COMPLIANCE OF PERIPHERAL CAPACITANCE VESSELS IN PATIENTS WITH VARIOUS KINDS OF EDEMA

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A METHOD for measuring compliance of the peripheral capacitance vessels was reported from our laboratory. The values of compliance in patients with congestive heart failure measured by this method were compared with values in normal subjects, and also with values from former patients after the congestion disappeared following treatment with digitalis and other drugs. The mean value of compliance of the peripheral capacitance vessels in patients with congestive heart failure was only half of that in normal subjects. After the congestion disappeared the value of compliance became nearly the same as in normal subjects.¹

Congestive heart failure is usually accompanied by edema; therefore, the present study was done to study both the compliance of the peripheral capacitance vessels and the resistance of the peripheral resistance vessels in patients with various kinds of edema.

MATERIALS AND METHOD

Thirty-eight patients hospitalized at Iwate Medical University Hospital with various kinds of edema were studied for this study. Eighteen were patients paralyzed on one side from cerebral vascular disease (hemiplegia due to cerebral

apoplexy, average age 58 years), ten had congestive heart failure (average age 57 years), three had hypothyroidism (average age 30 years), five had nephrotic syndrome (average age 56 years), and two had Angio-Behçet (average age 28.5 years). As a control, 19 normal subjects (average age 37 years) were studied. Also the unparalyzed sides of the 18 patients with cerebral vascular disease were tested, and five patients with hyperthyroidism (average age 35 years) were tested for contrast with the patients with hypothyroidism.

Each subject was kept quiet in recumbent position for about 20 minutes in the experimental room with the room-temperature at 23–25°C. Then the heart rate and systemic blood pressure (systolic and diastolic) were measured five or six times to ascertain the stabilization of these values.

Pneumoplethysmograph FM-10 (Fukuda Den-shi Co., Ltd.) was used for recording the volume pulses.² Schematic representation of the instrument was shown in Fig. 1. The subject's right forefinger was first inserted into the venous occlusive cuff (1 cm in width and 3 to 4 cm in diameter), and then into the plethysmograph. Plethysmograph was connected to the apparatus which includes the fine pressure-transducer, the meter and the air leakage by the solid rubber tube. Mechanical phenomenon is changed to the electrical one by this apparatus, and then was conducted to the recorder.

Air was rapidly forced into the occlusive cuff through the solid rubber tube by a new instantaneous compressor connecting it to a much

Key Words:

Compliance of the peripheral capacitance vessels
Congestive heart failure
Cerebral vascular disease
Hypothyroidism
Nephrotic syndrome
Angio-Behçet

(Received on February 4, 1978; Accepted on July 7, 1978)

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Fig.1. Schematic representation of the instrument.
 A: venous occlusive cuff,
 B: digital plethysmograph,
 C: new instantaneous compressor,
 D: a much larger cuff (femoral "Manschette"),
 E: pressure transducer,
 F: recorder

larger cuff (20 cm in width, 40 cm in length) in which pressure had been previously adjusted to exactly 60 mmHg. Volume of the finger in-

Fig.2. A more simplified diagram of the systemic system.

creased quickly because the outflow of the venous vessels stopped, and the finger was saturated after two or three pulsations. The digital blood flow was calculated as the inflow of the first beat, that is, from the beginning of the inflow to the time point of one average heart cycle as reported in the previous communication.²

Measurement of the digital blood pressure and calculation of the effective digital mean blood pressure were reported elsewhere from our laboratory.³⁻⁵ According to Poiseuille's law, the peripheral vascular resistance was calculated from both the effective digital mean blood pressure and the digital blood flow.

Guyton⁶ explained the circulatory system by

Fig.3. Recovery of the skin color after removing the press on the skin of the right forefinger. The time constant of this case was 0.18 seconds.

Compliance of the capacitance vessels

Fig.4. Mean and standard error of compliance of the peripheral capacitance vessels in patients with various kinds of edema.

using a simplified electrical analog; that is, vascular resistances are represented by standard electrical resistance symbols; the capacitances, by standard symbols for condensers; the propulsion of blood by the left and right hearts, by standard symbols for batteries.

From this electrical analog of Guyton, it is possible to omit both the resistance of the systemic capacitance vessels and the capacitance of the systemic resistance vessels because the resistance of the systemic capacitance vessels is much smaller than that of the systemic resistance vessels, and at the same time, the capacitance of the systemic resistance vessels is much smaller than that of the systemic capacitance vessels.⁷ Thus, Guyton's simplified electrical analog of the systemic circulation can be further simplified as shown in Fig. 2, because we need to consider only the time when the current flows transiently

through this circuit.

When the skin is pressed for a short time, color disappears from it, but the original color returns immediately after the pressure on the skin is removed. Pressing the skin corresponds to closing the switch of a condenser, and removing the pressure corresponds to opening the switch so that the condenser can be charged with electricity. Changes of the skin color were recorded by means of a solar battery (SS 201) at the ventral part between the proximal and the distal interphalangeal joint of the right forefinger. The curve obtained by this method is shown in Fig. 3. When the time course of change in the skin color was plotted on the semilogarithmic chart, a linear relationship between the time course and the height of the signal was observed. Therefore, it is demonstrated that the curves are exponential. The time constant (τ) could be calculated from

Fig.5. Mean and standard error of the peripheral vascular resistance in patients with various kinds of edema.

these curves.

In the simplified electrical diagram (Fig. 2), the following equation applies:

$$\tau = R \times C$$

in which τ is time constant (sec), R is resistance, and C is capacitance. R is determined from both the effective digital mean blood pressure and digital blood flow and represented as the unit of dyne·sec/cm⁵.⁵ Therefore, C can be calculated and its unit is represented as milliliters per mmHg.

RESULTS

Both mean value and standard error of compliance of the peripheral capacitance vessels in patients with various kinds of edema are shown in Fig. 4 as the bargrams for comparison with those in normal subjects. Regarding unparalyzed

sides of patients with cerebral vascular disease and patients with hyperthyroidism as contrasts, mean value and standard error for these are also shown in this figure. The mean value of compliance of the peripheral capacitance vessels was greatest in cases of hypothyroidism, and in descending order was less in normal subjects, hyperthyroidism, congestive heart failure, the unparalyzed side of the cerebral vascular disease, Anglo-Beçet, the paralyzed side of the cerebral vascular disease, and nephrotic syndrome. There were significant differences between normal subjects and hypothyroidism, normal subjects and congestive heart failure, normal subjects and the unparalyzed side of the cerebral vascular disease, normal subjects and Anglo-Beçet, normal subjects and paralyzed side of the cerebral vascular disease, normal subjects and nephrotic syn-

Fig.6. Relationship between peripheral vascular resistance and compliance of the peripheral capacitance vessels (See text for details).

drome, but no significant difference was found between normal subjects and hyperthyroidism. The mean value for patients with nephrotic syndrome was only about one-fifth that for normal subjects.

Both the mean value and the standard error of resistance of the peripheral resistance vessels in patients with various kinds of edema are depicted in Fig. 5 for comparison with those in normal subjects. The mean value of resistance of the peripheral resistance vessels was the greatest in patients with congestive heart failure, and in descending order was less in hypothyroidism, the paralyzed side of the cerebral vascular disease, nephrotic syndrome, the unparalyzed side of the cerebral vascular disease, Anglo-Beçet, normal subjects, and hyperthyroidism. There were significant differences between normal subjects and congestive heart failure, normal subjects and the paralyzed side of the cerebral vascular disease, normal subjects and hypothyroidism, normal subjects and nephrotic syndrome, normal subjects and the unparalyzed side of the cerebral vascular disease, but no significant differences were found between normal subjects and Anglo-Beçet, normal subjects and hyperthyroidism.

A relationship between peripheral vascular resistance and compliance of the peripheral capacitance vessels was observed in all patients with various kinds of edema as shown in Fig. 6. No

remarkable relation was found between them, but the stronger the peripheral vascular resistance, the less the compliance of the peripheral capacitance vessels, so generally speaking, there was an inverse correlation between them.

DISCUSSION

In order to know compliance of the peripheral capacitance vessels and resistance of the peripheral resistance vessels, patients with various kinds of edema, for example, congestive heart failure, nephrotic syndrome, paralyzed sides of the cerebral vascular disease, hypothyroidism, and Anglo-Beçet were studied for this report. As the contrasts, normal subjects, unparalyzed sides of the patients with cerebral vascular disease and the patients with hyperthyroidism were also studied.

According to our previous result,¹ compliances of the peripheral capacitance vessels were smaller and venous pressures were higher in patients with congestive heart failure than in normal subjects when both compliances and venous pressures were measured simultaneously, and the mean value of compliance in the former was only half of that in the latter. In addition to this result, compliances of the peripheral capacitance vessels decreased gradually in accordance with the increase in pressure of the brachial vein.⁸ Therefore, the decrease in compliance in patients with congestive heart failure was considered to be not

due to an organic change but to a functional change of the vessels caused by distention, because the value of compliance became normal when the congestion of blood had disappeared and the venous pressure had decreased in these patients after treatment with digitalis and other drugs.

The plasma protein concentration is decreased below normal (hypoalbuminuria) in patients with nephrotic syndrome because of massive proteinuria. Five patients with nephrotic syndrome in this study presented proteinuria of 3.4–13.6 g/day and the plasma protein concentration was 4.6 (3.7–5.6) g/dl before treatment. At this stage, the venous pressure was 79 (64–101) mm H₂O and compliance of the peripheral capacitance vessels was 0.14 (0.055–0.19) ml/100 ml of tissue/mmHg (Fig. 4). Though the patients were not improved satisfactorily even after treatment with steroid hormone, diuretics and other drugs had been continued several weeks, the proteinuria decreased, the plasma protein concentration increased and the venous pressure decreased only within normal range. The averages and distribution ranges of these values were 1.7 (trace – 3.7) g/day, 5.5 (5.1–5.8) g/dl, and 68 (53–92) mm H₂O respectively. However, compliance of the peripheral capacitance vessels increased and the average and distribution range was 0.27 (0.11–0.40) ml/100 ml of tissue/mmHg after treatment. Therefore, the decrease in compliance of the peripheral capacitance vessels in patients with nephrotic syndrome is attributed to the hypoproteinemia, especially to the hypoalbuminemia.

The decrease in plasma albumin and consequent fall in the plasma colloid osmotic pressure results in an increased transudation of fluid from the bloodstream to extravascular spaces. As the plasma colloid osmotic pressure decreases in severe nephrosis, the plasma volume likewise decreases. The decrease in plasma volume is caused by a shift of fluid into the tissue spaces, which become filled with fluid to the point where the interstitial fluid pressure becomes positive. The positive interstitial fluid pressure presses the peripheral vessels. Therefore, it can be explained by this factor that compliance of the peripheral capacitance vessels decreases in patients with nephrotic syndrome.

On the other hand, compliance of the peripheral capacitance vessels in patients with hypothyroidism is greater than that in normal subjects. Hypothyroidism is always accompanied with

myxedema, nonpitting edema, in which the total quantity of mucopolysaccharide is greatly increased. This increases the bulk of elastically recoiling substance and produces a gel-like consistency within the interstitial spaces.⁹ According to Guyton et al⁹, the gel brings two important physical characteristics that influence the dynamics of interstitial fluid: (1) elastic support for the cells and other tissue elements and (2) restriction of movement of fluid through the tissue. The time constant measured in patients with hypothyroidism is far greater than that of patients with other diseases, though the peripheral vascular resistance in these patients is greater. Among all patients with the various kinds of edema, compliance of the peripheral capacitance vessels is found to have the largest value in patients with hypothyroidism. The reason why it has the largest value may be the increased elasticity of tissue under the skin and/or of the peripheral capacitance vessels wall themselves.

It is said that in patients with hyperthyroidism, cardiac output is frequently above normal with a rapid or normal circulation time in spite of an elevated venous pressure. However, mean value and distribution range of the venous pressure was 87 (76–97) mm H₂O in the five patients with hyperthyroidism measured in this study and it was not so elevated. The condition mentioned above is one of several examples of a so-called “high-output failure”. Even though cardiac output is elevated, it is unable to satisfy the high metabolic requirement of the body. This is attributed to the decreasing of the vascular tone, by the fact that compliance of the peripheral capacitance vessels is relatively large, and by the fact that the peripheral vascular resistance is at its weakest, though cardiac output is above normal and venous pressure is slightly elevated.

Two patients with Angio-Behçet were tested in the same way as the patients with edema, especially the upper half of their bodies, because it was confirmed by the veno-angiograms that they had stenosis of the superior caval vein, tortuosity, enlargement, and by-pass of the upper stream veins. Therefore, the venous pressures measured from the cubital vein were far higher than those of normal subjects, for example, 388 mm H₂O in one case and 440 mm H₂O in another case. Thus, compliance of the peripheral capacitance vessels is very small in patients with Angio-Behçet.

Compliance of the peripheral capacitance

vessels of the paralyzed side of 18 patients with cerebral vascular disease was compared with that of normal subjects and that of the unparalyzed side of these patients. Compliance of the paralyzed side is less than that of the unparalyzed side in patients with cerebral vascular disease, and that of both sides is less than that of normal subjects. The same results were reported by Oginio.¹⁰ The venous pressures were not measured in all patients with cerebral vascular disease, because it seemed that they were not elevated. A reason why compliance of the paralyzed side is less than that of the unparalyzed side in patients with cerebral vascular disease is explained as follows: it is thought that motor and premotor areas in the cerebral cortex are also the central representation of autonomic functions, and impulses from there influence the vasomotor center in the reticular substance of the lower third of the pons and upper two-thirds of the medulla. This may produce an inhibitory effect on the sympathetic vasoconstrictor center. These fibers from the cortex to the vasomotor center are damaged simultaneously with the pyramidal and extrapyramidal tracts in the internal capsule when patients have an attack of apoplexy. Therefore, the vascular tone of small vessels increases because impulses from the sympathetic vasoconstrictor center are reinforced by disinhibitory impulses from the central nervous system.

Compliance of the unparalyzed side in patients with cerebral vascular disease was also smaller than that of normal subjects. Compliance of the peripheral capacitance vessels decreases usually in accordance with age in normal subjects, for example, the average value of compliance is 0.72 ml/100 ml of tissue/mm Hg in 21–30 years group, 0.63 in 31–40 years group, 0.59 in 41–50 years group and 0.35 in 51–60 years group in our present data observed on 36 normal subjects.¹¹ Therefore, this may be attributed by the difference of age between patients with cerebral vascular disease and normal subjects, because the age was 58 years old in the former and 37 years old in the latter group in this study.

SUMMARY

1) The mean value of compliance was greatest in hypothyroidism, and in descending order was

less in normal subjects, hyperthyroidism, congestive heart failure, the unparalyzed side of the cerebral vascular disease, Angio-Behçet, the paralyzed side of the cerebral vascular disease, and nephrotic syndrome.

2) The mean value of resistance was the greatest in patients with congestive heart failure, and in descending order was less in hypothyroidism, the paralyzed side of the cerebral vascular disease, nephrotic syndrome, the unparalyzed side of the cerebral vascular disease, Angio-Behçet, normal subjects, and hyperthyroidism.

3) Generally speaking, the greater the resistance of the peripheral resistance vessels, the less is the compliance of the peripheral capacitance vessels.

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