QUANTITATIVE ESTIMATION OF COMPLIANCE OF HUMAN SYSTEMIC VEINS BY OCCLUSION PLETHYSMOGRAPHY WITH RADIONUCLIDE

—Methodology and the Effect of Nitroglycerin—

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Volume-pressure relationship and compliance of human systemic veins were estimated quantitatively and noninvasively using radionuclide. The effect of nitroglycerin (NTG) on these parameters was examined.

Plethysmography with radionuclide (RN) was performed using the occlusion method on the forearm in 56 patients with various cardiac diseases after RN angiocardigraphy with ^{99m}Tc -RBC. The RN counts-venous pressure curve was constructed from (1) the changes in radioactivity from region of interest on the forearm that were considered to reflect the changes in the blood volume of the forearm, and (2) the changes in the pressure of the forearm vein (fv) due to venous occlusion. The specific compliance of the forearm veins (Csp.fv ; $(1/V) \cdot (\Delta V / \Delta P)$) was obtained graphically from this curve at each patient's venous pressure (P_v). Csp.fv was $0.044 \pm 0.012 \text{ mmHg}^{-1}$ in class I (mean $\pm$ SD; $n = 13$), $0.033 \pm 0.007 \text{ mmHg}^{-1}$ in class II ($n = 30$), and $0.019 \pm 0.007 \text{ mmHg}^{-1}$ in class III ($n = 13$), of the previous NYHA classification of work tolerance. There were significant differences in Csp.fv among the three classes.

The systemic venous blood volume (V_{sv}) was determined by subtracting the central blood volume, measured by RN-angiocardigraphy, from total blood volume, measured by the indicator dilution method utilizing ^{131}I -human serum albumin. Systemic venous compliance (C_{sv}) was calculated from $\text{C}_{sv} = \text{Csp.fv} \cdot V_{sv}$. The C_{sv} was $127.2 \pm 24.8 \text{ ml} \cdot \text{mmHg}^{-1}$ (mean $\pm$ SD) in class I, $101.1 \pm 24.1 \text{ ml} \cdot \text{mmHg}^{-1}$ in class II and $62.2 \pm 28.1 \text{ ml} \cdot \text{mmHg}^{-1}$ in class III. There were significant differences in C_{sv} among the three classes.

The class I C_{sv} value was calculated to be $127.2 \pm 24.8 \text{ ml} \cdot \text{mmHg}^{-1}$, and the C_{sv} /body weight was calculated to be $2.3 \pm 0.7 \text{ ml} \cdot \text{mmHg}^{-1} \cdot \text{kg}^{-1}$ of body weight, which was very close to the values for C_{sv} reported previously by other investigators in animal experiments.

The administration of NTG caused the RN counts – venous pressure curve to become steeper and shift upward. It increased C_{sv} significantly in all cases.

Key words:

Plethysmography
Systemic venous compliance
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THE systemic veins contain the vast majority of the circulating blood volume. In response to various stimuli, they can adjust their volume, acting as a reservoir for the heart; this has led researchers to label them as capacitance

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TABLE I DIAGNOSIS OF HEART DISEASE
IN THREE CLASSES BY PREVIOUS
NYHA CLASSIFICATION IN
56 PATIENTS

CLASS I (n = 13)	
Af	2
SVPC	2
VPC	2
WPW syndrome	2
HCM	2
AR	1
MVP	1
VSD (Roger disease)	1
CLASS II (n = 30)	
AP	12
DCM	7
OMI	3
MS	2
MR	1
AR	1
TR	1
MS + AR	1
MVP	1
III° AV block	1
CLASS III (n = 13)	
DCM	5
OMI	3
MS	1
MR	1
MS + AR	1
MR + AR + TR	1
Pericarditis	1

Af = atrial fibrillation; SVPC = supraventricular premature contraction; VPC = ventricular premature contraction; WPW syndrome = Wolff-Parkinson-White syndrome; HCM = hypertrophic cardiomyopathy; AR = aortic regurgitation; MVP = mitral valve prolapse; AP = angina pectoris; DCM = dilated cardiomyopathy; OMI = old myocardial infarction; MR = mitral regurgitation; MS = mitral stenosis; TR = tricuspid valve regurgitation.

vessels. The compliance of the human capacitance vessels has been estimated based on data obtained in animal experiments by Guyton,¹ Drees & Rothe² and Shoukas & Sagawa,³ because it. It is very difficult to measure the compliance of the systemic veins in human beings.⁴ In human, total vascular compliance has been estimated only with invasive methods, i.e., massive blood transfusion or hemorrhage.⁵ In clinical settings, studies using water-filled^{6,7} or strain gauge plethysmography^{8,9} have been carried out to determine the "distensibility" of human capacitance vessels, in which "distensi-

bility" was evaluated from the rate of increase in blood volume per unit tissue volume of the forearm (ml/mmHg/100 ml·tissue) or from the increase in tissue volume in the forearm in response to the increase of venous pressure from zero to 30 mmHg (VV[30]). No standard method for estimating human systemic venous compliance, taking the patient's venous pressure into account, has been devised. In recent years, occlusion plethysmography with RN has been introduced, however, only the RN counts – venous pressure relationship has been obtained from the changes in RN counts due to venous occlusion.¹⁰

In the present study, we constructed RN counts – venous pressure plots for the forearm veins by performing plethysmography with RN and then devised a new method for estimating the specific compliance (Csp.fv) of the forearm and the compliance of the systemic venous system (Csv). In addition, comparisons were made between work tolerance as defined in the previous NYHA classification and systemic venous compliance in cardiac patients. Finally, the effect of nitroglycerin on the compliance of human systemic veins was examined in some cardiac patients.

In this study, compliance and specific compliance (coefficient of volume distensibility) were defined as follows; "compliance is the ratio of the change in volume (ΔV) resulting from a change in transmural distending pressure (ΔP) or $\Delta V/\Delta P$, and it is the slope of the pressure-volume curve,"¹¹ and "specific compliance is defined as the change in volume per unit volume relative to a change in pressure, that is, $(1/V) \cdot (\Delta V/\Delta P)$."¹²

SUBJECTS AND METHODS

Subjects

Fifty-six patients with various cardiac diseases consented to participate in this study. There were 52 males and 4 females, ranging in age from 19 to 71 years (mean $\pm$ SD; 51.2 ± 11.5 years). Their physical activities were found to be compatible with classes I to III of the previous NYHA classification (Table I), and sublingual administration of nitroglycerin (0.6 mg, abbreviated as NTG) was performed in 33 cases.

Methods

- 1) Estimation of systemic venous volume (Vsv)

Total blood volume (TBV) was determined by

Fig.1. Arrangement of occlusion plethysmography with radionuclide.

Fig.2. Changes in RN counts from ROI set over the forearm by venous occlusion. The dotted line represents the RN decay line.

the dilution method utilizing ^{131}I -human serum albumin and Volmetron (Ames Co., Ltd.). Next, radionuclide (RN) angiocardigraphy was performed, using a gamma camera (ZLC, Siemens Co., Ltd.) equipped with a parallel hole ultra-high resolution collimator in the left anterior oblique view, by injecting 20 mCi of $^{99\text{m}}\text{Tc}$ -pertechnetate to label in vivo the red blood cells in all patients. A data processing computer system (Scintipac 1200 or 2400, Shimadzu Co., Ltd.) was used to analyze RN-angiocardigraphy.

Cardiac output (CO) was determined by TBV and data calculated from RN-angiocardigraphy using the indicator dilution method.

Central blood volume (CV) was calculated by equation (1), using the mean transit time from the right atrium (RA) to the left ventricle (LV), i.e., $\text{MTT}_{\text{RA-LV}}$ obtained from the first pass phase of the time activity curve.

$$\text{CV} = \text{CO} \cdot \text{MTT}_{\text{RA-LV}} \quad (1)$$

By definition, blood volume in the systemic venous system (V_{sv}) was 80% of the blood volume in the systemic circulatory system which was calculated by subtracting the CV from TBV. Thus, V_{sv} was obtained using equation (2).

$$V_{\text{sv}} = (\text{TBV} - \text{CV}) \cdot 0.8 \quad (2)$$

2) Venous occlusion plethysmography with radionuclide in the forearm

i) Measurement of the forearm venous pressure

A 19-gauge needle was inserted into the superficial vein of the forearm, located midway between the wrist and elbow, and both a pressure transducer and the site of the venipuncture to measure venous pressure were set at the mid thoracic level, resulting in patients' measured

venous pressure (P_v).

ii) Occlusion plethysmography

Occlusion plethysmography with RN was performed at the forearm while patients were resting in the supine position, for at least 15 min after conducting RN-angiocardigraphy when the isotope had reached equilibrium state. As described in strain gauge plethysmography^{8,9} the height of the forearm was adjusted to attain a venous pressure ranging from zero to 3 mmHg, and the pressure transducer (Gould Statham P231D) was placed at this level throughout the study. To draw the lowest possible segment of RN counts – venous pressure curve (vide infra) the examination was started at the venous pressure of 0–3 mmHg. The venous pressure of the forearm was recorded continuously on a polyrecorder (Nihon Kohden Kogyo Co., Ltd. RM-6300).

The region of interest (ROI) was set over the forearm, and the proximal and distal sides of the ROI were surrounded with lead plates to eliminate any outside radioactive influence, and radioactive counts from ROI were continuously recorded (Fig. 1).

After recording radioactivity for 7–10 min without venous occlusion, inflation of the occlusion cuff surrounding the upper arm was repeated 5 times with a pressure range of 5 to 40 mmHg, utilizing a rapid cuff inflator (Hokanson Co., Ltd.). The duration of each inflation was within 3 min, and deflation was performed after venous pressure had reached a plateau level during the preceding inflation, and the next inflation was performed 2 min after the preceding deflation. In patients for sublingual NTG study, after conducting 5 consecutive

Fig. 3. RN counts - venous pressure curve. R_0 was obtained graphically from the RN counts (R_{pv}) at venous pressure of patients and from a tangent drawn on the RN counts - venous pressure curve at P_v .

Fig. 4. Blood volume - venous pressure curve in the forearm. For the abbreviations, see Table II.

venous occlusions, 0.6 mg of NTG was given sublingually, and venous occlusion was repeated 4 to 5 times, 3 min after NTG administration. Room temperature was maintained at 22 to 24°C throughout the study. The time course of the changes in RN counts from ROI recorded using this method is shown in Fig. 2. RN counts alternately increased with inflation and decreased with deflation of the occlusion cuff. A problem arose because the changes in RN counts included the physical and biological decay of the isotope. Therefore, an isotope decay line was drawn by eye using the RN counts obtained immediately after starting the study, but without inflating

Fig. 5. Schema of blood volume - venous pressure curve in the forearm before and after sublingual administration of NTG. For the abbreviations, see Table II.

the cuff, and those obtained for several minutes after last occlusion (Fig. 2). In constructing the isotope decay line, there were variations in the counts of isotope in some cases at the points of time 1-2 min after starting the measurement and 30 seconds after deflating cuff. Therefore, isotope decay line in these cases was drawn from the counts of isotope at the periods of time 5 min before the first inflation of the cuff and 5 min before completing the study. This line was defined when the pressure within the cuff is zero, and it was thought the blood volume in the ROI would be constant along this line.

3) Estimation of the specific compliance of the forearm veins ($C_{sp.fv}$)

The RN counts - venous pressure relationship of the forearm was constructed. The value of RN counts, corrected for isotope decay, was plotted on the ordinate, and the value of venous pressure was plotted on the abscissa. As shown in Fig. 3, the curve was steepest at low pressures, becoming less steep as venous pressure increased, finally reaching a near plateau. $C_{sp.fv}$ was obtained as described below. A tangent was drawn on the RN counts - venous pressure curve at the venous pressure of patients (P_v), measured by setting the zero reference pressure at the mid-thoracic level and the RN counts at a point of contact (R_{pv}), and the RN counts at the point of intersection (R_0) of this tangent with the RN-axis were obtained. This tangent line was drawn by eye, and

TABLE II EXPLANATION OF THE ABBREVIATIONS USED IN THIS PAPER

CO	ml/sec	Cardiac output
Csp.fv	mmHg ⁻¹	Specific compliance of the forearm veins
Csp.fv _(NTG)	mmHg ⁻¹	Specific compliance of the forearm veins after NTG
Csv	ml/mmHg	Systemic venous compliance
Csv _(NTG)	ml/mmHg	Systemic venous compliance after NTG
CV	ml	Central blood volume
fv		Forearm vein
MTT _{RA-LV}	sec	Mean transit time from RA to LV
Pv	mmHg	Venous pressure measured at mid thoracic level
Pv _(NTG)	mmHg	Venous pressure measured at mid thoracic level after NTG
R _O	counts	Radioactivity of the Y axis intersection of the tangents
R _{O(NTG)}	counts	Radioactivity of the Y axis intersection of the tangents after NTG
R _{Pv}	counts	Radioactivity at the venous pressure of Pv
R _{Pv(NTG)}	counts	Radioactivity at the venous pressure of Pv after NTG
s		Conversion factor
TBV	ml	Total blood volume
Vfv	ml	Forearm venous blood volume
Vfv _(NTG)	ml	Forearm venous blood volume after NTG
Vsv	ml	Systemic venous blood volume
Vsv _(NTG)	ml	Systemic venous blood volume after NTG

the variation in the slope of the tangent line drawn by 2 experienced examiners was within $\pm 7\%$ ($n = 20$).

Since RN counts originate only from ^{99m}Tc labeled to RBC, there should be a proportional relationship between RN counts and blood volume within the ROI. Therefore, the blood volume of the forearm at a given venous pressure can be calculated by multiplying RN counts by a conversion factor(s). The relationship between blood volume of the forearm (RN counts $\cdot$ s, ordinate) and venous pressure (abscissa) can be shown according to Fig. 4.

Because the occlusion cuff was inflated to a pressure of less than 40 mmHg in the present study, we have assumed there is no change in the volume of the forearm arteries, and the observed changes in the blood volume of the forearm can be regarded as reflecting the changes in the venous blood volume. Therefore, the observed curve is considered to represent the volume-pressure relationship in the forearm veins. Assuming that these veins contain 80% of the blood volume in the forearm at the venous pressure of Pv, the forearm blood volume (Vfv) can be calculated using equation (3)

$$Vfv = R_{Pv} \cdot s \cdot 0.8 \quad (3)$$

The Csp.fv can be obtained, using equation (4), from the slope of the tangent drawn on this curve at Pv, i.e., $[\Delta V/\Delta P = \tan \alpha]$, and the above mentioned blood volume in the forearm veins (Vfv).

$$\begin{aligned} \text{Csp.fv} &= (\Delta V/\Delta P) \cdot (1/V) = \tan \alpha \cdot (1/V) \\ &= \{(R_{Pv} - R_O) \cdot s/Pv\} \cdot (1/Vfv) \end{aligned} \quad (4)$$

Substituting (4) for (3), we may write,

$$\begin{aligned} \text{Csp.fv} &= \{(R_{Pv} - R_O) \cdot s/Pv\} \cdot \{1/(R_{Pv} \cdot s \cdot 0.8)\} \\ &= (R_{Pv} - R_O)/(Pv \cdot R_{Pv} \cdot 0.8) \end{aligned} \quad (5)$$

As shown in equation (5), Csp.fv can be obtained from the actual venous pressure (Pv), and R_{Pv} and R_O obtained graphically from the RN counts – venous pressure curve, without using the values, which cannot be measured.

4) Estimation of systemic venous compliance (Csv)

Assuming that the specific compliance of the forearm veins (Csp.fv) is an average value for specific compliance of systemic veins, systemic venous compliance can be estimated using equation (6).

Fig. 6. Specific compliance of the forearm veins (Csp.fv) and systemic venous compliance (Csv) in classes I to III of the previous NYHA classification. (*p < 0.01)

$$C_{sv} = C_{sp.fv} \cdot V_{sv} \quad (6)$$

In patients receiving NTG, the RN counts – venous pressure relationships were obtained before and after NTG.

As shown in Fig. 5, the volume of the arterial system ($0.2 \cdot R_{pv} \cdot s$) was considered to be unchanged by the administration of NTG. Therefore the volume of the forearm veins after NTG ($V_{fv(NTG)}$) was calculated using equation (3)'.

$$V_{fv(NTG)} = (R_{pv(NTG)} - 0.2 \cdot R_{pv}) \cdot s \quad (3)'$$

Csp.fv after NTG ($C_{sp.fv(NTG)}$) was obtained as that before NTG in the following way;

$$C_{sp.fv(NTG)} = \{(R_{pv(NTG)} - R_{O(NTG)}) \cdot s / P_{v(NTG)}\} \cdot (1/V_{fv(NTG)}) \quad (4)'$$

$$= \{(R_{pv(NTG)} - R_{O(NTG)}) / P_{v(NTG)}\} \cdot \{1/(R_{pv(NTG)} - 0.2 \cdot R_{pv})\} \quad (5)'$$

In addition, systemic venous volume after NTG ($V_{sv(NTG)}$) was obtained, on the basis of the relation between $V_{fv(NTG)}$ and V_{fv} , as

$$V_{sv(NTG)} = V_{sv} \cdot (V_{fv(NTG)} / V_{fv}) \quad (2)'$$

Csv after NTG ($C_{sv(NTG)}$) was obtained in the same way as that before NTG using the final equation (6)'

$$C_{sv(NTG)} = C_{sp.fv(NTG)} \cdot V_{sv(NTG)} \quad (6)'$$

Abbreviations used in this study are listed in Table II.

RESULT

1) Reproducibility of measurement of specific compliance of the forearm veins (Csp.fv).

In a small number of cases ($n = 4$), Csp.fv obtainable in a manner of equation (5) was recalculated 15 min after the first measurement in the same patients, which showed a good correlation in the coefficient of variation ($\pm 5.6\%$) for Csp.fv measurement.

2) Specific compliance of the forearm veins (Csp.fv) and compliance of the systemic veins (Csv)

Figure 6 shows Csp.fv and Csv in all patients ($n = 56$), according to the previous NYHA classification of the work tolerance. Csp.fv was $0.044 \pm 0.012 \text{ mmHg}^{-1}$ in class I (mean $\pm$ SD; $n = 13$), $0.033 \pm 0.007 \text{ mmHg}^{-1}$ in class II ($n = 30$) and $0.019 \pm 0.007 \text{ mmHg}^{-1}$ in class III ($n = 13$), while Csv was $127.2 \pm 24.8 \text{ ml} \cdot \text{mmHg}^{-1}$ in class I, $101.1 \pm 24.1 \text{ ml} \cdot \text{mmHg}^{-1}$ in class II and $62.2 \pm 28.1 \text{ ml} \cdot \text{mmHg}^{-1}$ in class III, indicating that the more severe the limit of exercise tolerance the lower the Csp.fv and Csv. Furthermore, there were significant differences in Csp.fv and Csv between classes I and II ($p < 0.01$), between classes II and III ($p < 0.01$) and between classes I and III ($p < 0.01$).

3) Effect of sublingual NTG on the systemic venous system

i) Shift of RN counts – venous pressure curve in response to NTG

Figure 7 shows the RN counts – venous pressure curves before and after NTG in a typical

Fig. 7. Shift of RN counts – venous pressure curve due to sublingual NTG (0.6 mg) in a typical case (57 year-old male, angina pectoris).

The venous pressure, measured by setting the zero reference at the mid-thoracic level, was 7.6 mmHg before NTG (point A) and 4.7 mmHg after NTG (point B) in this case.

Csp.fv and C_{sv}, obtained from the slope of tangents drawn at points A and B, shifted from 0.022 mmHg⁻¹ to 0.036 mmHg⁻¹ and from 72.2 ml·mmHg⁻¹ to 144.3 ml·mmHg⁻¹, respectively. Closed circles; RN counts – venous pressure curve before NTG (control)

Open circles; RN counts – venous pressure curve after NTG

case. Sublingual administration of NTG (0.6 mg) caused the RN counts – venous pressure curve to shift upward and become steeper, and it shifted the driving point to the left (from points A to B) by lowering venous pressure (P_v); as a result, NTG increased Csp.fv markedly.

Sublingual NTG caused the upward shift of RN counts – venous pressure curves in all cases of each group. In addition, venous pressure (P_v) decreased significantly from 6.0 ± 2.1 to 4.0 ± 1.7 mmHg in class I ($n = 6$, $p < 0.01$), from 6.7 ± 1.9 to 5.3 ± 2.1 mmHg in class II ($n = 18$, $p < 0.01$) and from 11.8 ± 3.6 to 8.0 ± 3.0 mmHg in class III ($n = 9$, $p < 0.01$) with NTG.

Csp.fv was increased significantly from 0.042 ± 0.013 to 0.054 ± 0.015 mmHg⁻¹ in class I ($n = 6$, $p < 0.01$), from 0.031 ± 0.006 to 0.045 ± 0.012 mmHg⁻¹ in class II ($n = 18$, $p < 0.01$) and from 0.019 ± 0.008 to 0.028 ± 0.016 mmHg⁻¹ in

Fig. 8. Changes in C_{sv} in response to sublingual NTG in classes I to III of the previous NYHA classification. Variances are mean $\pm$ SD.

Closed circles; C_{sv} before NTG (control)
Open circles; C_{sv} after NTG * $p < 0.01$,
** $p < 0.05$

class III ($n = 9$, $p < 0.01$) with sublingual NTG.

ii) Changes in C_{sv} in response to NTG

Figure 8 shows the changes in C_{sv} in response to sublingual administration of NTG (0.6 mg) in 33 patients, classified according to the previous NYHA. C_{sv} increased significantly from 129.9 ± 25.9 ml·mmHg⁻¹ to 180.5 ± 55.4 ml·mmHg⁻¹ (mean $\pm$ SD) in class I ($n = 6$), from 82.9 ± 33.5 ml·mmHg⁻¹ to 148.9 ± 36.2 ml·mmHg⁻¹ in class II ($n = 18$) and from 62.2 ± 34.1 ml·mmHg⁻¹ to 91.4 ± 47.2 ml·mmHg⁻¹ in class III ($n = 9$) after sublingual NTG as compared with control values.

DISCUSSION

1) Systemic venous blood volume

We defined the blood volume in the systemic venous system (V_{sv}) as being 80% of the blood volume in the systemic circulation, excluding the central blood volume. Systemic veins are considered to be the venules, small and large veins which have the largest capacitance in the systemic circulation. In order to verify this 80% figure, we calculated venous blood volume from the previous reports¹³⁻¹⁷ which studied the distri-

TABLE III REPORTED VALUES FOR SYSTEMIC VENOUS COMPLIANCE

Compliance Value ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{mmHg}^{-1}$)	Reference
1.4	Guyton et al ¹⁹
1.6	Larochelle et al ²⁰
1.8	Caldini et al ²¹
2.3	Richardson et al ²²
2.4	Shoukas and Sagawa ³
3.3	Green and Attix ²³
4.2	Drees and Rothe ²
2.3	this study

bution of intravascular volume, and found that the blood volume in venules, small and large veins varied from 76.2 to 81.6% of the blood volume in the systemic circulatory system, excluding heart and pulmonary circulation.

A problem may arise in that the distribution of the blood in the systemic circulation would be equal in all classes of previous NYHA classification. So, we tried to calculate systemic blood volume in three classes, using the equation, systemic blood volume = (total blood volume – central blood volume)/body weight. As a result, it was found that systemic blood volume was 65.0 ± 9.4 ml/kg of body weight, 62.1 ± 7.4 ml/kg of body weight, 69.6 ± 10.6 ml/kg of body weight (mean $\pm$ SD) in classes I, II and III, respectively. There was no significant difference in the systemic blood volume between classes I and II and between classes I and III, probably because patients in classes II and III were previously treated with diuretics. Therefore, it was assumed that the distribution of the blood volume in the systemic circulation might remain undisturbed.

2) Venous occlusion method

It was assumed that only venous blood volume in the forearm would increase in response to venous occlusion, and only the venous return would be inhibited and there would be no change in the volume of the arteries. Furthermore, as had been previously reported,¹⁸ the rate of filtration of intravenous fluid across the capillary wall, being proportional to the duration of occlusion and occlusion pressure, was calculated as 0.0036 ml/100 ml·tissue/min/mmHg. Therefore, within the venous pressure range we used to draw a tangent to estimate compliance in our study, only a small amount of intravenous fluid would

be filtrated. Additionally, since almost all of the isotope would be labeled to red blood cells, the amount of free isotope, leaking from the intravenous space, would be negligible.

Based on these assumptions, it was possible to say almost all of the changes in radioactivity within the ROI due to venous occlusion would reflect changes in blood volume in the venous system.

3) Estimation of specific compliance of forearm veins

As mentioned above, water filled or strain gauge plethysmography has been conventionally used for evaluating the “distensibility” of forearm veins. However, “distensibility” of the forearm obtained using these methods was only the rate of increase in blood volume per unit tissue volume per unit increase in pressure, but not the actual value of compliance. Specific compliance could be obtained using our method, and it was useful to estimate systemic venous compliance, if the volume in these systems was known.

4) Estimation of compliance of the systemic veins

Compliance of the systemic veins has been evaluated in animal experiments by measuring changes in mean systemic pressure when the heart had stopped or by measuring the change in venous pressure in response to massive blood transfusion or hemorrhage.^{1–3} However, as these methods are invasive, they are very difficult to apply in humans. Echt et al⁵ estimated human total vascular compliance based on changes in central venous pressure due to massive and rapid blood transfusion, but here again, it is impossible to apply this method to patients in a clinical setting, especially if they are suffering from congestive heart failure. A new non-invasive method was developed to estimate human C_{sv} after performing routine RN-angiocardigraphy and in patients with heart failure of varying severity. As a result, it was found that C_{sv} was 127.2 ± 24.8 ml·mmHg⁻¹ (mean $\pm$ SD, n = 13) in patients whose physical activity was compatible with class I of the previous NYHA classification and whose hemodynamics were considered to be almost normal. Converting this C_{sv} value to a value per body weight, we obtained 2.3 ± 0.7 ml·mmHg⁻¹·kg⁻¹ for C_{sv}/body weight. This value was very close to those reported by other investigators in their animal experiments (Table III). The compliance of the veins is assumed not to be uniform throughout the body.

However, taking the role of the venous system in the systemic circulation including the heart into account, it is very important to know the compliance of the entire systemic venous system quantitatively. In the present study, we estimated the compliance of the systemic venous system as described above assuming that the compliance of the forearm veins would represent the average of the compliance of the systemic venous system, and obtained the values for compliance of the systemic veins, which were very close to those reported in the animal experiments. Therefore, it was not unreasonable to assume that the compliance of the forearm veins including the veins of skin would represent the average of the compliance of the systemic venous system.

5) Effect of NTG

This study disclosed that sublingual administration of NTG (0.6 mg) shifted the RN counts — venous pressure curve upward, becoming steeper (Fig. 7). Additionally, it was found that the driving point shifted to the steeper portion of the new curve because of the lowered venous pressure induced by NTG; i.e., NTG not only improved the volume-pressure relationship of the capacitance vessels but also changed the driving point to a steeper portion of the volume — pressure curve in vivo. It was possible to evaluate quantitatively the effect of drugs on the compliance of the systemic veins using the volume-pressure curve as we did in this study, because both the change in volume-pressure relationship of the veins and the increase of compliance due to the decrease of venous pressure were included in the value of C_{sv} .

A new non-invasive method for measuring compliance of systemic veins, based on specific compliance measurements of the human forearm veins, using venous occlusion plethysmography with radionuclide, was developed. It appeared to have validity in detecting the "severity" of heart failure and in evaluating the efficacy of vasodilator therapy.

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