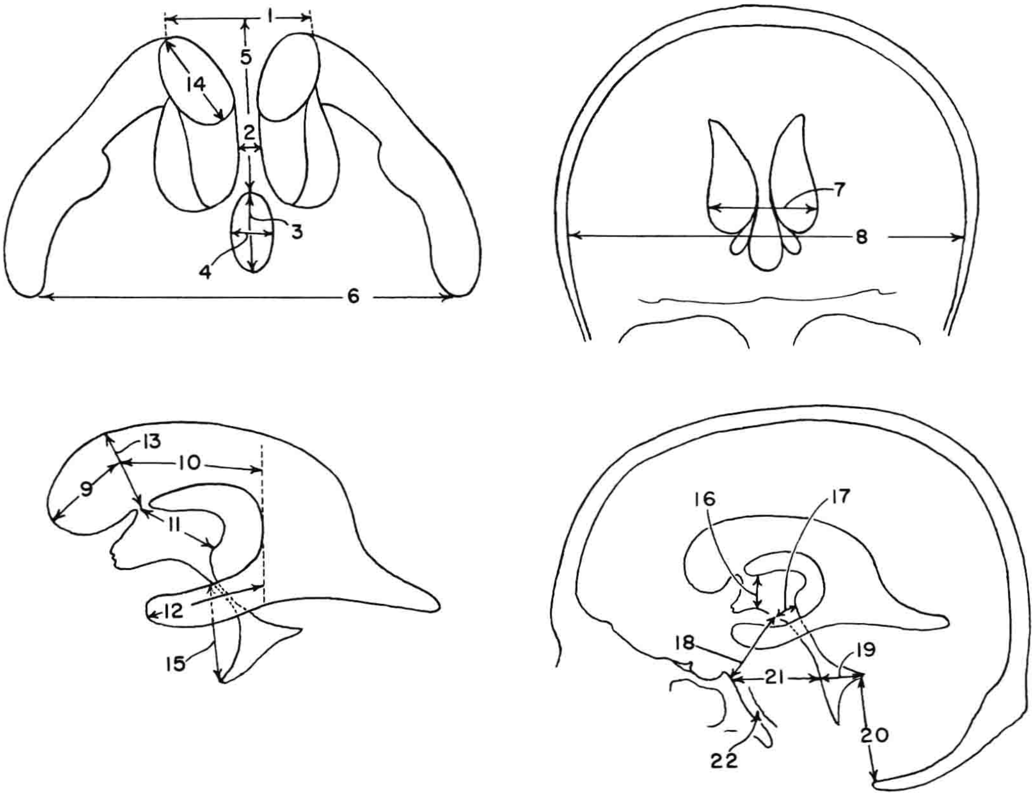
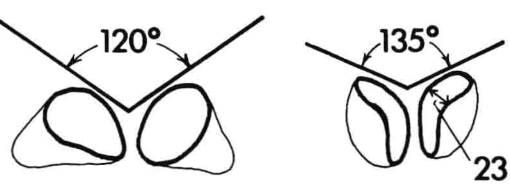


Fig 1-1.—Cerebral ventricles. *Top,* anteroposterior projection. *Bottom,* lateral projection. (Redrawn from Orley.)

Fig 1-2.—Corpus callosal angle.* *Left,* erect. *Right,* anteroposterior supine. For measurement 23, septum caudate distance, see page (8).



*LeMay, M., and New, P. F. J.: Radiology 96:347, 1970.