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Spectral characteristics of the high-resolution liver CT data: detection of iron-overload and cirrhosis

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Background. *Statistical methods and Fourier analysis of CT values were used to detect the presence of liver cirrhosis and of iron-overload in the sets of high-resolution liver CT data.*

Subjects and methods. *Eleven liver cirrhosis patients, seven hemodialysed patients with iron-overload and 51 control individuals were included. CT unit SIEMENS SOMATOM DRH was used (kernel 2, 0.2 mm wide and 2 mm thick pixels). Square sample areas, 50 pixels wide, two per control and three per patient were collected. The areas were statistically analysed and decomposed in 100 linear fragments (50 lines and 50 columns of 50 pixels) for Fourier analysis. The mean and standard deviations of harmonic powers were calculated for each sample.*

Results. *The high-resolution CT data in the iron-overload patients differed from the controls by the increased mean density (≥79 HU) and reduced power of many harmonics ($p<0.01$). The high-resolution CT data of the cirrhotic patients showed the decreased mean density (<50 HU) and increased power of harmonics from 0.1 to 0.9 cycles/mm (wavelengths from 10 to 1.1 mm) ($p<0.01$).*

Conclusions. *Information extractable from the high-resolution liver CT data can distinguish between the normal and cirrhotic, or iron-overload livers.*

Key words: liver cirrhosis, liver diseases; iron overload; tomography, x-ray computed, Fourier analysis

Introduction

Ultrasound, CT and MR are dominant methods of liver imaging, mainly used for the detection of focal liver diseases. Conventional CT images with large pixels are unable to define CT characteristics of the cirrhotic liver. Fibrosis and altered liver architecture, as the main pathological characteristics of liver cirrhosis, do not substantially alter the mean density on these images[1], presumably due to the effect of partial volume. Each voxel of the conventional abdominal CT image contains parts of several liver lobules and the effect of partial volume thus disables the visualisation of detailed densitometric texture.

The present study was aimed to test whether the high-resolution CT values can distinguish

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normal liver images from the images of the cirrhotic or iron-overload livers. Statistical methods and Fourier analysis of CT values were used for this purpose.

Patients and methods

The control group consisted of 51 patients scheduled for abdominal CT examinations of kidneys, spine or other organs, without history or clinical signs of diffuse liver diseases. Eleven patients with a clinic diagnosis of liver cirrhosis were CT examined to exclude the possibility of liver neoplasm. All patients were in the condition of decompensated liver cirrhosis with ascitic fluid on this or any of the previous hospital stays. The iron-overload group consisted of seven hemodialysed patients with chronic renal failure and iron-overload (serum ferritin more than four times above normal). These patients were scheduled for the abdominal CT because of their renal or spine pathology.

A single, 2 mm thick liver CT image was taken through the central part of the liver on a SIEMENS SOMATOM DR-H CT unit before the contrast application. We used the abdominal kernel 2, 720 projections in four seconds with zoom factor 5.2. Pixels were 0.2 mm wide and 2 mm thick in all images.

CT data were stored and square areas wide 50 pixels (2500 pixels per square) were later transferred to a portable PC. A simple RS-232 adapter and XTALK program were used to connect the PC in the place of a DIGITAL control console. We used the command ABS/DIA/LIS from the measuring program of SOMATOM DRH to export the chosen area of CT values to the capture file on a portable PC. Files were edited in a DOS editor to discard textual information and, after that, the data were realigned to reconstruct the initial CT matrix.

From these data simple statistical measures were calculated.[2] Then, each sample area of CT values was decomposed in 50 columns and 50 rows (in total 100 linear segments of 50 pixels). These segments were analysed by the conventional Fourier analysis. Amplitudes of sine and cosine components were calculated for the harmonics ranging from 0. to 25. (from 0 to 2.5 cycles/mm). Amplitudes of the cosine and the sine components were used to calculate the power of each harmonic in the linear segment.[3] The mean harmonic power spectrum with standard deviations was calculated for each sample.

Observed parameters were tested by the calculation of ROC curves.[4] Numbers of true positive/negative and false positive/negative were used in 2•2 tables for the calculation of $\chi 2$ values.[2]

Results

Table 1 shows the statistical characteristics of the collected sets of CT data and calculated sets of contrast values.

The high-resolution (HR) CT data of the livers with iron-overload showed the increased mean density in comparison to the control samples with the decreased mean densitometric contrast value. Both characteristics are probably caused by the abundant and evenly distributed iron in liver tissue.

On the contrary, the HR CT data of the cirrhotic livers showed the reduced mean density and increased mean contrast value.

Table 2 shows the results of Fourier analysis. Mean powers with a standard deviation are shown only for the first 10 harmonics. Omitted harmonics include the 0. harmonic, whose power equals the mean densities already shown in Table 1. The powers of higher harmonics (from 11. to 25.) were similar in the controls and groups of patients and considered unimportant.

In comparison to the HR control CT data, the harmonic powers are increased in the group of the HR cirrhotic liver CT data and decreased in the group of the HR iron-overload liver CT data.

To test the described differences among the three groups of the HR CT data, elements of the ROC curves were calculated. Cut off points of

Table 1. Statistical characteristics of the high-resolution liver CT data

	Mean minimal value per sample (HU)	CT Mean maximal CT value per sample(HU)	Mean density (HU)	Standard deviation of CT values (HU)
Controls (102 samples of HR liver CT data)	-26.19	148.58	60.91	31.56
Cirrhotic liver patients (33 samples of HR liver CT data)	-75.27	156.73	45.04	44.08
Iron-overload patients (21 samples of HR liver CT data)	-5.81	146.76	71.87	29.85

Table 2. Results of the Fourier analysis. The power of the 0. harmonic equals the mean density from the Table 1. Undistinguishing harmonics in the range from 11. to 25. are omitted as unimportant

Harmonic	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
Cycles/mm	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
Wavelength(mm)	10	5	3.33	2.5	2	1.67	1.43	1.25	1.11	1
Controls (102 samples)										
Mean power (HU)	19.0	17.1	14.9	11.7	8.2	5.6	3.9	2.9	2.2	1.7
St. deviation (HU)	11.2	10.1	8.5	6.8	5.0	3.5	2.3	1.8	1.4	1.1
Cirrhotic liver patients (33 samples)										
Mean power (HU)	25.9	22.9	18.0	14.5	10.0	6.3	4.4	3.3	2.6	2.0
St. deviation (HU)	18.7	14.6	11.2	8.8	5.8	3.7	2.6	2.1	1.7	1.4
Iron-overload patients (21 samples)										
Mean power (HU)	16.1	14.5	13.3	10.1	7.0	5.0	3.5	2.5	1.8	1.4
St. deviation (HU)	9.1	8.1	8.1	5.4	4.0	2.9	2.1	1.5	1.1	0.9

the highest P^2 value and overall accuracy were selected as optimal.

The results of the comparison between the HR cirrhotic liver CT data and the control CT data are shown in Table 3.

The cirrhotic liver HR CT data can be distinguished from the controls by the decreased mean density (<50 HU, P^2=37.28, $p<0.0001$) and by the increased power of harmonics from 0.1 to 0.9 cycles/mm (wavelengths from 10 to 1.1 mm)($p<0.01$). Some harmonics showed an increased standard deviation of harmonic powers among linear segments ($p<0.01$).

The results of the comparison between the HR iron-overload liver CT data and the control CT data are shown in Table 4.

The iron-overload liver CT data can be distinguished from the controls by the increased mean density (>78 HU, P^2=30.44, $p<0.0001$), decreased power of many harmonics from 0.1 to 2.5 cycles/mm (wavelengths from 10 to 0.4 mm) ($p<0.01$).

Discussion

Spectral analyses proved to be a suitable technique for discriminating the ultrasound images of normal livers and steatotic ones. The reported study included six cases (two normal and four with steatosis).[5] The texture measure values were compared with the corresponding biopsy scores and the results indicated the ability of the spectral texture measure to discriminate the two conditions and to estimate the severity of histological change.

Table 3. ROC curve elements for the parameters distinguishing the cirrhotic liver HR CT data from the controls (P^2>6.63, p<0.01)

			Characteristics of HR CT data			Sensitivity	Specificity	Accuracy	χ^2
			Cirrhotic liver	Cut off point (HU)	Controls				
Mean density			<	50.0	≥	0.70	0.85	0.81	37.28
Cycles/mm		Wavelength (mm)			Fourier analyses				
Mean power (HU)	0.1	10	≥	25.0	<	0.48	0.88	0.79	20.45
	0.2	5	≥	23.0	<	0.52	0.92	0.82	31.52
	0.4	2.5	≥	14.0	<	0.48	0.81	0.73	11.57
	0.5	2	≥	10.0	<	0.48	0.84	0.76	14.83
	0.7	1.43	≥	4.4	<	0.55	0.74	0.69	8.84
	0.8	1.25	≥	3.5	<	0.45	0.86	0.76	14.88
	0.9	1.11	≥	2.4	<	0.55	0.72	0.67	7.49
St. dev. (HU)	0.1	10	≥	12.5	<	0.45	0.87	0.77	16.23
	0.2	5	≥	10.0	<	0.55	0.72	0.67	7.49
	0.4	2.5	≥	7.5	<	0.52	0.81	0.74	13.79
	0.5	2	≥	5.2	<	0.52	0.78	0.72	10.88
	0.9	1.11	≥	1.6	<	0.45	0.86	0.76	14.88

The same method was used to analyse trabecular patterns in digitised wrist radiographic images.[6] Authors found in the group of 68 patients that three spectral indices permitted quantification of the cancellous bone structure, and detection of the age related structural bone changes.

Another example is the reported study of the cross-sectional images of the posterior mandible.[7] In these images, useful diagnostic information was in the range of 0.12 to 0.6 cycles/mm for the contact radiographs and the 3 mm cross-sections images.

The idea of using high-resolution liver CT values was based on previous reports that high-resolution CT abdominal imaging proved useful in the detection of the adjacent organs' invasion by the stomach cancer.[8]

A CT slice thickness ranging from one to three millimetres is used in the chest CT imaging.[9] The high-resolution CT of the lungs correlates well with the pathologic findings.[10] It provides detailed visualisation of the lung parenchyma.[11] It is useful in differentiating similar patterns of abnormalities seen on chest radiographs, such as those seen in lymphangitic carcinomatosis and sarcoidosis, and in delineating the extent of co-morbid lung diseases, such as emphysema and asbestosis. The characteristics of the margins of metastatic pulmonary nodules noted on histopathologic examination correlated well with their high-resolution CT findings (z04),[12] while microscopic intravascular tumour emboli and lymphangitic tumour spread were difficult to detect.

Actual CT values or „pixel mapping" were found important in accurate diagnosing of small kidney angiomyolipomas.[13]

The images in iron-overload patients differed from the controls by the increased mean density (>79 HU) and reduced power and standard deviation of power of many harmonics. It is in accordance with the reported observation that the mean liver densities in patients with haemochromatosis are increased and in the range from 75 do 132 HU.[14] The reduced pow-

Table 4. ROC curve elements for the parameters distinguishing the HR iron-overload liver CT data from the controls (χ^2>6.63, p<0.01)

			Characteristics of HR CT data			Sensitivity	Specificity	Accuracy	χ^2
			Iron-overload	Cut off point (HU)	Controls				
Mean density			≥	79.0	<	0.38	0.98	0.87	30.44
Cycles/mm		Wavelength (mm)			Fourier analyses				
Mean power (HU)	0.1	10	<	16.0	≥	0.71	0.70	0.70	12.53
	0.2	5	<	14.0	≥	0.57	0.75	0.72	8.82
	0.4	2.5	<	10.0	≥	0.62	0.71	0.69	8.09
	0.7	1.43	<	3.5	≥	0.71	0.66	0.67	9.94
	0.7	1.43	<	4.4	≥	0.55	0.74	0.69	8.84
	0.8	1.25	<	2.4	≥	0.52	0.75	0.72	6.53
	0.9	1.11	<	1.9	≥	0.67	0.69	0.68	9.27
	1.0	1	<	1.3	≥	0.52	0.80	0.76	9.92
	1.1	0.91		1.2		0.67	0.68	0.67	8.68
	2.5	0.4		0.3		0.62	0.68	0.67	6.5
St. dev. (HU)	0.0	4	<	8.0	≥	0.57	0.78	0.75	11.02
	0.4	2.5	<	5.3	≥	0.71	0.66	0.67	9.94
	0.5	2	<	3.7	≥	0.67	0.74	0.72	12.66
	0.75	1.43	<	1.9	≥	0.67	0.68	0.67	8.68
	0.9	1.11	<	1.0	≥	0.57	0.76	0.73	9.5
		1							8.82
		0.91							8.09
	1.0	0.83		0.8					6.53
	.	0.77		.					7.00
	.	0.66	<	.	≥	-0.6	-0.7	-0.7	11.02
	.	0.62		.					9.30
	.	0.59		.					8.09
	2.3	0.55		0.4					6.50
		0.43							7.75
		0.42							6.53

ers of harmonics suggest reduced variability in the densities of adjacent pixels. Possible interpretation is that an evenly diffused iron-overload increases the mean density and simultaneously blurs the normal variability of the high-resolution liver CT data.

The high-resolution CT data of the cirrhotic liver in the present study differed from the controls by the low mean density (<50 HU), possibly because of the reduced partial volume effects, allowing visualisation of the infiltration of the fat in alcoholic liver steatosis.[15]

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