Establishment of carpal contents/canal ratio by means of magnetic resonance imaging

Magnetic resonance imaging (MRI) was used to determine cross-sectional areas and volumes of carpal canals and carpal canal contents in five cadaver specimens in an assessment of the reliability of MRI for establishing contents/canal ratios. Volumes of the carpal canals and their contents were accurately calculated from MRI with a previously described correction factor (0.8161) for carpal tunnel volumes and a calculated correction factor (1.078) for carpal tunnel contents volume. There was no significant difference between laboratory-measured or MRI-calculated ratios from either volumes (p = 0.86) or surface areas (p > 0.79). Cross-sectional area contents/canal ratios were significantly higher (p = 0.0001) at the level of the distal aspect of the hook of the hamate (0.54) as compared with those at the level of the distal radial styloid (0.42) and proximal metacarpals (0.44). MRI provides an effective and reliable means of determining contents/canal ratios from both cross-sectional area and volume calculations. (J Hand Surg 1992;17A:843-9.)

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Carpal tunnel syndrome (CTS) is considered the most common entrapment neuropathy in the upper extremity. An anatomic basis has been proposed by some authors. In 1980 Dekel et al.[1] used computerized tomography (CT) to show a decrease in the cross-sectional area of CTS patients. Later Merhar et al.[2] found no significant difference in cross-sectional area measurements between wrists with and without symptoms. In 1987 Bleecker[3] evaluated the carpal tunnel cross-sectional area in 14 male electricians. This study included three normal persons, seven CTS patients with symptoms, and four patients with subclinical manifestations of CTS. The patients with CTS and subclinical CTS had significantly smaller carpal canals than the controls (1.75 ± 0.21 cm^2, 1.83 ± 0.22, and 2.2 ± 0.19, respectively). The depth of the carpal canal at the level of the median nerve was reportedly the same in patients with CTS patients and those with subclinical CTS; in both, the canal depths were less than in the controls. Bleecker concluded that a small carpal canal may be a risk factor for CTS.

Recently, Richman et al.[4] described the use of three-dimensional computer reconstruction of magnetic resonance images (MRI) of cadaveric wrists to determine carpal tunnel volume and carpal arch width. They found volumes estimated by MRI to be consistently larger than actual volumes (5.84 ml ± 1.24 ml and 4.73 ± 1.01 ml, respectively). A correction factor of 0.8161 was proposed to adjust MRI-acquired volumes.

Analysis of anatomic variation as a cause of increased pressure in the carpal canal resulting in CTS might best be evaluated by means of a ratio of canal contents to canal size. The free space available for tissue expansion within the carpal tunnel is probably more important than merely the size of the tunnel itself. A large contents/canal ratio might allow for the decompensation and symptoms seen in some patients and could explain why various forms of stress cause symptoms in some patients and not in others. The purpose of this study is to determine the reliability of MRI for determining a

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contents/canal ratio and to determine possible approaches for subsequent clinical studies.

Materials and methods

Five upper extremities were harvested from four embalmed cadavers by below-elbow amputation. MRI was performed with a Magnetom SP 1.5 Telsa imaging system (Siemens Medical Systems, Erlangen, Germany). For imaging, specimens were positioned palm up with the wrist in a neutral position on a 17 mm (diameter) circular surface coil. Imaging techniques consisted of spin-echo sequences with a repetition time of 500 ms and an echo time of 25 ms. Imaging techniques were repeated in a second series with a repetition time of 2000 ms and echo times of 20 and 80 ms. Fifteen 3 mm slices with 1.5 mm gaps were taken in the axial plane from the distal radius to the distal aspects of the metacarpal bones. A field of view of 150 mm was used in both series. Pixel sizes of 0.682 × 0.586 mm and 0.781 × 0.586 mm were used in series 1 and 2, respectively.

The five cadaveric specimens were frozen in liquid nitrogen and sectioned with a band saw at the level of the distal radial styloid (Fig. 1) and the distal aspect of the hook of the hamate (marked under fluoroscopy prior to freezing) (Fig. 2). The contents of the canal were removed, and the volume was determined by water-displacement measurements. Molds were constructed by injection of hydrophilic vinyl polysiloxane impression material (L.D. Caulk Division, Dentsply International Inc., Milford, Del.) into the upright carpal tunnels, and the molds were then used to determine the actual volumes of the canal.

The distal portion of each specimen was also sectioned at the proximal aspect of the metacarpals, 1 cm distal to the third carpometacarpal joint (Fig. 3). Cross-sectional areas were determined from photographs of the cut surfaces of cadaver specimens at three levels: the tip of the radial styloid, the distal aspect of the hook of the hamate, and the proximal aspect of the metacarpals 1 cm distal to the third carpometacarpal joint. Micrometers were placed in the photographic fields to ensure proper adjustment for magnification.

A Bioquant II digitizer (R & M Biometrics, Nashville, Tenn.) was used to determine cross-sectional areas on contiguous MRI slices from the distal tip of the radial styloid to the distal aspect of the hook of the hamate. Volumes were calculated by the trapezoidal rule of numerical integration with sequential cross-sectional areas determined by MRI. The cross-sectional areas were averaged and multiplied by the length of the mold constructed in the canal of each specimen to more accurately compare MRI-constructed volume to actual volume. Volumes were determined for the canal as well as for its contents, which consisted of nine flexor tendons and the median nerve. Volume and cross-sectional area were determined by two observers. Five observations were made for each wrist.

To determine the ratios for both measured and calculated (from MRI) volumes, the volume of the contents of the carpal tunnel of each wrist was divided by the volume of its canal. Ratios were also established for measured and calculated (from MRI) cross-sectional areas by division of the cross-sectional area of the contents by that of the canal. The Student *t* test and analysis of variance were used where indicated. All values are reported as the mean ± the standard deviation.

Results

T2 weighted images were found to provide better contrast between canals and surrounding tissue. Volumes constructed from MRI T2 weighted images yielded consistently larger values than actual volumes measured in the laboratory (Table I). With use of the correction factor proposed by Richman et al.[4] (0.8161), the calculated volumes were adjusted and found to have a mean of 3.43 ml, compared with a measured volume mean of 3.48 ml. The mean absolute difference between hydrophilic vinyl polysiloxane mold volumes and calculated carpal tunnel volumes was 0.1196 ± 0.14 ml. There was no significant difference between hydrophilic vinyl polysiloxane mold volumes and calculated carpal tunnel volumes ($p = 0.54$).

Tendon and median nerve volumes calculated from MRI images were found to have a mean of 2.00 ml, compared with a mean measured volume of 2.16 ml (Table I). A mean correction factor of 1.078 was used to determine actual volumes accurately. The mean absolute difference between actual measured contents and corrected calculated contents was 0.2246 ± 0.15 ml. There was no significant difference between the two ($p = 0.99$).

Contents/canal ratios based on the calculated volumes were consistently lower than ratios based on measured volumes. There was no significant difference ($p = 0.86$) between ratios based on corrected calculated volumes and ratios based on measured volumes. The mean absolute difference between the two groups was 0.07 ± 0.09 (Table I). There was no significant difference between contents/canal ratios constructed

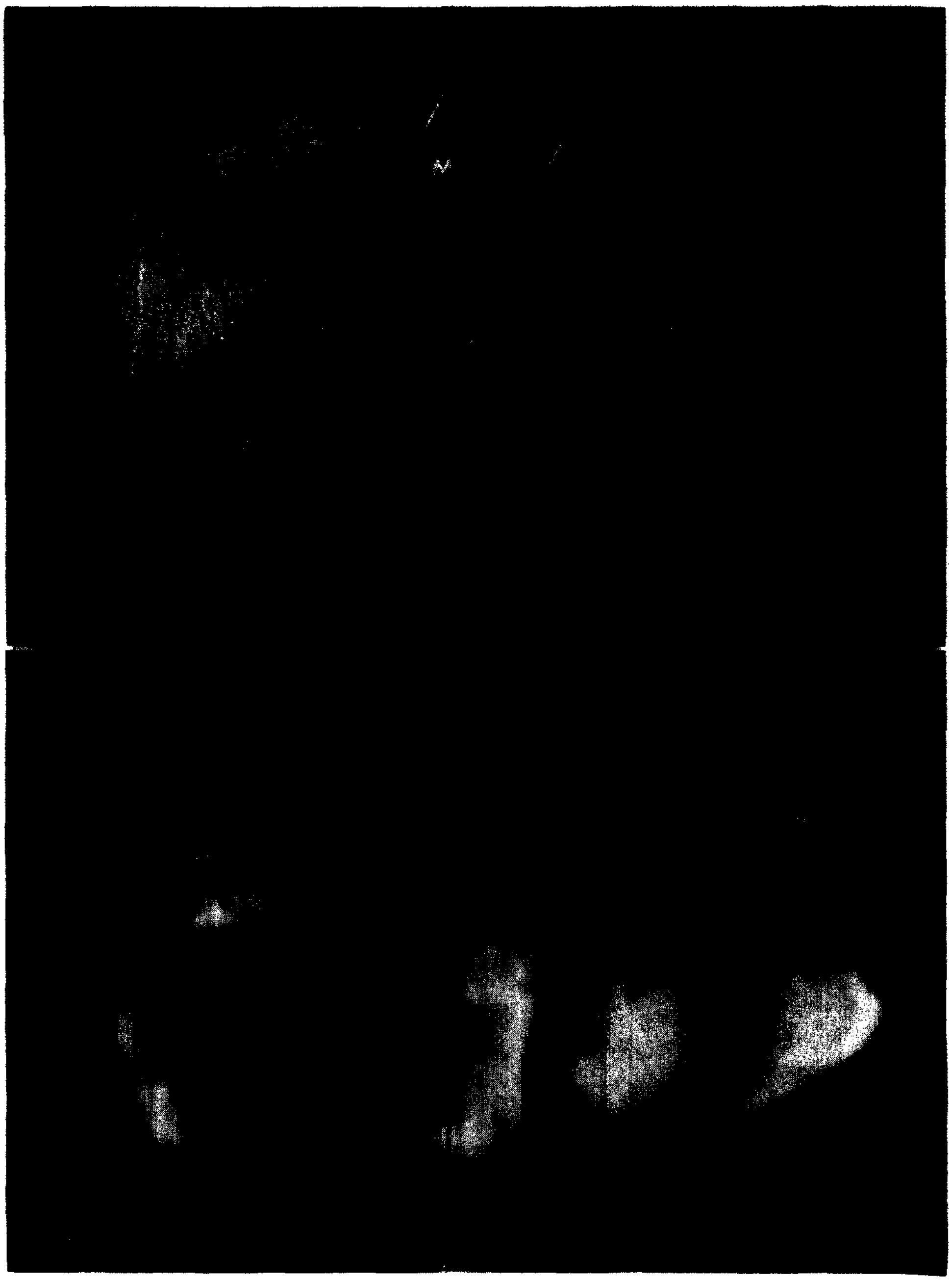

Fig. 1. Gross specimen **(A)** and MRI scan **(B)** of same cadaveric wrist at the tip of the distal radial styloid. *Arrows* mark area of synovial hypertrophy compared with other specimens. The thin proximal portion of the flexor retinaculum can be visualized in both *(arrowheads)*. The median nerve *(M)* and the tendons of the palmaris longus *(P)* and flexor carpi radialis *(F)* are labeled for orientation.

from calculated cross-sectional areas and measured cross-sectional areas ($p > 0.79$). The cross-sectional area at the level of the hamate was significantly smaller than cross-sectional areas at either the radial styloid, pisiform, or proximal metacarpals ($p = 0.0001$), as shown in Table II. Analysis of variance indicated that the contents/canal ratios based on cross-sectional area measurements were significantly higher at the level of

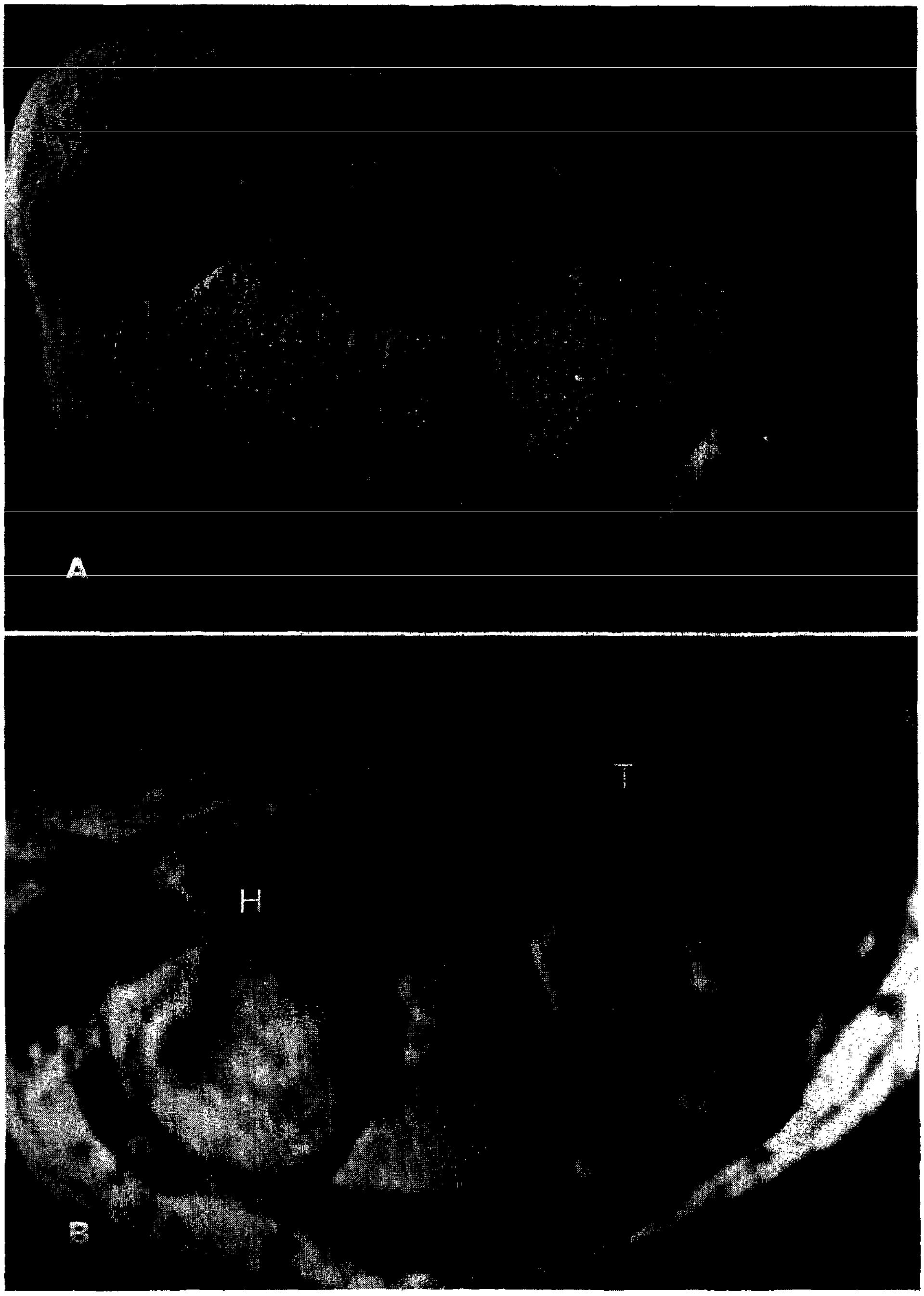

Fig. 2. Gross specimen (A) and MRI scan (B) of same cadaveric wrist at level of hook of hamate. Note the transverse carpal ligament extending between the hook of the hamate *(H)* and the tubercle of the trapezium *(T)*. Note also, by comparison with the other levels (Figs. 1 and 3), the evident crowding of tendons at this level.

the distal aspect of the hamate (0.54 ± 0.021) than at the level of the distal radial styloid (0.42 ± 0.028) and proximal metacarpal (0.44 ± 0.031), (p = 0.0001).

Discussion

Pressure on the median nerve in the carpal tunnel is probably a function of both contents and canal volumes. Persons who have high contents/canal ratios will have

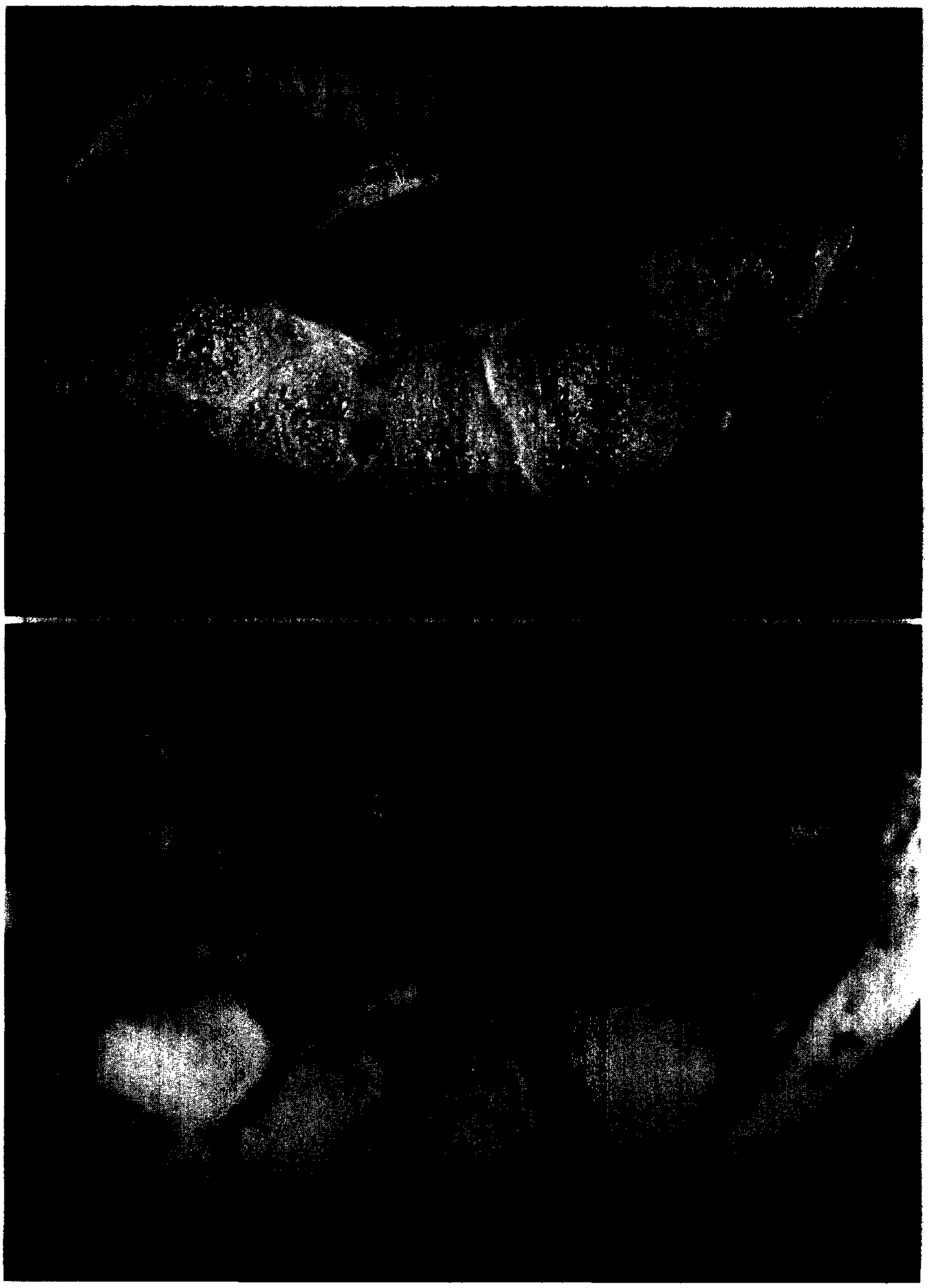

Fig. 3. Gross specimen (**A**) and MRI scan (**B**) of same cadaveric hand at level of proximal metacarpals. Note increase in the cross-sectional area of the carpal tunnel with less tendon crowding as compared to other levels (Figs. 1 and 2). The distal extent of the flexor retinaculum *(arrow)* and the first metacarpal *(M)* are labeled for orientation.

less space to accommodate pathologic increases in volume due to hypertrophy of synovium or other space-occupying lesions.

Luchetti et al.[5] measured intracanal pressures in patients with CTS and in control subjects over a 5 cm distance. They found that pressures in the former group had a bell-shaped distribution with a maximum pressure (44 mm Hg) in the central portion of the distribution,

Table I. Comparison of measured and calculated volumes and ratios for carpal canal and carpal canal contents

Measurement	*Wrist No. (ml)*					*Mean (ml)*	*Standard deviation*
	1	*2*	*3*	*4*	*5*		
Measured canal volume	3.8	3.5	3.5	4.0	2.8	3.48	0.54
Calculated canal volume	4.56	4.45	3.86	4.89	3.23	4.20	0.70
Corrected canal volume (0.8161)	3.72	3.63	3.15	3.99	2.63	3.43	0.54
Measured contents volume	2.8	2.2	1.8	2.2	1.8	2.16	0.41
Calculated contents volume	2.16	2.22	1.82	2.23	1.59	2.00	0.29
Corrected contents volume (1.078)	2.32	2.40	1.96	2.40	1.71	2.16	0.31
Ratios using volume							
Contents/canal volume measured	0.74	0.63	0.51	0.55	0.69	0.62	0.10
Contents/canal volume calculated	0.47	0.50	0.47	0.46	0.49	0.48	0.02
Corrected contents/canal volume calculated	0.62	0.66	0.62	0.60	0.65	0.63	0.02

Table II. Comparison of measured and calculated cross-sectional areas and ratios at the tip of the radial styloid and hook of the hamate for carpal canal and carpal canal contents

Measurement	*Wrist No.*					*Mean*	*Standard deviation*
	1	*2*	*3*	*4*	*5*		
Surface areas at radial styloid (mm^2)							
Canal measured	175.59	213.40	183.27	180.21	171.27	184.75	16.65
Canal calculated	203.83	228.72	182.99	194.65	209.29	203.90	17.09
Contents measured	74.66	78.56	79.56	78.65	78.76	78.04	1.93
Contents calculated	92.23	92.39	78.69	76.35	93.94	86.72	8.47
Ratio measured	0.43	0.37	0.43	0.44	0.46	0.43	0.03
Ratio calculated	0.45	0.40	0.43	0.39	0.45	0.42	0.03
Surface area at hamate (mm^2)							
Canal measured	151.49	150.56	176.02	154.76	146.05	155.78	11.74
Canal calculated	185.31	186.67	166.25	183.35	170.21	178.36	9.43
Contents measured	87.83	83.39	84.52	87.85	63.37	81.39	10.27
Contents calculated	97.25	104.39	93.58	94.86	90.55	96.13	5.21
Ratio measured	0.58	0.55	0.48	0.56	0.49	0.53	0.04
Ratio calculated	0.52	0.56	0.56	0.52	0.53	0.54	0.02

compared with a linear distribution in the latter group. Robbins,[6] in his anatomic study, noted the cross-sectional area of the carpal tunnel to be its smallest and the median nerve to be compressed and flattened to the greatest degree at the level of the hook of the hamate. The present study yielded similar results. The cross-sectioned area was consistently smaller and contents/canal ratios were consistently higher at the level of the distal aspect of the hook of the hamate (Fig. 2).

Synovial hypertrophy has previously been linked to CTS.[7, 8] Moreover, it has been identified with the use of MRI.[9] Synovial hypertrophy was found in one specimen in the present study. This was not noticed on MRI before sectioning; on review, however, the hypertrophy could be identified on MRI by an increase in medium-intensity structures separating the tendons as compared with a normal wrist (Fig 1). Synovial hypertrophy in this specimen was not diffuse but, rather, isolated to a transverse band ranging in thickness from 1.3 to 2.7 mm. The past medical history of the person used in this study was not available.

Volumes calculated in the present study do not correlate with those found by Richman et al. This, however, is not surprising in view of the differences in method. In their study, a dissection was carried out in an attempt to reconstruct the volume of the entire canal. The purpose of the present study was not to reconstruct the volume of the entire canal but, rather, to establish a contents/canal ratio. We used easily definable landmarks, including the proximal aspect of the canal, which may be duplicated in future clinical studies. Previous clinical investigations have designated the proximal aspect of the carpal tunnel as the site of median nerve constriction.[7,8] The hook of the hamate has been shown to be the most constrictive portion of the canal.[6,10] Both of these sites were included in the present study. Furthermore, cross-sectional area measurements were used to evaluate the canal distal to the hamate (Fig. 3). It should be noted that the contents used to construct ratios included only the tendons and the median nerve. The synovial sheaths were not included in laboratory measurements; nor were any attempts made to calculate the synovial volume from MRI.

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