TECHNICAL REPORT

Apparatus for Taking Radiograph of the Whole Human Body with the Projected Line of Gravity

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Abstract Radiography is a very useful technique for anthropology in the fields of traditional morphology, functional morphology, biomechanics, and kinesiology. For a small-area radiograph (28×71 cm at most) we can use easily medical radiography apparatuses supplied for general purposes. But in the case of a whole-body radiograph we must develop a special apparatus and work out a certain standardized method. The apparatus we have developed here makes it possible to take optimal whole-human-body radiographs in an upright position. Additionally, a perpendicular line going through the center of gravity of the body is superimposed in these radiographs. This line is very important for the functional analysis of the total skeletal system.

Keywords Whole body radiograph, Line of gravity

General Remarks

It is beyond dispute that a whole-human-radiograph is very useful in anthropology, especially in studying the bipedal erect posture. If it is taken by means of a certain standardized method, it becomes easy to observe the arrangement of the skeletal system geometrically. And, if one may hope for so much, it should not be of a cadaver but of a living body. The skeletal arrangement of cadavers is different from that of a living body, mainly because of degenerated or relaxed muscles. In any

case, for this radiography special apparatuses are required, such as a large cassette and a developing processor, which are used for outsized X-ray films. These X-ray films themselves are not so easily obtained.

For medical purposes radiography has been utilized profitably. The number of radiographs which have so far been taken is enormous. But the figures taken in radiographs are not those of normal persons and they show only part of the body, that is, the affected part. This legacy is, therefore, of no use for anthropology.

Before World War II the harmful influ-

ence of X-rays on a healthy body was not seriously discussed; nevertheless, there are quite a few studies in which the complete skeletal system of living human bodies was taken (JANKER, 1934). In Japan Kenzo HORIE tried it at Nagoya University in 1912. Since World War II such studies have no longer been carried out. On the other hand, there are some studies which deal with radiographs of the total spine of normal subjects (SOLLMANN, 1955; RASPE, 1956; EDINGER *et al.*, 1956; EDINGER *et al.*, 1957; SOLLMANN *et al.*, 1961; ZEITLER, 1963; ROSS, 1964). There are no explanation in radiography textbooks of human radiography as a whole (YOKOI *et al.*, 1956; MESCHAN, 1959; GREENFIELD *et al.*, 1973; BIRKNER, 1977a, b).

In traditional anthropology, it is customary to observe human bones morphologically in detail by use of a knowledge of anatomy. But the geometrical location of every skeletal element, which of course changes if the posture changes, cannot be inferred perfectly.

A discussion of the movable limits of bone joints from macerated bones cannot expect to be accurate because of the differences in limits between macerated bones and the bones in living bodies. For example, the movable limits of the upper limbs in the shoulder are not decided solely by the relation between the humerus and the scapula. If a man abduct his upper limb until upright position, the scapula is also abducted. In order to ascertain the relative position among the humerus, the scapula, and the trunk, radiography is necessary by all means.

On the other hand, especially in the case of spine, we have a few data about the sigmoid curve patterns and the thickness of

each intervertebral disc in healthy men in the standing posture and in other postures, such as bowing.

Not only for morphological studies but also for biomechanical studies, it is very useful if the line of gravity, which is a perpendicular line to the ground going through the center of mass of the body, is superimposed in the radiograph. For example, we can tell from a radiograph in the sagittal direction whether this line goes through the osseous semicircular canals, and through the anterior or posterior sides of the hip-joint and the knee (cf. MCLEISH *et al.*, 1970).

If a subject attaches before radiography small spheres made of lead to the somatometrical landmarks, we can ascertain the geometrical positions between these landmarks and the bones.

A three-dimensional reconstruction of the whole-body skeletal system from radiographs in the sagittal and frontal direction is possible (cf. BROWN *et al.*, 1976; DIMNET *et al.*, 1978; HIERHOLZER *et al.*, 1982).

The apparatus which we have developed here will make it possible to take radiographs for such purposes. The construction of this apparatus is shown in Table 1 and Fig. 1. The conditions for X-ray exposure is shown in Tables 2.

The Construction of the Apparatus

The outline of this apparatus is shown in Table 1 and Fig. 1. It consists mainly of two parts, one being the unit for radiography, and the other the unit pulling a trigger to take the X-ray at the moment when the center of gravity of the body comes at the center of the force plate.

Table 1. Important apparatuses used here. (Parenthesized letters correspond to the same letters in Fig. 1.)

X-ray tube (A) and its power source (K) :	Toshiba KXO-1000
Force plate (C), Preamplifier for force plate (E), Analog adder (F), Analog divider (G) and X-ray trigger unit (J) :	Patella Stiometer S-112 as a whole
Amplifier (H) :	Sanei 1205B*
Free selector unit :	Sanei 5114A*
Monitoring oscilloscope (L) :	Sanei 2G48*
Pen-oscillograph (M) :	Sanei Rectigraph 8S*
Automatic film developing processor :	Sakura 524S
Other standardized accessories and their dimensions	
Film cassette (B) :	Custom made (Okamoto) (inside measurement, 180×70 cm, 200×60 cm)
Intensifying screen :	Kyokko HS
Grid wafer :	Lysholm's diaphragm (Grid ratio, 4:1) (Grid radius, ∞)
X-ray film :	Sakura Type M regular or Sakura Type A (180×60 cm)
Lead wire (D) :	0.7 mmφ (2.5 m×2)
Weight for the wire :	50 g×2
Water cup :	for ca. 100 ml ×2

* These units are supplied as Sanei Polygraphy 142-8 in all.

The point of application of body gravity resultant

In an upright position of a healthy man the center of gravity of his body is always fluctuating slowly and irregularly within a certain small area, even if his posture looks stable. In order to measure this fluctuation of the center of gravity, a force plate is usually applied.

It is generally considered that the center of body gravity is just above the point of action in a force plate. But, strictly speaking, this is incorrect. The point of action in a force plate indicates the point at which the line of action of a resultant created by the gravitation and other forces at the center of gravity goes through the force plate. Because the fluctuation of the center of gravity is slow and confined within a

small area, the other forces which act on the center of gravity are not remarkable. Therefore, we regard this quasiposition of the application of the body-gravity resultant as the true position of the body-gravity perpendicular.

The spacial arrangement of the units (see Fig. 1)

The most important point in arranging this apparatus is: the X-ray tube (A), the lead wire (D), and the y-axis at the center of the force plate (C) must be in the same plane, which is vertical to the ground and meets the film cassette perpendicularly at its center.

The distance between the X-ray tube and the film cassette (B) is 400 cm in our case because of the limitation of the room size

and the capacity of the X-ray tube. The distance from the lead wire to the cassette is 50 cm and from the center of the force plate to the cassette 28 cm. The height of the X-ray tube center (the focal spot) is adjusted with each subject at the height of the iliospinale antarius. The X-ray unit itself is an Toshiba ordinary product. We have two types of custom-made film cassette. Their inside measurements are 180×70 cm and 200×60 cm. There are two sheets of intensifying screen inside them, and an X-ray film (180×60 cm) is put between them. When radiographing, a Lythholm's diaphragm is attached to the surface of the cassette, which is facing the X-ray source. The number of X-rays required to radiograph the thoracic and lumbar spine is so great that the other parts of the body will be overexposed—in the case of the frontal-direction radiograph, this means that the neck will be overexposed, and the sagittal-direction radiograph, also the neck, and the upper and lower limbs will be overexposed. We therefore used some thin lead plates as a filter and attached them to the X-ray beam exit of the housing in order to get an equal exposure for the whole body. The thickness of this lead plate is 0.1 mm and it will be layered up to 0.3 mm. In our radiographic conditions this lead plate of 0.1 mm in thickness can equalize the exposure difference of 3 cm thickness of a living human body.

The lead wire is hung from the ceiling, and at its bottom end a weight (50 g) is attached. There is a cup filled with water just under this wire and this weight is hanging in mid-water. Because of this water the wire is always still and does not swing like a pendulum.

The force plate is the four-points sup-

ported type; thus, there are four load cells under the corners of this rectangular plate. In Fig. 1 these load cells are called A, B, C, and D. Their outputs (a, b, c, d) are pre-amplified by the strain meter units (E). Firstly, the outputs of B and C, thus b and c, are added. In the same way the outputs c and d are added through an analog computer (F). On the other hand the sum total of a, b, c and d is also calculated. Secondly, the sum of b and c, as well as c and d, is divided by the sum total separately (G). The result of the former indicates the position of the application point of body gravity resultant in the x-direction, which is parallel to the film surface, and the latter shows it in the y-direction, which is perpendicular to the film.

The movement of this position of the perpendicular of body gravity in the x-direction acts as a trigger for radiographing. If it is on the y-axis, which goes through the middle of the force plate horizontally from the X-ray tube toward the cassette and is in the plane made by the X-ray tube and the lead wire, the result of

$$\frac{b+c}{a+b+c+d}$$

is just 0.5. Looking from the X-ray tube toward the cassette, if the position of the body gravity perpendicular goes to the left, these result will decrease to under 0.5. Likewise, if it goes to the right, the result will increase to over 0.5.

The relay switch in the X-ray trigger unit (J) is closed at the moment when the result of x-direction is 0.5, but only when the result goes from less than 0.5 to more than 0.5. This means that the X-ray is radiated only when the position of the body gravity perpendicular moves from the left

to the right over the y-axis at the center of the force plate. This radiated moment is displayed in the oscilloscope (L) with the movement of the position of the body gravity perpendicular in the x- and y-direction as the three scanning lines. At the same time this progress is recorded by a pen-oscillograph (M). There is a time lag (ca. 0.07 sec) between the moment when the switch in the trigger unit is closed and the moment when the X-ray is radiated. But in normal subject the point of application of body gravity is moved slowly in a certain small area on the force plate, and the discrepancy between the true perpendicular line of body gravity and the superimposed line is at the most 5 mm in our experiments. In order to minimize this discrepancy, we can change the trigger level, for example, from 0.5 to 0.4875 (that is 0.5-0.0125). This 0.0125 is proportionate to a 5 mm movement of the point of the body gravity perpendicular in the x-direction on the force plate. Thus, it means that the switch of the trigger unit is closed when the point of the body gravity perpendicular crosses a line which is parallel to the y-axis and 5 mm apart from it to the left looking from the X-ray source. If the point of the body gravity perpendicular moves continuously towards the y-axis after it crosses the 0.4875 line, then because of the time lag it is hoped that the moment of radiation coincides almost completely with the moment when the point of the body gravity perpendicular crosses the y-axis. In each case, we can confirm this moment in the record paper from the pen-oscillograph after the radiation.

The Radiograph Procedure

- 1) Before radiographing, calibrate the

force plate. The position movement of perpendicular of body gravity must be recorded in both the x- and the y-direction at the same magnifying ratio in the oscilloscope and pen-oscillograph. Then put a weight at the center of the force plate and let the scanning lines and pen points of the each recorder move to the neutral position. Remove the weight. Because the ON-level of the relay switch in the X-ray trigger unit is already set at the neutral position, the X-ray is radiated only at the moment when the point of perpendicular of body gravity crosses the y-axis in the force plate from the left to the right looking from the X-ray

Fig. 2. Two types of arm attitudes in the case of the frontal-direction radiograph. Actually the humerus overlaps with the upper part of the thoracic spine in the case of (a), but the contours of all the skeletal elements which appear as figures in the films are easily recognized separately. In the case of (b), this overlapping is avoided, but the drawback is that the center of gravity of the thoracic part of the body, including both sides of the upper limbs, is moved anteriorly by this motion. As a result, the subject is apt to throw back his head.

tube. Then put a styrofoam-spacer (P) (ca. 7 cm in thickness) on the force plate.

2) A subject stands up on the center of the force plate.

3) He should move his whole body so

that the scanning line in the x- and the y-direction in the oscilloscope comes as close to the neutral line as possible. (Caution! In this case he must slide his feet on the force plate back and forth or to the right

Fig. 3. Examples taken by this method. The white vertical lines in the center of each figure are projected lines which go perpendicularly through the center of the body mass. These lines fall inside both plantar planes.

(a) Dorsoventral-sagittal direction in standing posture.

(b) Dorsoventral-sagittal direction in one-legged standing posture.

(c) Dextrosinistral direction in standing posture. Note: The arms are at the position of type (b) in Fig. 2.

and left in order to change the position of his whole body. Never move only the upper part of the body without sliding the feet or the body will tilt unnaturally.)

4) Place himself in an attitude of attention. In the case of the frontal-direction radiograph there are two patterns of the position of the upper limbs such as in Fig. 2 taken in order to avoid the overlapping of the spine and the bones of the upper limbs in a radiograph.

5) Be sure that the scanning line in the oscilloscope frequently crosses the neutral line.

6) Turn on the main switch of the X-ray unit (N).

7) Wait until the relay switch in the X-ray trigger unit turns on and the radiation is completed.

8) Remove the subject.

9) Develop the film.

10) Be sure from the recorded lines of the pen-oscillograph that X-ray is radiated when the center of the body gravity comes as close to the center of the force plate as practical.

Conditions for the radiographing

Table 2 shows the conditions for the radiographing. For teleradiography a larger X-ray dose is required than for ordinary radiography. In our case, the radiation time must be short (from 0.03 to 0.1 seconds) in order to freeze the movement of the point of application of body gravity. For this momentary radiography it is necessary to

Table 2. Conditions for the radiographing

Film-focus distance:	400 cm
Tube voltage:	90-120 kV
Tube current intensity:	20-250 mAs
Exposure time:	0.03-0.1 sec

increase the tube current intensity. But as a whole the irradiated amount of X-ray was between ca. 20 to 500 milirem (surface dose) according to the obesity index of the subjects. Because high-sensitivity films are used, the amount is not so great; usually it is equivalent to the amount of one chest radiography (at the most 150 milirem). All of the subjects are volunteers who already know about the harmfulness of X-rays.

Conditions for film developing

The automatic developing processor (Sakura 524S) is large enough to develop 180×60 cm films. The developing and fixing solution, as well as the temperature of the solution bath and the film speed, were optimally selected and controlled according to the film type.

Note

This research was carried out in conformity with the "Declaration of Helsinki (1975)". We have also developed several sizes of protective lead-supporter in order to shut out the X-ray influence to the genital organs. Their efficiency is already tested.

抄 録

体重心線を写しこんだ全身X線撮影装置

鈴木裕視・足立和隆

ヒトを対象としたX線写真撮影法は、専ら病気の診断のために開発されてきたものであるが、人類学でも、形態学、機能形態学、バイオメカニクス、動態学の分野において、非常に有用な計量的、計質的な解析方法のひとつである。狭い範囲のX線撮影（最大でも28×71 cm）には、医療用に開発された装置が流用できるが、それ以上、とりわけ全身のX線撮影ともなると、それに適した装置類を開発しなければならない。さらに計量的解析にも十分に利用できるように一定の基準化された撮影条件を設定する必要がある。

今回、筆者らが開発した装置は、直立位における全身のX線写真を撮影するためのものであり、撮影条件も基準化した。さらにフォースプレートを利用して、撮影像には体重心をとる地面に垂直な線が写しこまれるようにしてある。この重心線は骨格の機能的な解析に、非常に役立つ。

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