Simple Technique in the Measurement of Liver Volume

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Abstract

The measurement of liver volume is considered to be a highly effective prediction of post-operative liver failure in hepatectomized patients and selection of the proper size of the liver obtained from a living donor. The aim of the paper was therefore, to develop a simple, inexpensive and practical technique for the measurement of liver volume.

Computerized tomography (CT) imaging sections were used to measure sectional areas of liver sections *via* a graphic program. The volumes of livers were then calculated from the combined sectional areas using mean-area, end-area, and prismodial methods. The calculated volumes of livers obtained were compared to those manually measured in a water replacement technique.

The findings of the results indicated that the liver volume could be estimated from CT scan films with typically less than 5 per cent difference compared to the manual method.

Key word : Computerized Tomography, Liver Volume, Mean-Area, End-Area, Prismodial Method

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Post-operative liver failure is one of the major causes of death in patients who have had a hepatectomy. It usually occurs because their liver functional reserve is inadequate to support their physiologic function after they have an operation. According to previous studies(1,2), the measurement of liver volume can be used to determine the status of liver functional reserve of patients before the occurrence of hepatectomy(2). In addition, measurement of liver volume can be used in the field of liver trans-

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plantation to assess graft sizes for living-related liver transplantation. However, this technique has not yet been received widely in clinical application. This is possibly due to very complicated and expensive instruments.

Given this background, the main objective of the present study was to develop a simple method to estimate a sector of liver volume from simple CT scan films.

MATERIAL AND METHOD

This a retrospective study on twelve patients admitted to Rajavithi Hospital for hepatectomy from January 2000 to December 2000 were selected for the study. All of them obtained a different degree of hepatic resection of more than one segment according to the liver anatomy of Couinaud. As indicated in Table 1, there were 2 patients had a left hepatectomy (Couinaud's segments 2, 3 and 4), 6 patients had a right hepatectomy (Couinaud's segment 5, 6, 7 and 8), 2 patients had a right tri-segmentectomy (Couinaud's segment 1, 4, 5, 6, 7 and 8) and 2 patients had liver transplantation. There were 8-male and 4-female patients. The ages of the patients ranged from 4 years to 66 years. Their liver functions were assessed by using Child's classification. It could be categorized to Child class A (8 cases), Child class B (2 cases) and Child class C for liver transplantations (2 cases).

After the population used for the study was selected, the program of work was then divided into three phases:

First, within four weeks prior to the operation of the patients, their livers were monitored by scanning with contrast Computed Tomography (CT) with a 1-cm interval. The scanning started at the level of the diaphragm until the whole liver was observed. During the operation, part of the resected liver of the patient was removed and its volume was then measured directly by water replacement technique and recorded. After the operation, the surgeon marked the line of hepatectomy on the CT scan film. Then the scanning films with an identification of section number were obtained and their images were taken using a digital camera with an imaging size of 1280 x 960 pixels. Fig. 1 shows the cut section of the liver from patient no 6.

Second, the selected liver area of each scanning image was determined using a GIS (The Geographics information System) computer program, which is normally used in collecting, managing and analyzing data from geographic maps and also satellite pictures. The liver volume was then interpolated from cumulative liver areas being measured. As evenly interval sections of the liver area were collected, the Newton-Cotes formulas were applied to determine the volume of the liver(4). These included mid point (end area), trapezoidal (mean area), and Simpson's rules (prismoid area). The mid-point and trapezoidal rules are easy to operate and good for the numerical solution of ordinary differential equations, whereas Simpson's rule gives an acceptable result when applied to any function whose third derivative is zero.

Third, the results obtained from the first and second phases were compared and analyzed.

Statistical analysis

Samples were collected from the 12 patients operated on between January 2000 and December

Table 1. Characteristics of patients.

Patient	Sex	Age	Child's classification	Diagnosis	Procedure
1	Male	51	B	Hepatocellular carcinoma	Lt.Hepatectomy
2	Female	48	A	Giant hemangioma	Tt.Hepatectomy
3	Female	60	A	Hepateocellular carcinoma	Rt.Hepatectomy
4	Male	55	B	Hepateocellular carcinoma	Rt.Hepatectomy
5	Male	58	A	Cystadenocarcinoma	Rt.Hepatectomy
6	Female	44	A	Peripheral Cholangiocarcinoma	Rt.Hepatectomy
7	Male	46	A	Hepatocellular carcinoma	Rt.Hepatectomy
8	Female	54	A	Hilar Cholangiocarcinoma	Rt.Tri-segmentectomy
9	Male	62	A	Intrahepatic bile duct stone	Rt.Tri-segmentectomy
10	Male	61	A	Hilar Cholangiocarcinoma	Rt.Tri-segmentectomy
11	Male	42	C	Cirrhosis	Liver Transplantation
12	Male	4	C	Budd-Chiari syndrome	Liver Transplantation

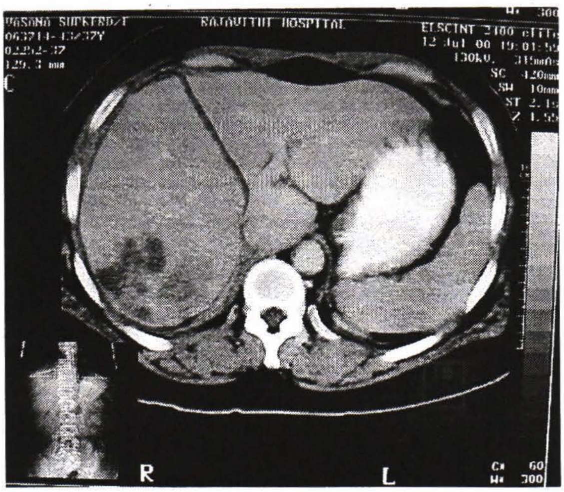

Fig. 1. Marking the line of hepatectomy on the CT scan film.

2000. The relationships between results obtained from the second and third phases of the present study were analyzed by using linear regression (SPSS program). Significance of the correlation was then tested by *t*-test and *f*-test with the selection of $p < 0.05$.

RESULTS

Since the imaging sizes of CT scan films were taken with a resolution of 1280 x 960 pixels, the resolution of files obtained from the GIS program was found to be similar. At this stage, the authors assume that an error obtained from the resolution was negligible. Then the selected area of the liver was measured directly from automatically counting pixels within the area. The results obtained were recorded and then transferred to a database file. Table 2 shows the selected areas of liver of patient no 6 with respect to the corresponding sections of the CT scan films. It can be seen that the interval of scanning section was very small, compared to the selected area measured. It can be implied that the Newton-Cotes formulas are theoretically suitable for the study. Similar trends were observed for the other patients.

The volumes of selected liver obtained from 12 patients were interpolated from the area under the graph using mid point, trapezoidal, and Simpson's rules. The results are given in Table 3 with their corresponding results measured from the water replacement technique. It is interesting to note that the smallest relative errors for all cases were found to be less than ±5 per cent. In addition, three model analyses of all patients are given in Table 4. It can be seen that all the models have a close linear relationship with reference. Volumes calculated by Prismoidal area were also found to have a significant coefficient of correlation less than 0.05 for both *t*-test and *f*-test. However, the standard error of estimates for all models was still high.

When all the results were closely investigated, it was found that the liver volume interpolated by all three methods could be used for most of the patients. Accordingly, further attempts have been made to find the relationships between a selected sectional area of the liver and CT scan section in order to find the correct interpolated methods. The relationships were then approximated using Lagrange polynomial. As expected, the selected liver volumes obtained from mean-area methods were found to be close to the corresponding reference liver volumes when the degree of derivatives of the relationships

Table 2. Typical areas of selected section area of liver of patient no 6.

CT scan section (mm)	Area (cm^2)	CT scan section (mm)	Area (cm^2)
79	-	169	113.508
89	72.985	179	111.7648
99	83.625	189	101.342
109	92.622	199	82.018
119	85.319	209	56.708
129	99.081	219	39.825
139	97.302	229	36.702
149	109.482	239	31.082
159	122.024	240	-

Table 3. Comparison of selected liver volumes obtained from water replacement technique and interpolations.

Patient	Volume (ml)				Least relative error (%)	Degree of derivatives of the relationship
	Water replacement technique	Interpolation				
		Mean area (MA)	End area (EA)	Prismoidal area (PA)		
1	415	543	574	435	4.8	≥ 3
2	720	685	755	620	4.8	< 3
3	730	695	750	560	2.7	< 3
4	552	535	540	470	2.2	< 3
5	1,200	1,322	1,368	1,260	5.0	≥ 3
6	1,140	1,252	1,283	1,115	2.2	≥ 3
7	565	610	615	584	3.4	≥ 3
8	328	315	340	288	3.7	< 3
9	950	1010	1,024	930	2.2	≥ 3
10	347	335	360	247	3.4	< 3
11	720	687	730	588	1.4	< 3
12	1,250	1,180	1,220	1,195	2.4	< 3

Table 4. Model analysis of all patients.

Model	R	R square	Standard error of the estimate	F	Sig	T	Sig
MA	0.980	0.961	67.9659	243.769	0.0022	0.704	0.497
EA	0.928	0.965	64.0495	275.782	0.0027	0.290	0.778
PA	0.982	0.964	64.9284	268.097	0.000	2.475	0.003

Table 5. Model analysis of all patients whose relationship between cut-sectional area and depth has a degree of derivatives of the relationship lower than 3.

Model	R	R square	Standard error of the estimate	F	Sig	T	Sig
MA	1.00	1.00	3.8531	39,059	0.000	-3.35	0.020
EA	0.998	0.996	20.825	1,332.174	0.000	-1.406	0.219
PA	0.990	0.980	48.276	243.837	0.000	2.650	0.045

were two or less with coefficients of correlation beyond 0.95 (Tables 3 and 5). The significance of coefficient of the mean-area method was also accepted. Whereas, the volumes calculated by the prismoidal method were not different from those reference liver volumes when the degrees of derivatives of the relationships were higher than three (Tables 3 and 6). These findings are in line with those numerical analysis rules given in reference 4.

Practical implications

The study suggests that the CT scan can provide an accurate means of measuring the liver volume to some extent. Regarding the intact hepatocyte theory[3], the function of the individual hepatocytes is thought to be equal. The more hepatocytes identified in the liver, the better the liver function can be predicted. The measurement of liver volume will, therefore, be reflected on the net quantity of hepato-

Table 6. Model analysis of all patients whose relationship between cut-sectional area and depth has a degree of derivatives of the relationship higher than 3.

Model	R	R square	Standard error of the estimate	F	Sig	T	Sig
MA	0.995	0.989	41.9596	273.6	0.000	-1.073	0.362
EA	0.990	0.981	55.7505	153.6	0.001	-0.761	0.502
PA	0.997	0.995	39.969	614.88	0.000	3.30	0.020

cytes in a normal liver. Accordingly, it can be one of the factors to assess the liver function prior to operation[5].

In cirrhotic patients, the reduction of liver function reserve is presented although their liver volume is not decreased. It can be explained as a decrease in the total number of their hepatocytes is replaced by an increase of fibrous tissue in the liver. Measurement of total liver volume in cirrhotic patients can be represented by neither the total amount of hepatocytes nor the liver function of these patients.

To solve this problem, the authors will try to find a practical way to evaluate the liver function reserve in cirrhotic patients This may include the measurement of direct hepatocyte volume or using the retention rate of indocyanine green combined with the measurement of liver volume[6].

The methods for the estimation of selected liver volumes that are presented are very simple, easy to operate and give accurate results to some extent. However, to give more accurate results, larger populations are required.

SUMMARY

The findings of the results indicated that the liver volume could be estimated from CT scan films with less than 5 per cent difference compared to the manual method. The method is simple and the liver volume is easy to estimate in a short period. Further improvement of the program will be very useful for assessing the function reserve of the liver prior to surgery.

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REFERENCES

1. Henderson JM, Heymsfield SB. Measurement of liver and spleen volume by Computed Tomography. Radiology 1981; 141: 525-7.
2. Okamoto E, Kyo A, Tanaka N. Prediction of the safe limits of hepatectomy by combined volumetric and functional measurements in the patient with impaired hepatic function. Surgery 1984; 95: 5: 586-91.
3. Kawasaki S, Immamura H. Direct evidence for the intact hepatocyte theory in patients with cirrhosis. Gastroenterology 1992; 102: 1351-5.
4. Burden RL, Douglas JD. Faires Numerical analysis. Boston: PSW Kent Publishing Company, 1988.
5. Kubota K, Makuuchi M. Measurement of liver volume and hepatic functional reserve as a guide to decision-making in resectional surgery for hepatic tumors. Hepatology 1997; 26: 5: 1176-81.
6. Kwon AH, Matsui Y. Functional hepatic volume measured by Technetium-99m-Galactosyl-Human serum albumin liver scintigraphy. Am J Gastroenterol 2001; 96: 2: 541-6.

การวัดปริมาตรตับอย่างง่าย

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ปริมาตรของตับ เป็นปัจจัยที่สำคัญในการทำนายการเกิดภาวะตับวายได้ดี โดยเฉพาะภายหลังการผ่าตัดมะเร็งตับ แต่การวัดขนาดของตับในปัจจุบันจำเป็นต้องใช้เครื่องมือที่มีราคาแพงและซับซ้อน ดังนั้นคณะผู้วิจัยจึงได้ศึกษาถึง การวัดปริมาตรของตับจากแผ่นฟิล์มเอกซเรย์คอมพิวเตอร์ โดยใช้โปรแกรมคอมพิวเตอร์ ที่ใช้สำหรับวัดขนาดพื้นที่จากแผนที่ภูมิศาสตร์ แล้วนำมาเปรียบเทียบกับปริมาตรของตับจริงที่วัดโดยวิธีแทนที่น้ำ ผลการศึกษาพบว่า ปริมาตรของตับที่วัดจากโปรแกรมคอมพิวเตอร์มีความแตกต่างไม่เกินร้อยละ 5 จากปริมาตรของตับจริงที่วัดโดยการแทนที่น้ำ

คำสำคัญ : ปริมาตรของตับ, โปรแกรมคอมพิวเตอร์

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