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A comparative study of dynamic CT and ultrasonic pulsed Doppler method for estimation of the portal blood flow.

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A comparative study of dynamic CT and ultrasonic pulsed Doppler method for estimation of the portal blood flow.*

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Abstract

A new dynamic CT method for evaluating the portal blood flow is described. Thirty healthy volunteers were injected with non-ionic hypo-osmotic iodine contrast medium to estimate the portal blood flow. Time density curves (TD-curves) for the abdominal aorta and the main trunk of the portal vein were determined on the basis of data obtained by dynamic CT. From the TD-curves, portal blood flow coefficient and circulation time to flow into the portal vein (P-P time) were calculated. More detailed data of the TD-curves could be obtained by the new dynamic CT than by the previous methods. Subjects were simultaneously studied by an ultrasonic pulsed Doppler method which has been clinically accepted. There was a significant correlation between our dynamic CT method (portal blood flow coefficient) and the ultrasonic pulsed Doppler method concerning the measurement of portal blood flow. Therefore, it may be concluded that this CT method is reliable and clinically acceptable.

KEYWORDS: dynamic CT, portal blood flow, ultrasonic pulsed Doppler method

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A Comparative Study of Dynamic CT and Ultrasonic Pulsed Doppler Method for Estimation of the Portal Blood Flow

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A new dynamic CT method for evaluating the portal blood flow is described. Thirty healthy volunteers were injected with non-ionic hypo-osmotic iodine contrast medium to estimate the portal blood flow. Time density curves (TD-curves) for the abdominal aorta and the main trunk of the portal vein were determined on the basis of data obtained by dynamic CT. From the TD-curves, portal blood flow coefficient and circulation time to flow into the portal vein (P-P time) were calculated. More detailed data of the TD-curves could be obtained by the new dynamic CT than by the previous methods. Subjects were simultaneously studied by an ultrasonic pulsed Doppler method which has been clinically accepted. There was a significant correlation between our dynamic CT method (portal blood flow coefficient) and the ultrasonic pulsed Doppler method concerning the measurement of portal blood flow. Therefore, it may be concluded that this CT method is reliable and clinically acceptable.

Key words : dynamic CT, portal blood flow, ultrasonic pulsed Doppler method

The hepatic blood flow is maintained by a dual supply: 25 % of the blood flow is supplied by the hepatic artery and 75 % is supplied by the portal vein in the normal subjects. Knowing the state of the hepatic blood flow in patients with diffuse liver diseases and hepatoma is important for understanding condition of patients and planning therapeutic schedules.

Various methods have been proposed and tried to evaluate the hepatic blood flow or the portal blood flow: methods using bromsulphalein (BSP) and indocyanine green (ICG) (1,2), the nuclear medicine method (3-8), and an ultrasonic pulsed Doppler method (9-12). A dynamic CT method for diagnosis of liver disease has also been tried, but only the dynamics of contrast medium in the parenchyma could be evaluated (13-15). Each image required 4-10 sec to scan by the previous dynamic CT methods (13-15).

The new dynamic CT method using TCT900S and an ultrasonic pulsed Doppler method were performed on thirty volunteers for evaluating the portal blood flow.

Subjects and Methods

Portal blood flow was examined in 30 healthy volunteers (16 men and 14 women, mean age of 32 ± 6 and 39 ± 13 years) whose liver function test were normal and

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did not have a past history of liver diseases. The volunteers signed consent forms of this examination. In this study, a new dynamic CT using TCT900S (Nutate/Rootate, Slip-ring, Toshiba, Tokyo, Japan) and an ultrasonic pulsed Doppler method (Sonolayer 270A, Toshiba, Tokyo, Japan) were performed on these volunteers. Results taken from two methods were compared statistically. Scanning time can be three to four times shorter and much more data can be obtained in a given period because of higher contrast and spatial resolution capacity of the TCT900S than previous CT scanners.

Liver dynamic CT method/portal blood flow coefficient and P-P time. Plain CT was conducted in advance to decide the position of the subjects so that the abdominal aorta and the main trunk of the portal vein could simultaneously be observed in a specified slice. As a rule, a venous route was secured by placing an 18G elastic needle in the right cubital vein of the subjects. Starting at 4 sec after beginning of a bolus injection of non-ionic hypo-osmotic contrast medium (0.8 ml/kg BW), scanning was performed while the subjects held their breath for 57 sec. Eleven images of 1 sec scanning at 2

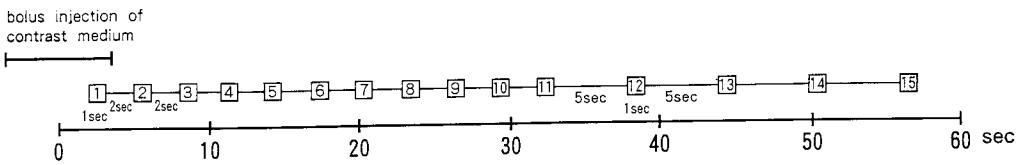

Fig. 1 Scanning program for dynamic CT study for main trunk of the portal vein and the abdominal aorta. After a bolus injection of contrast medium, 15 consecutive images of the same slice were obtained within 57 sec. Time density curves were obtained by scanning time and CT numbers for the appropriate region of interest of the main trunk in the portal vein and the abdominal aorta.

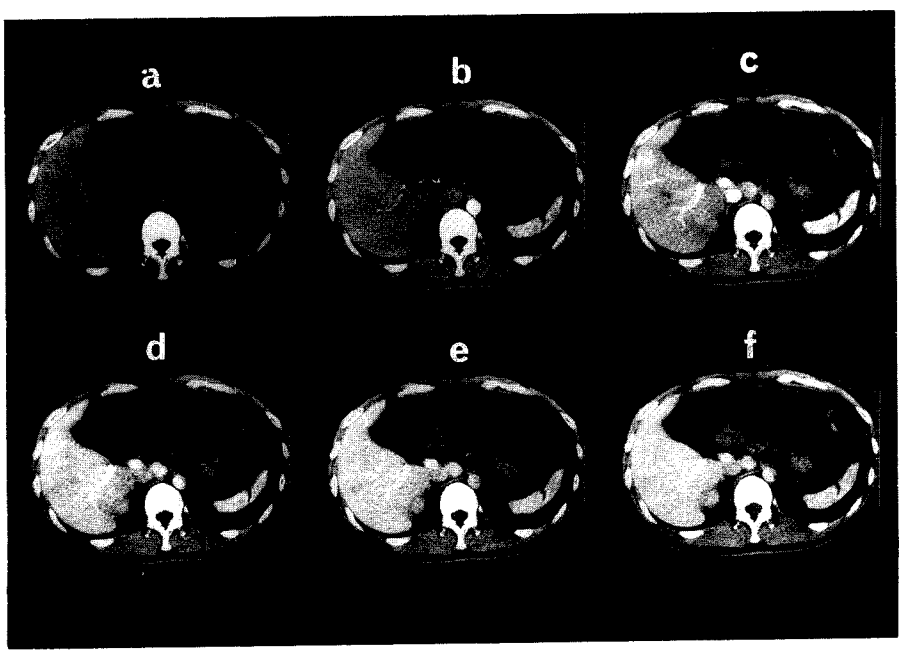

Fig. 2 Dynamic CT images of the main trunk of the portal vein and the abdominal aorta. Starting at 4 sec after a bolus injcection of non-ionic hypo-osmotic contrast medium, 11 images of 1 sec scanning at 2 sec intervals and 4 images of 1 sec scanning at 5 sec intervals were obtained; *i.e.*, 15 images were taken during 57 sec period. a ~ f, the images taken at different times after the start of the scanning; a, at 3 sec; b, at 9 sec; c, at 21 sec; d, 27 sec; e, 33 sec; and f, 39 sec.

sec intervals and 4 images of 1 sec scanning at 5 sec intervals were obtained; *i. e.*, 15 images were taken during a 57 sec scanning poriod (Figs. 1, 2).

Time density curves (TD-curve) of the abdominal aorta and the main trunk of the portal vein were determined by plotting the CT numbers on the vertical axis and by plotting scanning times on the horizontal axis. The CT numbers were obtained by tracing the region of the interest (ROI) that appeared in the display.

These curves were corrected to gamma variate curves by a least square method using a computer program in the TCT900S. Starting and ending points for fitting the curve were determined by the points at 10 % and 70 % of the highest CT numbers respectively, according to the method of Fijikawa *et al.* (14.15).

Portal blood flow coefficient was determined by obtaining the ratio of the area of the TD-curve of the aorta (Ao) to the area of the main trunk of the portal vein

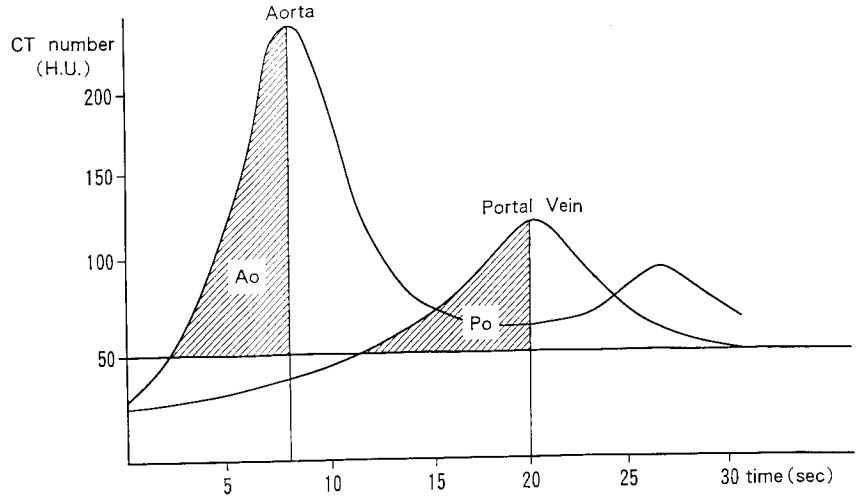

Fig. 3 Portal blood flow coefficient. Ao is an area covering under the TD-curve of the abdominal aorta from the start to peak of the curve and Po is an area of TD-curve of the portal vein. CT numbers less than 50 H.U. were omitted. Portal blood flow coefficient was calculated from the ratio of Ao to Po.

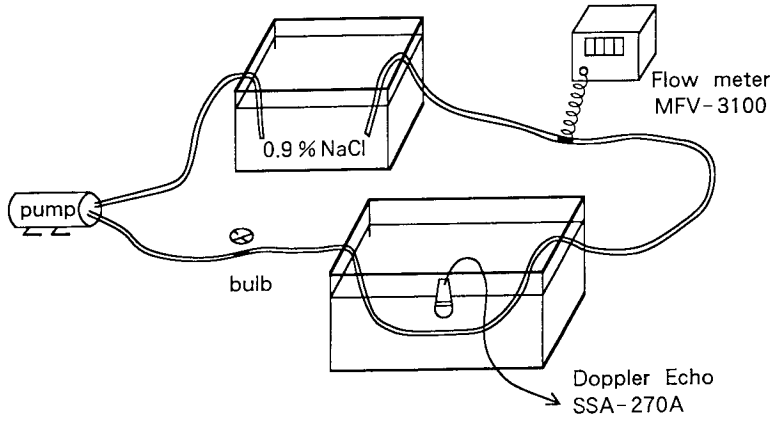

Fig. 4 Schematic diagram of experimental blood flow. A blood flow model was made in advance using an ultrasonic pulsed Doppler method and a basic experiment was carried out.

(Po). Each area of Ao and Po is shown in Fig. 3. As shown in Fig. 3, CT numbers less than 50 H.U. were omitted when calculaing the areas of Ao and Po. The time required for the contrast medium to reach a peak in the abdominal aorta and the main trunk of the portal vein was determind from the gamma variate curve. Peak to peak time (P-P time) was calculated by the determined curves. P-P time was considered to represent the circulation time during which contrast medium injected by bolus injection flowed into the portal vein via the aorta.

Ultrasonic pulsed Doppler method/maximum portal blood flow velocity (PF_{max}), mean portal blood flow velocity (PF_{mean}) and mean portal blood flow volume (PV_{mean}). PF_{max} was obtained using Sonolayer 270A according to an ultrasonic pulsed Doppler method. The equation to calculate PF_{max} is as follows:

$$PF_{max} = C \times f_d / 2\cos\theta \times f_0,$$

where C represents the rate of transmission of ultrasonic waves in the body; f_d, deviated ultrasonic wave transmission frequncy; and f_0, ultrasonic wave transmission frequency; C was 1500m/sec and f_0 was 3.75 MHz, respectively. θ is the angle formed by a Doppler beam and blood flow.

To determine PF_{mean}, a blood flow model was made in advance using the ultrasonic pulsed Doppler method and a basic experiment was carried out (Fig. 4). Physiological saline was allowed to flow through a vinyl tube to obtain actual flow volume by an electromagnetic flow meter (Nihon Koden, Co., Tokyo, Japan). The actual PF_{mean} was obtained by calculating a ratio of actual volume to a cross-sectional area of the vinyl tube. PF_{max} was obtained using the ultrasonic pulsed Doppler method. As flow velocity depends upon the angle formed by a Doppler beam against the long axis of the portal vein, various values were obtained in the different angles. From our experiment, PF_{mean}/PF_{max} was determined to be 0.70 when the angles were between 50–70 degrees. Therefore, an approximate value of PF_{mean} was obtainable. PV_{mean} was calculated by the follwing equation:

$$PF_{mean} \times \pi r^2 \times 60,$$

where r represents the radius of the portal vein in which PF_{mean} was measured.

Results

The values of each parmeter in this study are shown in Table 1. The portal blood flow coefficient and P-P time obtained by our dynamic CT method were compared with the PF_{mean} and PV_{mean} obtained by the ultrasonic pulsed Doppler method and all the results obtained were studied according to the ages and sex of the subjects. There were significant correlation between portal blood flow coefficient and PF_{mean}, and between portal blood flow coefficient and PV_{mean}. But there were no significant correlations between either P-P time and PF_{mean}, or between P-P time and PV_{mean} (Figs. 5, 6). Gender was not significant in each parameter; portal blood flow coefficient, PF_{mean} and PV_{mean} were slightly decreased, and P-P time was significantly pro-

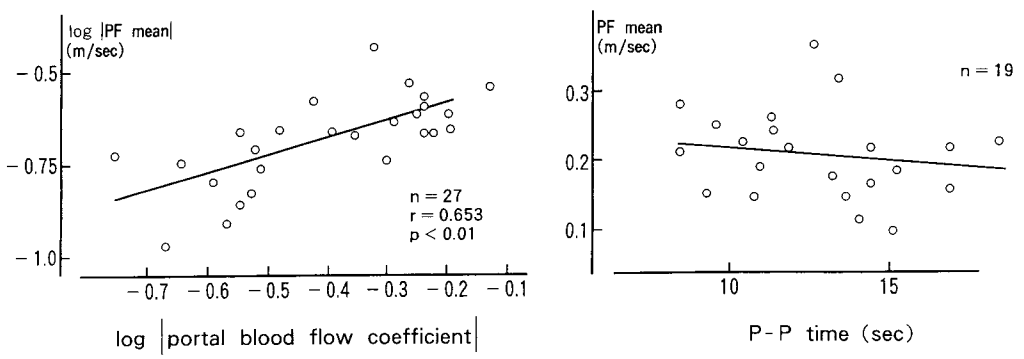

Fig. 5 Correlation between portal flow coefficient, mean flow velocity (PF_{mean}) and peak to peak time (P-P time). Significant correlation was found between portal blood flow coefficient and PF_{mean}. But no correlation was found between portal blood flow coefficient and P-P time.

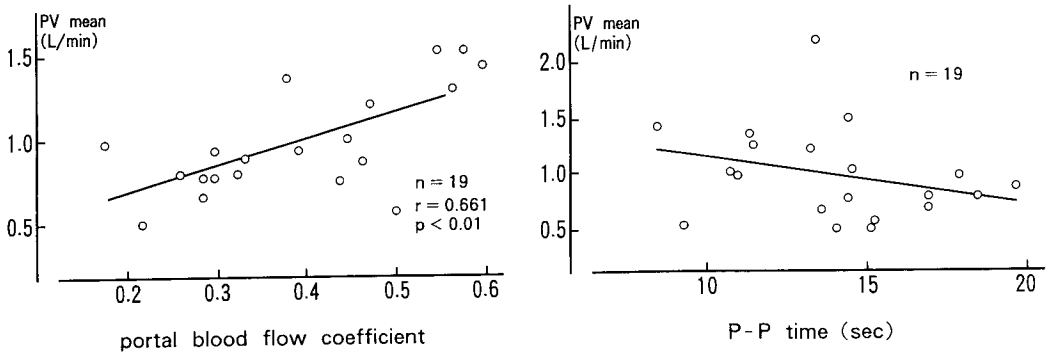

Fig. 6 Correlation between portal blood flow coefficient, mean flow volume (PV_{mean}) and P-P time. Significant correlation was found between portal blood flow coefficient and PV_{mean}. There was no significant correlation between P-P time and PV_{mean}. P-P time : See Fig. 5.

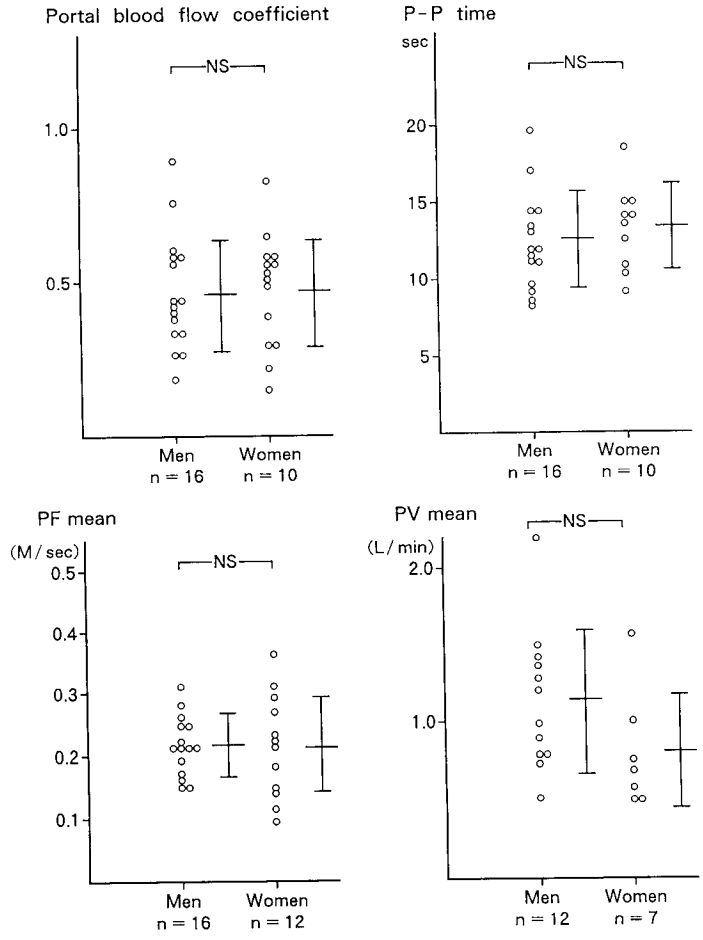

Fig. 7 Correlation between sex and each parameter. Gender was not a significant variable. PF mean, P-P time, PV mean : See. Figs 5 and 6.

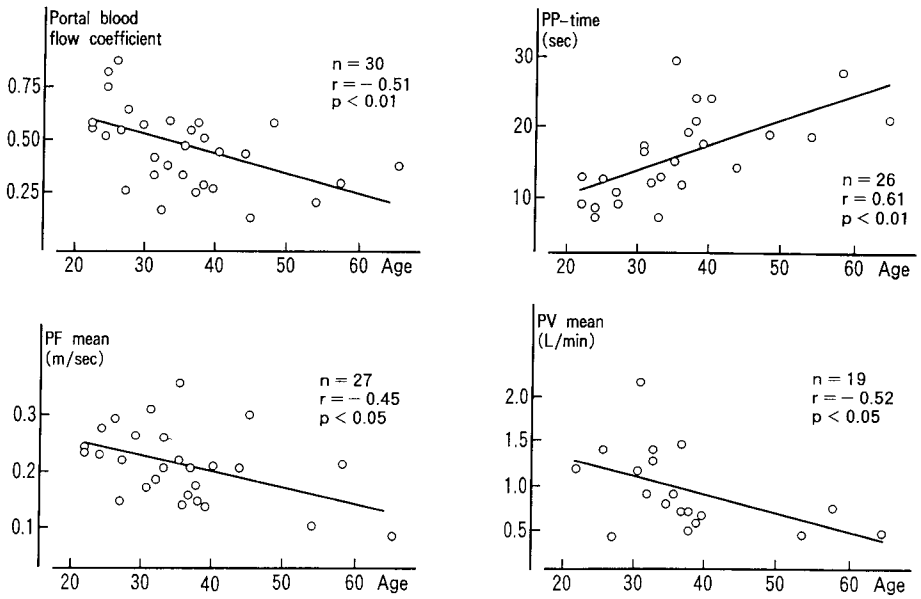

Fig. 8 Correlation between ages and each parameter. Portal blood flow coefficient, PF_{mean} and PV_{mean} were slightly decreased, and P-P time was significantly prolonged as the ages increased. PF mean, PV mean, P-P time : See Figs 5 and 6.

Table 1 Results obtained for different parameters

Parameters	Mean ± SD
Portal blood flow coefficient	0.46 ± 0.18
Peak to peak time (P-P time) (sec)	12.90 ± 3.01
Mean flow velocity (PF_{mean}) (m/sec)	0.21 ± 0.06
Mean flow volume (PV_{mean}) (L/min)	1.01 ± 0.45

longed as the ages increased (Fig. 8).

Discussion

Various methods have been used to measure the portal blood flow such as the methods of nuclear medicine (3–8), an ultrasonic pulsed Doppler method (9–12), and dynamic CT (13–15).

The ultrasonic Doppler method was first applied clinically by Satomura *et al.* (16) in 1955. A variation of the ultrasonic pulsed Doppler method enabled us to measure deep blood flow (17,18). Due to the recent progress, the ultrasonic pulsed Doppler method has been used not only for circulatory diseases, but also for liver diseases, especially cirrhosis of the liver (9–12). According to Doppler measurements of Moriyasu *et al.* (10,11) and Tanabe *et al.* (12), both mean velocity and volume of the portal vein were less than our data. Different methods of calculation, measurement techniques and Doppler apparatus may have caused the discrepancy in the results.

Sako *et al.* (13) reported the method of "aortico-hepatico ratio" for evaluating hepatic blood flow by dynamic CT. They obtained the time density curves for the abdominal aorta and the liver parenchyma. Then liver dyeing concentration was calculated from the following ratio:

$$100\,H_p/A_p(H_{pt}-A_{pt}),$$

where H_p represents peak CT numbers of the liver, A_p, peak CT numbers of the abdominal aorta, H_{pt}, peak time of the liver, and A_{pt}, peak time of the aorta. Fujikawa *et al.* (14,15) used three parameters such as rise time (RT), decay time (DT), and corrected first moment (MC) to evaluate the dynamics of the contrast medium in the liver in diffuse liver diseases.

In this study, portal blood flow coefficient and P-P time calculated by dynamic CT were compared with PF_{mean} and PV_{mean} measured by the ultrasonic pulsed Doppler method. The poral blood flow measured by dynamic CT (portal blood flow coefficient) correlated well with that measured by the ultrasonic pulsed Doppler method (PF_{mean}, PV_{mean}).

We found out the effectiveness of our devised dynamic CT method for evaluating the portal blood flow by comparing our results with those obtained by other dynamic CT method. Our method requires three to four times less scanning time and give less motion artifact and much more data in a fixed period, because the TCT900S has higher contrast and spatial resolution capacity than other scanners (13–15).

The gamma variate curve (Fig. 9) used in this study was expressed by the following equation:

$$C(t)=k(t-A_T)^{\alpha}\cdot e^{-(t-A_T)/\beta},$$

where $C(t)$ represent increasing values of CT number, t, time after the start of the scanning, k, constant scale factor, α and β, fitting parameters, and A_T, arrival time of contrast medium. The gamma variate curve has frequently been used for flow measurements using pigments and radioactive materials, such as cardiac output and shunting ratio of the congenital heart diseases (19–22). The gamma variate curve is useful to eliminate the recirculating factor in the flow measurement. The reason why the peak time of the TD-curve of the portal vein was determined at 12 sec after the peak of the TD-curve of the aorta was based on the present data and Hirata's study (8). According to both studies, peak time of the portal vein was usually at 12 sec after the peak time of the aorta. On the other hand, TD-curves of the aorta and the portal vein were considered to depend on the cardiac output. To minimize the differences of the cardiac output by individuals, we used the portal blood coefficient by calculating Po/Ao.

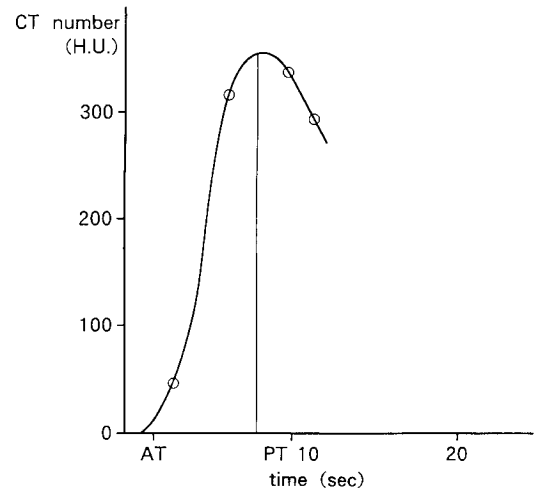

Fig. 9 Gamma variate curve. The method to obtain this curve: See text.

Differences in ages were found in each parameter, but not in sex in this study. As ages increased, the values of PF_{mean} and PV_{mean} slighly decreased, while P-P time significantly prolonged. PF_{mean} and PV_{mean} were consistent with those by Fujimiya *et al.* (23) who reported the reason for decreased values in the aged was due to decreased cardiac output (24, 25), but they did not mention P-P time. We assumed that P-P time mainly expressed the circulation time during which the contrast medium flowed into the main portal vein via the abdominal, aorta, splenic artery, spleen, and splenic vein. Therefore, prolonged P-P time may be due to increased blood vessel resistance and decreased portal blood flow velocity as well as the decreased cardiac ontput.

We suggest that this dynamic CT method would be more useful and clinically more applicable than the previously reported methods, because it is reliable and data of the portal blood

flow may be obtained more quickly.

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References

1. Bradly SE, Ingelfinger FJ and Bradly GP: The estimation of hepatic blood flow in man. J Clin Invest (1945) **24**, 800–807.
2. Leevy CM, Mendenhall CL, Lesko W and Howard MM: Estimation of hepatic blood flow with indocyanine green. J Clin Invest (1982) **41**, 1169–1179.
3. Kashiwagi T, Kamada T and Abe H: Dynamic study on the portal hemodynamics by scintiphotosplenoportography: The visualization of portal venous system using 99mTc. Gastroenterology (1974) **67**, 668–673.
4. Sarpar R, Fajman WA, Rypins EB, Henderson JM, Taran YA, Galambos JT and Warren WD: A noninvasive method for measuring portal venous/total hepatic flow by hepatosplenic radionuclide angiography. Radiology (1981) **141**, 179–184.
5. Rypins EB, Fajman W, Sarpar R, Henderson JM, Kutner MH, Taran YA, Galambos JT and Warren WD: Radionuclide angiography of the liver and spleen. Am J Surg (1981) **142**, 574—579, ND.
6. Castell DD, Grace ND, Wenner MH, Chalmers TC and Moore EW: Evaluation in portal hypertension in hepatic circulation: A new method using Xenon. Gasteroenterology (1969) **57**, 533–541.
7. Tonami N, Nakajima K, Hisada K, Tanaka N, Kobayashi K: A noninvasive method for evaluating portal circulation by administration of Tl-201 per rectal. J Nucl Med (1982) **23**, 965–972.
8. Hirata K, Endo H, Nishina K, Shimamura J and Inoue T: Analysis of hepatic blood flow by Tc-99m phytate scintigraphy in various liver diseases. Kanzou (1984)**25**, 74–78 (in Japanese).
9. Gill RW: Pulsed Doppler with B-mode imaging for quantitative blood flow measurement. Ultrasound Med Biol (1979) **5**, 223–225.
10. Moriyasu F, Nishida O, Ban N, Nakamura T, Sou Y, Ochi J, Miura K, Sakai M, Tsukada H, Miyake T and Uchino H: Quantitative measurement of the portal blood flow in patients with various liver diseases studied using an ultrasonic duplex system. Kanzou (1985) **26**, 93–98 (in Japanese).
11. Moriyasu F, Ban N, Igarashi A, Yamamoto T, Shiomura T, Suzaki T, Kanematsu Y, Okazaki K, Miyake T and Uchino H: A new method of transcutaneous method of portal blood flow by an ultrasonic "Duplex" system composed of a pulsed Doppler flowmeter and a linear-type real time B mode electroscanner. Kanzou (1983) **24**, 537–544 (in Japanese).
12. Tanabe T, Tobe K, Koide N, Morichika N, Tuchiya T, Yoshida K, Nagashima H and Haraoka S: Blood flow dynamics studied by the ultrasonic pulsed Doppler method. Kanzou (1985) **26**, 93–98 (in Japanese).
13. Sako M, Watanabe H, Ohtsuki S and Yokokawa S: An approach to hepatic blood flow evaluation by dynamic CT. Nihon Housyasen Igakukai Zasshi (1983) **43**, 1370–1375 (in Japanese).
14. Fujikawa K, Inagawa A, Yokoyama T, Iwamoto T, Katayama Y, Mori M, Itou K and Katsuta S: Utility of dynamic computed tomography in diffuse liver diseases. Kanzou (1985) **26**, 905–912.
15. Fujikawa K: Clinical studies on utility of dynamic computed tomography in diagnosis in diffuse liver diseases. Hiroshima Daigaku Igaku Zasshi (1985) **33**, 1319–1340 (in Japanese).
16. Satomura S: Ultrasonic Doppler method for the inspection of cardiac function. J Acoust Soc Am (1957) **29**, 1181–1185.
17. Barker DW: Pulsed ultrasonic Doppler blood flow sensing IEEE trans on sonics and ultrasonic. Semin Ultrasound **17** (1970) 170–185.
18. Nanda NC: Doppler Echocardiography, Igaku Shoin (1984) New York-Tokyo.
19. Evans RN: Two comments on the estimation of blood flow and central volume from dye-dilution curves. J Appl Physiol (1959) **14**, 457.
20. Thompson HK, Starmer CF, Wholen RE and McIntosh HD: Indicator transit time considered as a gamma variate. Circ Res (1964) **14**, 502–515.
21. Starmer CF and Clark DO: Computer computation of cardiac output using the gamma function. J Appl Physiol (1970) **28**, 219–220.
22. Maltz D and Trevers S: Quantitative radionuclide angiocardiography-determination of Qp: Qs in children. Circulation (1973) **47**, 1049–1056.
23. Fujimiya M, Inoue H, Chikamochi N, Nakajyo S, Nakagawa M, Baba T and Hosoda S: Correlation between aging and portal blood flow measuring by ultrasonic pulsed Doppler method. Nihon Rounen Igakukai Zasshi (1984) **21**, 150 (in Japanese).
24. Matstushita T, Kuramoto T, Nakahara K, Toda G, Takahashi R and Murakami M: The cardiovascuiar system: Indices of aging. Nihon Rounen Igakukai Zasshi (1986) **21**, 197–201 (in Japanese).
25. Brandfouberer M, Landowre and Shock NW: Changes in cardiac output with age. Circulation (1955) **11**, 537.

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