Bull. Tokyo Med. Dent. Univ., 20: 19–34, 1973.

EFFECT OF SITTING POSTURE ON HUMAN BODY

BY

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ABSTRACT

To know the effect of sitting posture on human body, various postures and blood flow changes in right big toe were examined. The subjects were 10 healthy adult males and 8 females. The sitting postures were classified by seat height as (1) the lower legs were vertical and the foot sole touched flat on the floor (2) 10 cm lower than the height of (1), (3) 10 cm higher than that of (1).

In each of three sitting postures, there were differences in sitting pressure distribution in some degree between males and females, and it was observed that the third sitting posture showed the most marked effect on the contact area of the thigh with seat and on blood flow of the toes. This result was also examined by plethysmography and its waves showed the disturbing effect on the blood flow. Namely, the plethysmograph taken in the third sitting posture showed the lowest relative crest time, and highest dicrotic index, with a stochastically significant difference ($P=0.05$).

These experiments showed that plethysmography is useful to determine the degree of pressure on thigh in various sitting postures.

INTRODUCTION

The effect of sitting posture on the human body cannot be neglected throughout his daily life. Efficiency of sitting work and many types of sitting posture have been investigated by various methods.

There are several reports on measurement of sitting pressure according to sitting postures; strain guage method by Ohara[1)], pressure-sensitive paper method by Hanaoka[2)], manometric measurement by Schoberth[3)], and the present author[4)] gave some basic anthropometric measurement which is essential for the design of chairs for adult males and females, and for school children. Ohara *et al.*[5)] examined the relation of body posture to chair condition using electromyograph (EMG) and designed several standard chair for different uses. There are also ergonomical studies by flicker values from a physiological point of view[6)].

It is also obvious that a certain sitting posture gives physical pain or discomfort and fatigue on the lower legs. One of the possible causes of

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Received for publication, November 22, 1972.

these phenomena will be the disturbance of blood flow in lower legs, which could be explained in relation to the distribution of sitting pressure on the chair according to sitting posture.

The present author measured the sitting presure in three types of sitting posture, in order to testify the presence of the blood flow disturbance in lower legs and it was plethysmographically proved that the peripheral circulation in the lower legs was disturbed.

METHODS

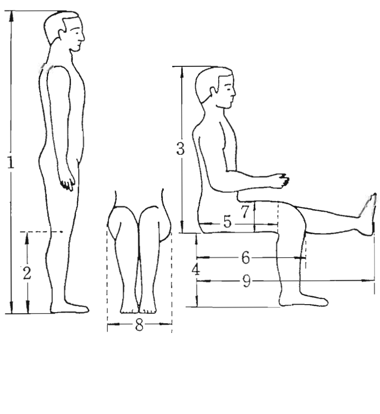
(1) Subjects

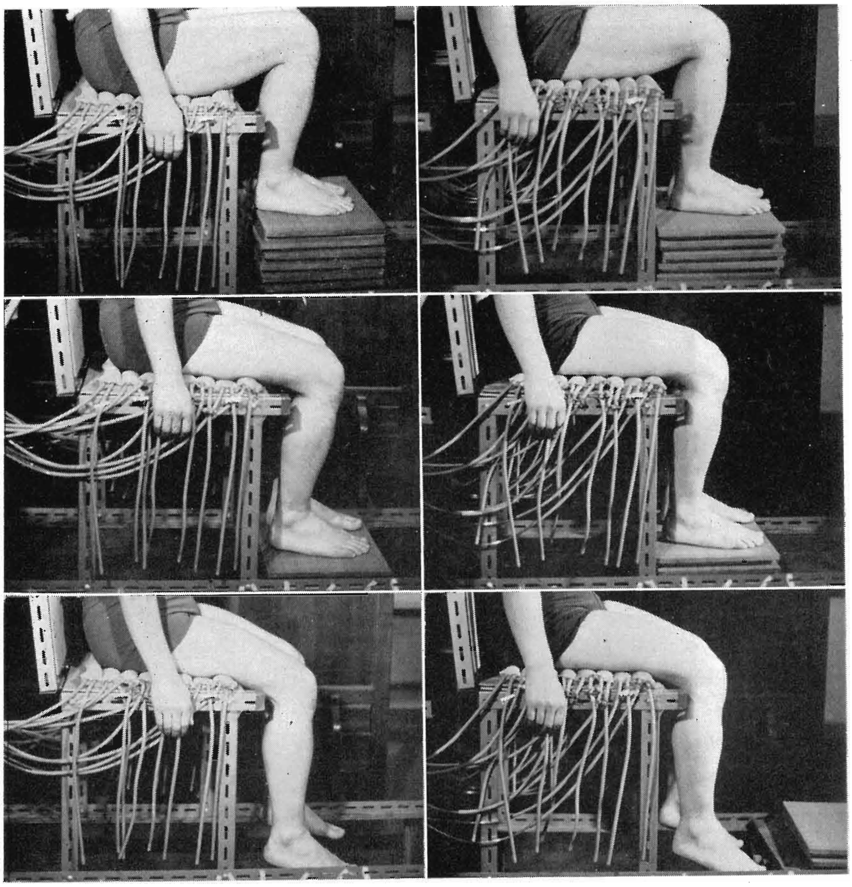
Subjects were 20 male and 8 female students, aged 20–24 years old, and all were examined medically and showed no sign of hypertension, heart diseases, or peripheral circular disturbances. The physical characteristics of some of these subjects are shown in Table 1.

All subjects given a 10-min rest before the experiments.

Table 1. Physical characteristics of the subjects

Items/Subject			Male			Female		
			MT	TK	SM	NM	AI	HN
1.	Body height	(cm)	170.0	158.0	162.0	157.0	153.2	155.0
2.	Patella height	(cm)	47.0	43.5	44.0	42.6	40.6	40.5
3.	Sitting height	(cm)	88.3	87.3	87.0	83.6	80.8	87.8
4.	Seat height	(cm)	46.0	39.6	42.8	39.3	38.5	37.9
5.	Seat length	(cm)	49.3	42.0	46.6	48.0	45.6	41.5
6.	Buttock-Knee length	(cm)	60.5	54.0	57.1	56.0	55.4	49.8
7.	Thigh height	(cm)	13.3	12.6	14.3	12.5	11.9	12.6
8.	Hip breadth	(cm)	34.0	33.2	32.7	32.3	33.8	33.0
9.	Buttock-leg length	(cm)	103.0	85.0	95.4	88.8	94.4	84.3
10.	Body weight	(kg)	63.0	49.0	65.0	44.0	48.0	44.0





2nd posture

1st posture

3rd posture

Front sitting Back sitting

Fig. 1. Types of sitting posture.

(2) Methods

a) Chair for experiment

The chair for the experiment was constructed based on the data of male adults measured by the author[4] and his collaborators.

Dimensions of the chair are as follows: width of seat 45 cm, length of seat 40 cm, height of seat 46 cm.

The back-rest angle to the seat was determined as 100°, as that of the standard working chair, according to the report of Hashimoto *et al.*[9] The chair for the experiment was made of iron frame, and was adjustable in each dimensions of width, length, and height.

Experiments were carried out so as to determine the differences of sitting pressure and of disturbance in blood circulation of the lower legs at the

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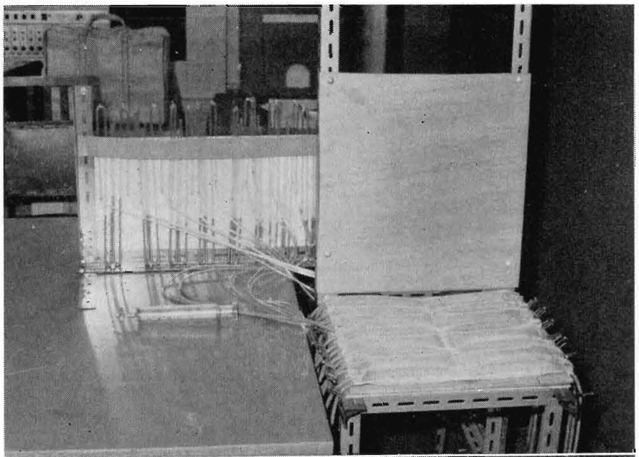

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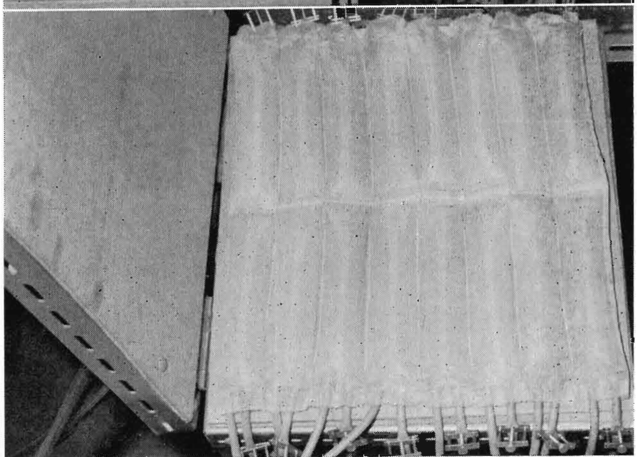

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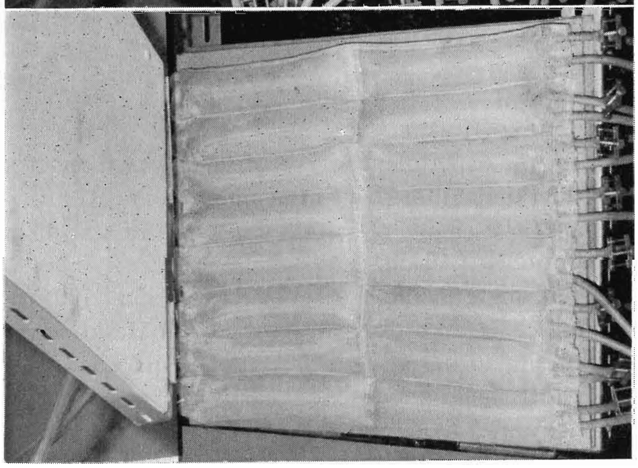

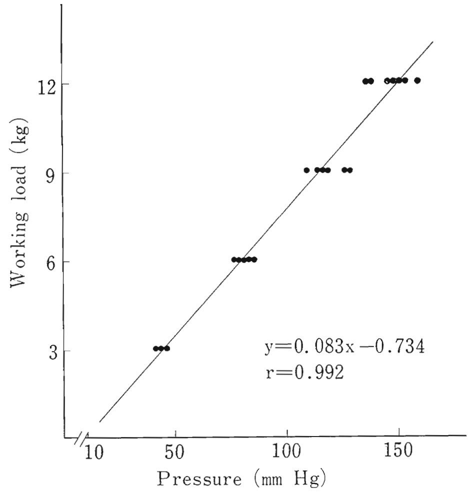

Fig. 3. Correlation between the load (kg) on balloons and their inner pressure (mm Hg).

following three sitting postures:

1) First (standard) posture: The lower legs are bent right angles at the knee, and the soles touched the floor flat.
2) Second posture: The seat height is 10 cm lower than that of the first posture.
3) Third posture: The seat height is 10 cm heigher than that of the first posture (Fig. 1), that is, the lower legs are dangling freely, and the soles do not touch the floor.

The sitting pressure distribution in above-mentioned three postures, being removed forward by 10 cm from the backrest of the experimental chair, were measured (forward sitting).

b) Environmental conditions during experiments.

To avoid the environmental influence on plethysmography, the experiments were carried out in a sound-proof room with a room temperature of 25°±1°C, and the subjects were kept in silence.

c) Measurement of sitting pressure distribution

The distribuiton of sitting pressure was measured by using a U-shaped mercury manometer (Fig. 2). Sixteen rubber balloons of Riva-Rocci's sphygmomanometer for children (length 20 cm, width 5 cm) were placed

Fig. 2. (1) The chair for the experiment with rubber balloons for measurement of sitting pressure distribution.
(2) Balloons rectangular with body axis.
(3) Balloons parallel to body axis.

side by side in two lines of 8 balloons into a sitting mat covered by a net cloth and each of them was connected to the mercury manometer. Rubber balloons were filled with 100 ml of air through a rubber tube and sealed. The internal air pressure of each rubber balloon was led to a manometer by a thick vinyl tube and was indicated by the height difference of mercury columns from these two tubes. The relation of the true pressure by standard weights (1–12 kg) to the height differences of the mercury column is shown in Fig. 3.

This mat was placed on the seat surface of the experiment chair, at right angle or parallel to the thighs. After measuring the pressures of each balloon, the pressure distribution was calculated (Table 5) from the results of the sitting pressures in two directions. The measured values were averaged for each subject and by experimental condition, and then they were discussed. An example of calculation of the sitting pressure of one subject is shown in Tables 3–5. Table 3 shows the pressure distribution (in mmHg) at right angle to the thighs and Table 4 that parallel to the thighs. Table 5 shows the pressure distribution by 8×8 (=64) blocks composed by the data shown in Tables 3 and 4.

Measured values of C in small blocks were calculated from the following formula:

$$C_{ij}\,(\%)=\frac{A_i \times B_j}{100}$$

where: A=sitting pressure right angle to the thigh
B=sitting pressure parallel to the thigh

$i=1, 2, \ldots 8$

$j=1, 2, \ldots 8$

$$\sum_{\substack{i=1\\j=1}}^{8} C_{ij}=100(\%)$$

d) Toe-type plethysmogram

Toe-type plethysmograms were recorded by a pneumatic plethysmograph using a strain-gauge. Volume change in the right big toe was led to a strain-gauge from an air-tight toe-cup and change in electrical resistance was led to the main amplifier through a carrier wave amplifier, and recorded by an ink-writing oscillograph as shown in Fig. 4. The calibration for the volume change of the toe was carried out by a microsyringe, 1 μl of air was injected into the receptor of a strain-gauge, and the recording paper speed was 50 mm/sec (Fig. 5).

CT (relative crest time) = B/A

D1 (dicrotic index) = b/a

where A: Wave length of plethysmogram

B: Duration from the starting point to the highest point of a wave
a: the highest height of the wave
b: height of the dicrotic notch

Because the plethysmogram shows a different wave pattern in expiratory and inspiratory phases of breathing, the subjects were ordered to hold breath for 5 sec at the inspiratory phase, and the measurement of plethysmogram was carried out for the last two waves in the series (Fig. 6).

RESULTS

(1) Body weight distribution on the chair

Table 6 shows the body weight distribution of 6 subjects on the seat of chair by six different sitting postures. As shown in this Table, the body

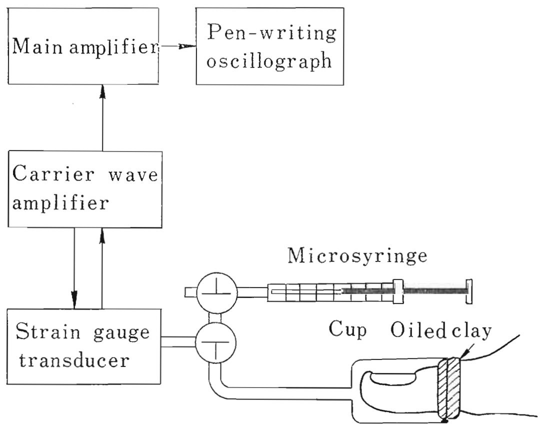

Fig. 4. Block diagram of toe-tip plethysmograph.

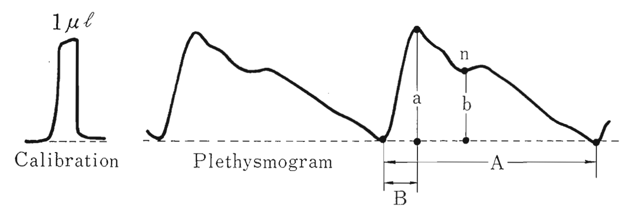

Fig. 5. Indices of toe-tip plethysmogram
CT (crest time) B/A
DI (dicrotic index) b/a
n (dicrotic notch)

Table 2. Plethysmographical data by subject and posture

1st posture

Subject	A (cm)	B (cm)	B/A	a (cm)	b (cm)	b/a
NU	3.35	0.50	0.15	2.40	0.45	0.19
SM	4.50	0.60	0.13	2.00	0.45	0.23
YS	3.75	0.60	0.16	1.43	0.25	0.17
MS	3.70	0.60	0.16	1.10	0.30	0.27
NH	3.90	0.45	0.12	1.98	0.25	0.13
HA	3.90	0.55	0.14	1.30	0.40	0.31
MA	3.40	0.55	0.16	1.20	0.30	0.25
NT	4.20	0.62	0.15	1.15	0.40	0.35
MO	4.70	0.65	0.14	1.80	0.70	0.39
MH	4.60	0.70	0.15	1.15	0.60	0.52
$\bar{x}$			0.14			0.28
SE			0.02			0.11

2nd posture

Subject	A (cm)	B (cm)	B/A	a (cm)	b (cm)	b/a
NU	4.10	0.60	0.15	1.58	0.20	0.13
SM	4.70	0.78	0.14	1.80	0.60	0.33
YS	3.50	0.51	0.15	1.50	0.30	0.20
MS	3.70	0.65	0.18	1.90	0.50	0.26
NH	4.80	0.55	0.11	1.40	0.24	0.17
HA	2.95	0.54	0.18	1.40	0.21	0.15
MA	3.20	0.60	0.19	1·50	0.40	0.22
NT	4.55	1.10	0.24	2.70	0.60	0.22
MO	4.45	0.70	0.16	2.35	0.80	0.34
MH	4.40	0.80	0.18	1.30	0.65	0.50
$\bar{x}$			0.17			0.26
SE			0.04			0.12

3rd posture

Subject	A (cm)	B (cm)	B/A	a (cm)	b (cm)	b/a
NU	3.75	0.45	0.12	1.85	0.40	0.22
SM	4.55	0.60	0.13	1.30	0.40	0.31
YS	4.35	0.50	0.11	1.70	0.40	0.24
MS	3.90	0.60	0.15	1.35	0.60	0.45
NH	4.45	0.55	0.12	2.40	0.55	0.23
HA	3.15	0.60	0.19	2.35	0.60	0.19
MA	3.30	0.51	0.15	0.86	0.18	0.21
NT	4.40	0.70	0.16	3.00	0.90	0.30
MO	4.45	0.55	0.10	1.30	0.55	0.42
MH	4.50	0.70	0.16	0.90	0.55	0.16
$\bar{x}$			0.13			0.32
SE			0.02			0.13

Table 3. An example of sitting pressure distribution (mm Hg and %) rectangular with body axis from the proximal balloon (A_1) to the distal (A_8)

	Pressure (mm Hg)		(1) + (2) = (3)	(3) /Total= (4) (%)
	(1)	(2)		
A_1	4	16	20	4
A_2	42	46	98	20
A_3	76	103	179	37
A_4	32	33	65	14
A_5	16	9	25	5
A_6	11	9	20	4
A_7	14	10	24	5
A_8	29	20	49	10
Total	224	256	480	99

(1) Right side (2) Left side (3) Total (4) Pressure distribution (%)

Table 4. An example of sitting pressure distribution (mm Hg and %) parallel to body axis from right end balloon (B_1) to the left end (B_8)

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	Total
(1) mm Hg	1	28	92	63	83	91	29	1	388
(2) mm Hg	1	21	27	12	6	21	22	0	110
Total	2	49	119	75	89	112	51	1	498
%	0	10	24	15	18	23	10	0	100

(1) Back part (2) Front part (3) Total (4) Pressure distribution (%)

Table 5. An example of sitting pressure distribution (%) in small sections (8×8)

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	
A_1	0	0	1	1	1	1	0	0	4
A_2	0	2	5	3	4	5	0	0	20
A_3	0	4	9	6	7	9	4	0	37
A_4	0	1	3	2	3	3	1	0	14
A_5	0	1	1	1	1	1	0	0	5
A_6	0	0	1	1	1	1	0	0	4
A_7	0	1	1	1	1	1	1	0	5
A_8	0	1	2	2	2	2	1	0	10
	0	10	24	15	18	23	10	0	

Table 6. Body weight distribution on the seat surface according to posture

Male subjects / Body weigt (kg)			MT		TK		SM		Mean	
			63.0		48.0		65.0		58.7	
			kg	%	kg	%	kg	%	kg	%
Back sitting	Parallel with body axis	1	50.4	80.0	38.4	80.0	60.0	92.0	49.6	84.0
		2	45.4	72.0	38.4	80.0	52.4	81.0	45.4	77.7
		3	60.5	96.0	41.7	87.0	54.8	84.0	52.3	89.0
	Rectangular with body axis	1	51.7	82.0	41.3	86.0	52.9	81.0	48.6	83.0
		2	50.4	80.0	36.5	76.0	47.3	73.0	44.7	76.3
		3	56.7	90.0	43.2	90.0	60.7	93.0	53.5	91.0
Front sitting	Parallel with body axis	1	56.7	90.0	46.0	96.0	60.9	84.0	54.5	90.0
		2	48.5	77.0	38.9	81.0	55.1	85.0	47.5	81.0
		3	59.2	94.0	47.0	98.0	60.9	94.0	55.7	95.3
	Rectangular with body axis	1	51.0	81.0	44.2	92.0	54.7	84.0	50.0	85.7
		2	49.1	78.0	41.3	86.0	52.7	81.0	47.7	81.7
		3	58.6	93.0	45.1	94.0	57.9	89.0	53.9	92.0

Female subjects / Body weight (kg)			NM		AI		HN		Mean	
			44.0		48.0		44.0		45.3	
			kg	%	kg	%	kg	%	kg	%
Back sitting	Parallel with body axis	1	40.5	92.0	44.2	92.0	40.0	91.0	41.6	91.7
		2	33.5	76.0	41.3	86.0	35.2	80.0	36.7	80.7
		3	40.9	93.0	45.1	94.0	40.9	93.0	42.3	93.3
	Rectangular with body axis	1	39.2	89.0	43.2	90.0	39.6	90.0	40.7	89.7
		2	37.9	86.0	43.2	90.0	37.1	84.0	39.4	86.7
		3	41.4	94.0	45.6	95.0	40.0	91.0	44.1	93.3
Front sitting	Parallel with body axis	1	37.2	85.0	43.7	91.0	40.5	92.0	40.5	89.3
		2	39.4	90.0	41.8	87.0	38.7	88.0	40.0	88.3
		3	41.8	95.0	45.1	94.0	40.9	93.0	42.6	94.0
	Rectangular with body axis	1	37.9	86.0	43.7	91.0	40.9	93.0	40.8	90.0
		2	40.0	91.0	39.8	83.0	37.6	35.0	39.1	86.3
		3	40.9	93.0	44.7	93.0	40.5	92.0	42.0	92.7

1: 1st posture, 2: 2nd posture, 3: 3rd posture

weight load to the seat surface was maximum in the case of the back sitting of the third posture (93%) and then that of the front sitting of the same posture; and minimum in the case of the back sitting of the second posture (80%) and then that of the front sitting of the same posture.

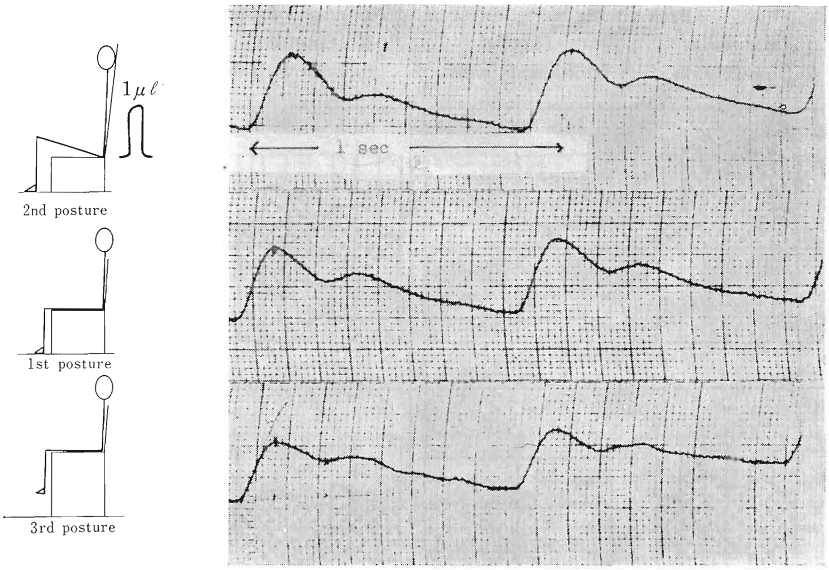

Fig. 6. Toe-tip plethysmogram according to posture.

(2) Measurement of sitting pressure distribution on the chair

Fig. 7 shows the sitting pressure distribution in percentage to the total pressure upon the seat surface by six different sitting postures, in two directions, parallel and right angle to the body axis. By this procedure, the difference in sitting pressure produced by the body weight difference of the subjects can be eliminated.

As shown in this figure, the high sitting pressure area is the region where the central line of each upper leg touches the seat surface and in the area centering around each tuber ischii. Therefore, the total pressure in combining two directions by sex is shown in Fig. 8. In this case, the pressure on each section (64 small sections) was measured by percentage to the body weight of each subject, and an isomanic line of sitting pressure shown as 1, 2, 4, 8% and son on. In this Fig. 8, the sitting pressure was centralized on the position 8 of tuber ischii and, along with the place where the thigh was placed the pressure was even on the front part in the case of first posture. In this case, there is no remarkable difference by sex, but the pressure is more centralized on the place of tuber ischii in females.

In the second posture, the pressure was centralized more on the position of tuber ischii than in the first posture, and in the third posture, the pressure was distributed on the lower (distal) part of the posterior surface of the thigh. In this case, there is a difference between male and female. This might be due to the characteristics of the sitting form of a female.

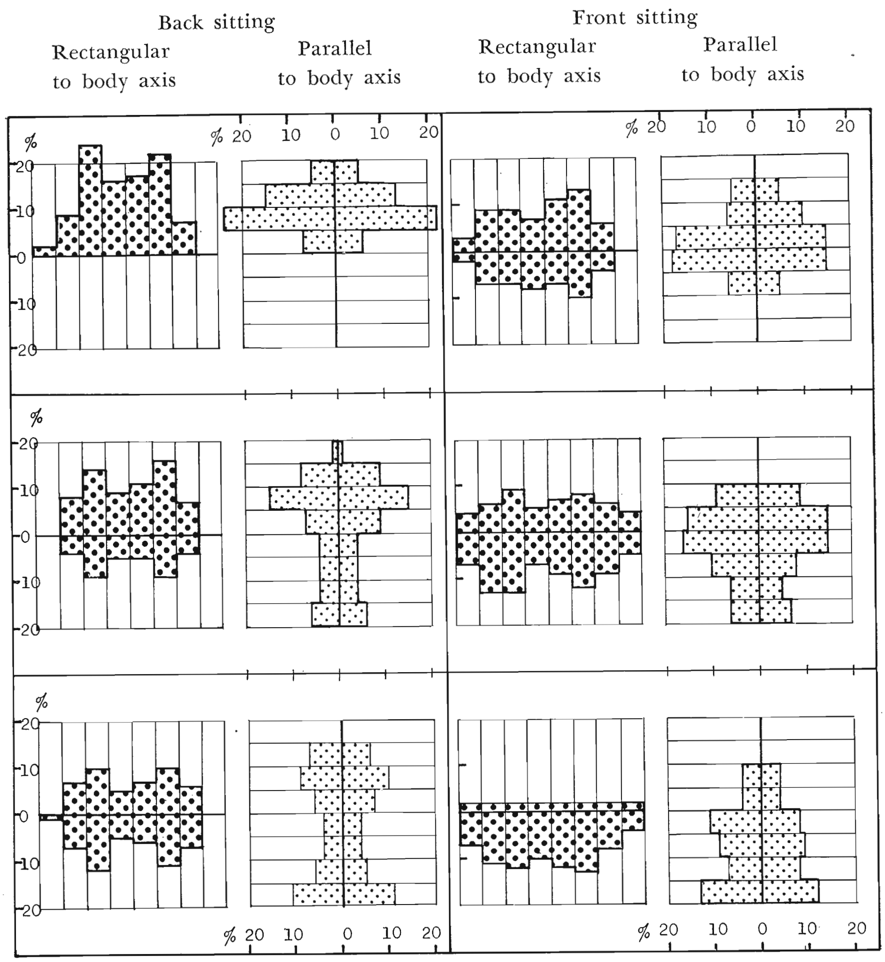

Fig. 7. Distribution of sitting pressure.

(3) Plethysmogram

In each subject, relative crest time (CT=B/A) and dicrotic index (DI=b/a) were calculated on the plethysmogram. Table 2 shows the values of CT and DI of plethysmogram in each sitting posture, and one of the patterns of the plethysmogram in the first, second, and third postures, and their values of B/A and b/a are shown in Fig. 6. As there was no difference in the calculated values of the plethysmogram between males and females, the mean values of B/A and b/a in each sitting posture were calculated and examined for the significance of the differences in these values among different postures.

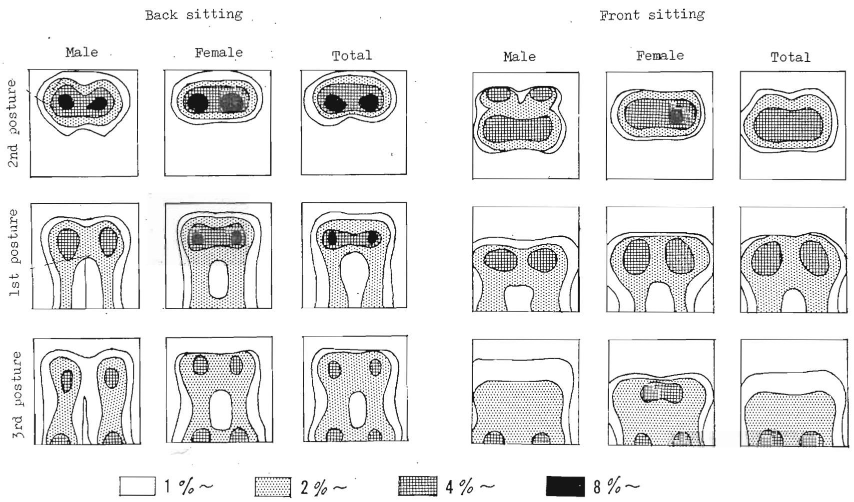

Fig. 8. Distribution of sitting pressure according to sex and postures.

The values of B/A of the second posture are smaller than that of the third posture and the b/a values of the second posture greater than that of third posture, with significant difference by the F-test (Table 2).

Discussion

As shown in Fig. 8, more sitting pressure is distributed at the front part of the seat in the case of the front sitting compared with the back sitting, and a remarkable difference in the pressure distribution was observed according to the patterns of sitting posture.

These three patterns were designed in respect to the distance between the sole and the floor, and the relation between the chair seat and the under-surface of the thighs. One of the remarkable points is the difference in the sitting pressure distribution by sex. A less pressed part of the seat was evident by the area between both thighs in the male, but not in the female. The other point is that the most pressed part on the seat is seen at the area where tuber ischii touches the seat and it is more clearly centralized in females than males. One of the reasons for this phenomenon may be due to the sitting custom of females, i.e., closing both things together, and a large hip and and thighs.

As for sitting pressure distribution by each posture, the area where the body touches the seat is small in the second posture, and as the whole body weight is loaded on this small area, the pressure is highest at the place where tuber ischii touches the seat.

On the other hand, in the third posture, the contact area of the body on the seat is large, and the high pressure zone is observed not only at the places where the tuber ischii touches but also at the poples area.

In the case of front sitting by males, highly pressed part was evident on the place of poples area and sitting pressure was seen at the front part of the seat. This means that the center of body weight is concentrated to the front part of the seat. Therefore, circulation disturbance of the second posture was the least and then that of the first posture was less then that of the third posture.

In this connection, conditions for an easy chair are include presence of armrests and a back-rest, with a seat height lower than the lower leg length, similar to that of the second posture.

When lower legs hung down and soles do not touch the floor, the front edge of the seat presses strongly on the back of the thighs and this will cause discomfort and disturbance of the venous blood return in the legs.

A study on plethysmograms was carried out to find changes in the flow of venous blood by occlusion caused by pressure load on the back of thighs in sitting. A measurement of relative crest time (CT) and dicrotic index (DI) became the object of this study. Relative crest time (B/A) means the rate of the time between the starting point and the systolic peak of a wave (up-stroke time) to the pulse duration. Rosenberg *et al.*[10] showed that the retention of venous return causes an increase in blood pressure of distal venules and extension of vessel wall, and then the tonus of the wall of peripheral arterioles might increase as a local reaction (local reflex). This means that the blood retention in the capillaries will raise the intravascular pressure in the capillary beds and decrease the arterial internal diameter and, as a result, the shortening of up-stroke time (B) and the decrease of the rate (B/A) are observed.

The dicrotic notch is caused by the closure of aortic valves and its elevation is often observed in a case of increased peripheral resistance[11]. As described before, through local reflex, increase in the arteriolar tonus causes the elevation of the incisula point of the wave and, therefore, the height "b" increases and also the rate b/a. These findings have been already confirmed by Yamaguchi[7] on the toe-plethysmograms. When the posterior parts of thighs are pressed by the front edge of the seat, the change in b/a shows the pressure effect on the venous return in legs.

Fig. 9 shows the relation of toe-plethysmographic findings to the pressure on the part of the seat where poples are placed. The pressure of this part is 0 kg in the second posture, 5.6 kg in the first posture, and 12.9 kg in the third posture, with the increase of pressure on the part of the seat, the value of B/A decreases and that of b/a increases, with stochastically high

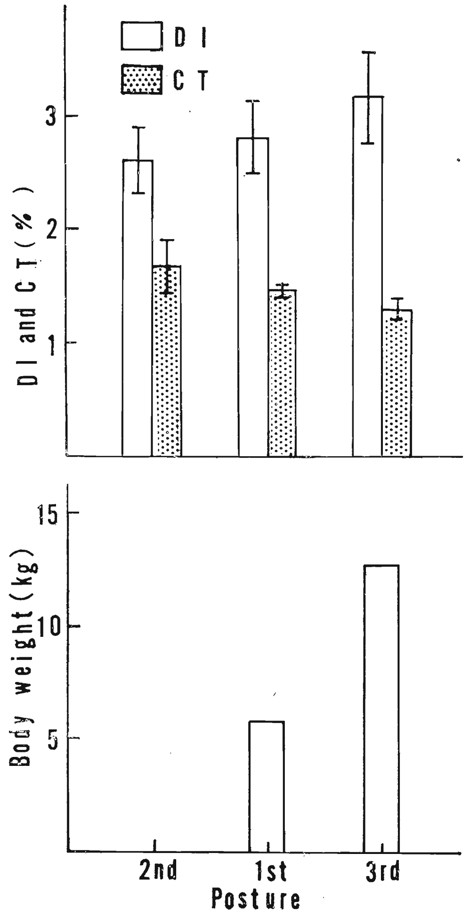

Fig. 9. Relation of plethysmographic data and body weight to poples space according to sitting postures.

significance compared with the value before the pression. Plethysmogram can measure objectively the blood flow disturbance by sitting pressure.

Although there are many reports on the conditions for a sitting chair, the effect of sitting pressure on the blood flow in lower legs cannot be neglected and the disturbance of the blood flow could be a cause of discomfort on sitting on a chair.

This study showed that plethysmogram is useful means for finding the circulatory disturbing effect of the seat to the lower legs and that the plethysmographic findings at sitting should be considered for designing chairs.

Acknowledgement

Grateful acknowledgment is made to Professor H. Kita for his cordial guidance, and to Dr. T. Kubota, Assistant Professor of Department of Hygiene, for his kind advice. The author's deep gratitude is also due to Dr. H. Yamaguchi, Assistant Professor of Department of Hygiene, School of Medicine, Showa University.

This work was presented before the 41st Annual Meeting of the Japanese Society for Hygiene, Tokyo, April, 1971.

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