
Human Liver Regeneration After Major Hepatectomy

A Study of Liver Volume by Computed Tomography

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Regeneration of the remnant liver after major hepatectomy in humans was studied by computed axial tomography (CT) in 12 noncirrhotic and five cirrhotic patients. Liver volumes were measured by abdominal CT 3 days, 10 days, 3 months, 6 months, 1 year, and 1.5 years after resection. Of the 17 patients, liver remnant volume was increased in $21.2\% \pm 6.7\%$ and $30.6\% \pm 12.7\%$ at 3 months and 6 months after resection, respectively. Noncirrhotic livers were $28.4\% \pm 9.5\%$ and $48.4\% \pm 17.8\%$ larger at 3 and 6 months. For cirrhotic livers, the increase was $8.5\% \pm 3.6\%$ and $12.9\% \pm 4.5\%$. In five patients with right hepatectomy (65% resection), the liver remnant volumes were increased $38.4\% \pm 11.7\%$, $48.0\% \pm 16.2\%$ and $95.1\% \pm 4.5\%$ at 3 months, 6 months, and 1 year after resection, respectively. In seven patients with right partial hepatectomy (30% to 35% resection), the percentages were $7.4\% \pm 3.2\%$, $21.8\% \pm 8.4\%$, and $63.9\% \pm 18.3\%$ and in five patients with left lateral segmentectomy (15% resection), they were $15.6\% \pm 8.2\%$, $27.8\% \pm 12.2\%$, and $33.0\% \pm 14.5\%$ 3 months, 6 months, and 1 year after resections, respectively. Noncirrhotic livers showed better regeneration than cirrhotic livers. Complete regeneration took about 1 year. The noncirrhotic liver that underwent right lobectomy also needed 1 year to double its postresection volume.

ANIMAL EXPERIMENTATION HAS shown the remarkable regenerative and restorative power of the liver after hepatic resection.¹⁻⁴ In humans functional and metabolic restoration can be found within 2 to 3 weeks after major hepatectomy.^{5,6} The normal liver remnant regeneration has been proved at secondary laparotomy⁷ and restoration of normal liver mass has occurred within 6 months, as demonstrated by repeated liver scanning with rose bengal I¹³¹ or Tc^{99m}.^{8,9} Therefore information on the rate of liver regeneration in humans is incomplete. There has been no satisfactory method for accurate and repeated measurement of liver volume and

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size. And whether the cirrhotic liver remnant can be regenerated is still controversial.⁸

The recent advent of computed tomography (CT) has made possible a noninvasive, *in situ* measurement of the volume of various organs in the body.¹⁰ Attempts to use the CT method to measure the liver volume and mass when studying liver regeneration in cirrhotic and noncirrhotic patients were inevitable.

Patients and Methods

Seventeen patients who underwent major hepatic resection due to liver trauma (3 patients), hepatolithiasis (4 patients), and hepatocellular carcinoma (HCC) (10 patients) at the Department of Surgery, Chang Gung Memorial Hospital, Taipei, Taiwan, during the 2-year period from 1987 through 1988¹¹ were included in the study. There were 12 men and 5 women. Their ages ranged from 24 to 72 years. Among them five patients with HCC were found to have associated liver cirrhosis. They were in the compensatory stage without evidence of ascites or jaundice.

Of the 17 patients, right lobectomy (hemihpatectomy) was done in 5, right partial hepatectomy (bisegmentectomy) in 7, and left lateral segmentectomy in 5 (Table 1).

Abdominal CT scan was performed 3 days, 10 days, 3 months, 6 months, 1 year, and 1.5 years after hepatectomy. Computed tomography scans transversing the whole liver were made with a cycle time of 5 seconds at intervals of 1 cm. To demonstrate the section margin more clearly, enhancement by an intravenous bolus injection of contrast medium was used routinely. The right and left lobes of the liver were separated by a line passing through the gallbladder and inferior vena cava (Cantlie

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TABLE 1. Seventeen Patients Underwent Major Hepatectomy

Pattern of Hepatectomy	HCC	Trauma	Hepatolithiasis	Total
Right lobectomy	4	1	0	5
Right partial lobectomy (bisegmentectomy)	5*	2	0	7
Left lat segmentectomy (left partial lobectomy)	1	0	4	5
Total	10	3	4	

* Liver cirrhosis.

TABLE 2. Increased Percentage of Liver Volume in Cirrhotic or Noncirrhotic Patients

With or Without Liver Cirrhosis	3 months	6 months
All patients (n = 17)	21.2 ± 6.7%	30.6 ± 12.7%
Noncirrhotic (n = 12)	28.4 ± 9.5%	48.4 ± 17.8%
Cirrhotic (n = 5)	8.5 ± 3.6%	12.9 ± 4.5%*

* p < 0.05, compared to the noncirrhotic group.

line) in a cut to permit visualization of both markers. A division between the left lateral and medial segments was drawn through the left sagittal fissure. The areas of the entire liver, lobe, or segment were measured, respectively, by planimetry. The volume of each part then was calculated by multiplication of the area of each part by interval thickness and magnification index and addition of the interval volume of each part.¹⁰

Results

Of the 17 patients, the liver remnant volume was increased 21.1% ± 6.7% and 30.6% ± 12.7% 3 and 6 months after resection, respectively. Noncirrhotic livers in 12 patients were 28.4% ± 9.5% and 48.4% ± 17.8% increased in comparison with 8.5% ± 3.6% and 12.9 ± 4.5% for cirrhotic livers in five patients 3 and 6 months after resection, respectively (Table 2).

Postoperative progressive increase in liver remnant volume was found in various types of hepatectomy. In five patients with right lobectomy, the liver remnant volume was increased 38.4% ± 11.7%, 48.0% ± 16.2%, and 95.1% ± 24.5% after resection 3 months, 6 months, and 1 year, respectively. In seven patients with right bisegmentectomy, the percentage of increase was 7.4% ± 3.2%,

TABLE 4. Increased Percentage of Liver Volume After Hepatectomy

Pattern of Hepatectomy	3 months (%)	6 months (%)	1 year (%)
S/P right lobectomy (n = 5)	38.4 ± 11.7	48.0 ± 16.2	95.1 ± 24.5
S/P right partial lobectomy (n = 7)	7.4 ± 3.2	21.8 ± 8.4	63.9 ± 18.3
S/P left partial lobectomy (n = 5)	15.6 ± 8.2	27.8 ± 12.2	33.0 ± 14.5

21.8% ± 8.4%, and 63.9% ± 18.3%, respectively, at 3 months, 6 months, and 1 year. In five patients with left lateral segmentectomy, the percentages of increase were 15.6% ± 8.2%, 27.8% ± 12.2%, and 33.0% ± 14.5% larger (Tables 3 and 4). It seemed that the greater the volume of liver resected, the greater the restoration capacity.

Discussion

Computed axial tomography permits accurate cross-sectional radiographic visualization of visceral organs. In clinical use of CT, some organ movement and incomplete resolution from the surrounding structure cannot be avoided. In many studies the preoperative CT estimation of volume of liver was compared with the actual measured volume of the resected specimen. The results indicated a close linear relationship between the CT volumes and the actual volumes, and the average difference was within ±3% to 5%.¹⁰ The difference suggests that this method, the quantitative CT technique, is sufficiently accurate for clinical use.

Extensive research has been directed at identifying the factors responsible for initiation and regulation of liver regeneration.¹²⁻¹⁴ Recently it was demonstrated that portal blood is important for restoration of the liver.¹⁴ When a hepatic lobe is removed, portal flow to the liver remnant is increased immediately. In the noncirrhotic liver, the bulk of the remaining liver remnant can increase rapidly due to vascular engorgement and interstitial edema. However the new circumstance created by hepatic lobectomy cannot be adjusted for immediately by a cirrhotic liver remnant.¹⁴

In our study we found that remnants of noncirrhotic liver can increase gradually in size by about 30%, increasing in 3-to-4-month intervals. Usually it took about 1

TABLE 3. Changes of Liver Volume After Hepatectomy or After Different Operation

Pattern of Hepatectomy	Postop. (cm ³)	3 months (cm ³)	6 months (cm ³)	1 year (cm ³)
S/P right lobectomy (n = 5)	541.8 ± 81.5	715.9 ± 81.2	801.8 ± 10.2	1056.8 ± 40.5
S/P right partial lobectomy (n = 7)	985.9 ± 110.2	1023.4 ± 120.2	1201.2 ± 80.4	1302.6 ± 20.4
S/P left partial lobectomy (n = 5)	1038.4 ± 3.9	1273.7 ± 28.6	1360.1 ± 20.8	1380.8 ± 15.6

year to double a postresection volume after right lobectomy. As for regeneration of cirrhotic livers, although Lin et al.⁸ reported that they failed to see any change in size of remnant on repeated liver scans, we found that they do have restoration capacity. Of course cirrhotic livers are less able to regenerate than noncirrhotic livers.

The proportion of each segment in the human liver has been estimated as 35% for the right posterior (segments VII and VIII), 30% for the right anterior (segments VI and V), 20% for the left medial (segment IV), and 15% for the left lateral segment (segments II and III).¹⁵ Surgeons assess the extent of hepatectomy conventionally by adding the percentages of the resected segments. For example 65% is allocated to right lobectomy and 35% to left lobectomy. In our series, we found remarkable regeneration of the liver remnant in those who underwent right lobectomy (60% resection) in comparison with other types of hepatectomy, such as right partial (30% to 35% resection) and left lateral segmentectomy (15%).

During operation resection progressively removes increasing numbers of vascular outflow tracts. With resections of less than 30%, significant obstruction and the resulting vascular pooling is rare. However hepatectomies excising greater amounts of liver lead to an increase in total hepatic blood flow and vascular engorgement. This is probably the reason why striking regeneration occurred in the remaining left liver after right hepatic lobectomy. Unlike opinions expressed in other reports, we do not think there is any time difference for complete liver regeneration between the patients with noncirrhotic HCC and those with other benign disease who underwent hepatectomy. Lin et al.⁸ reported that the remaining left liver regenerated within 3 months after right lobectomy in liver cyst patients. In HCC patients Lin et al.⁸ concluded that it took about 6 months to complete the regeneration process. But in both Lin's report and ours, the number of

patients in the study is too small to support any definite conclusion.

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