ASSESSMENT OF MANUAL SEGMENTATION OF MAGNETIC RESONANCE IMAGES OF SKELETAL MUSCLES

G. Zoabli[1-2], P.A. Mathieu[1-2], C.E Aubin[1-2], A. Tinlot[3], M. Beausejour[2], V. Feipel[3], A. Malanda[4]
[1]Institut de génie biomédical, Univ. de Montréal, Canada . [2]Laboratoire LIS3D, Hôpital Sainte-Justine, Canada,
[3]Univ. Libre de Bruxelles, Belgique. [4]Depart. de Ingeniería Eléctrica y Electrónica, Univ. Pública de Navarra, Spain

Abstract- **Technical considerations related to the manual detection of muscles boundaries from magnetic resonance images (MRI) are evaluated. Two commercial image processing software programs were used by two operators to obtain measurements on MRI from a phantom and from muscles of the upper limb and trunk. Optimization of MRI acquisition sequences, image resolution, image contrast, and sub-sampling effect were also experimented. No significant intra- and inter-operator variation was observed and results obtained from both softwares were similar. Generally, sub-millimetric slice thickness offers better definition but lower contrast than thicker slices. Differences in estimated length, surface and volume of upper limb and back muscles were small for slice thickness varying between 1.5 and 4 mm. Accuracy of manual segmentation of muscles with MRI was found more dependant on the contrast than on the human factors.**

I. INTRODUCTION

For the study of soft tissue such as muscles, radiographs and MRI scans are the main imaging modalities [3]. In most cases, plain radiographs remain the initial evaluation-imaging mainstay, followed by MRI. Muscle has a higher mobility of water protons than subcutaneous fat and bone marrow and shows significantly higher diffusion values [1]. With thin sections (1.5-2 mm) and appropriate pulse sequencing, a good contrast between bone, cartilage and joint fluid can be obtained [4]. Contrast agent can be used to enhance image quality but the procedure thus becomes invasive. In the evaluation of spinal trauma, MRI has a complementary role with computed tomography as it excels at the evaluation of deformities and neoplasms [2]. However, when information on muscles is considered, their individual boundaries are difficult to identify. That prevents the collection of reliable measurements for clinical or research purposes. This problem could be alleviated with a sequence providing well-contrasted images with a good resolution. Some image processing techniques could also help. For instance, information obtained on the contour of a muscle in one plane can be combined to the information obtained in other views to produce more reliable segmentation [5].

With this multi-plane segmentation approach, various measurements were done and a MRI acquisition was carried out to find out a good compromise between resolution, contrast, and acquisition time for muscle MRI.

II. METHODOLOGY

1) Segmentation accuracy: A generic MRI phantom consisting of a plexiglass cylinder (ϕ= 187 mm, 60 mm thick) was used. As illustrated in Fig. 1, it contains 55 holes, the diameters of which vary from column 11 (11.1, 11.2, 11.3, 11.4, 11.5 mm) to column 1 (1.1, 1.2, 1.3, 1.4, 1.5 mm). T1-weighted spin-echo images were obtained and contrast threshold between holes and plexiglass was set at 1100 (0= black, 4095=white). Pixel intensities ≤1100 were thus associated with the holes.

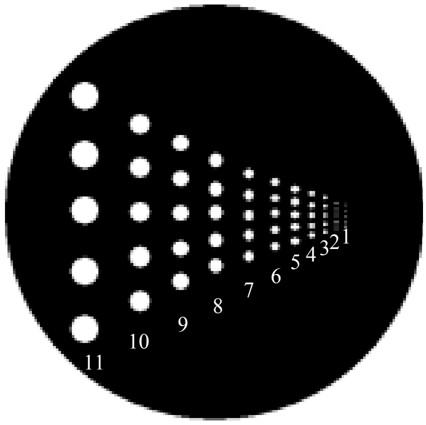

Fig. 1. Generic MRI phantom (M 222 FL, Siemens). Hole diameter ranges from 11.5 mm down to 1.1 mm.

2) Performance of image processing softwares: Two commercial softwares (Amira® 2.2 and SliceOmatic® 4.2) were used for the manual segmentation of MRI obtained with the phantom as well as images of the upper limb and the trunk of normal subjects. Ease and duration of the segmentation process, accepted read and write image formats, and surface statistics of both packages were compared.

3) Inter- and intra-operator variations: MRI of a deltoid muscle of a normal subject obtained under conditions similar to those of the phantom were used. Manual segmentation of the muscle was performed three times by two operators (O1, O2) well experienced with each software.

4) MRI acquisition sequences: To identify the sequence offering the best compromise between resolution, contrast and duration for muscles segmentation, 9 different T1- and T2-weighted spin-echo sequences with various slice thickness were experienced for imaging the trunk of a healthy subject.

5) Sub-sampling: To assess the influence of slice thickness on volume estimation accuracy, images of the upper limb and of the trunk were sub-sampled at ratios of 2, 3, 4, 5, 6, 7, before manual segmentation.

III. RESULTS

A. Segmentation accuracy with the phantom

An axial slice of the phantom obtained with a field of view (FOV) similar to clinical experiences (pixel of 1.41x1.41 mm) is illustrated in Fig. 2.

Report Documentation Page

Report Date	Report Type	Dates Covered (from... to)
25 Oct 2001	N/A	-

Title and Subtitle Assessment of Manual Segmentation of Magnetic Resonance Images of Skeletal Muscles	**Contract Number**
	Grant Number
	Program Element Number
Author(s)	**Project Number**
	Task Number
	Work Unit Number
Performing Organization Name(s) and Address(es) Institut de genie biomedical Univ de Montreal Canada	**Performing Organization Report Number**
Sponsoring/Monitoring Agency Name(s) and Address(es) US Army Research, Development & Standardization Group (UK) PSC 802 Box 15 FPO AE 09499-1500	**Sponsor/Monitor's Acronym(s)**
	Sponsor/Monitor's Report Number(s)
Distribution/Availability Statement Approved for public release, distribution unlimited	
Supplementary Notes Papers from 23rd Annual International Conference of the IEEE Engineering in Medicine and Biology Society, October 25-28, 2001, held in Istanbul, Turkey. See also ADM001351 for entire conference on cd-rom., The original document contains color images.	
Abstract	
Subject Terms	
Report Classification unclassified	**Classification of this page** unclassified
Classification of Abstract unclassified	**Limitation of Abstract** UU
Number of Pages 3	

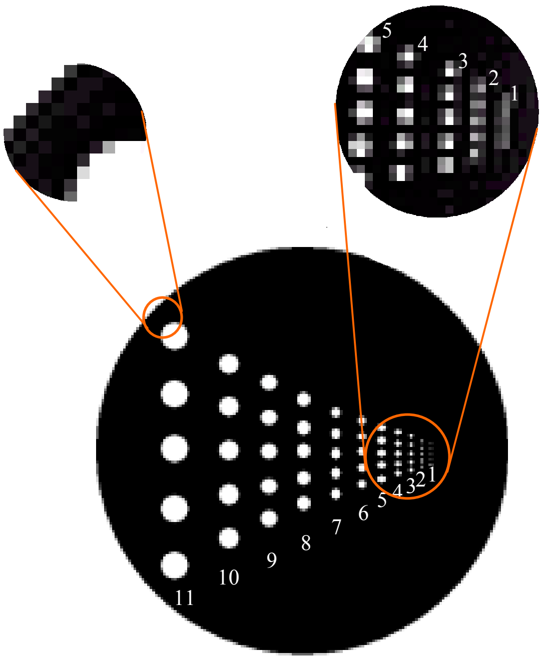

Fig. 2. Image of the phantom (inverted color map, TR=500 ms. TI=0, TE=14 ms). Pixel dimensions are 1.41x1.41 mm. Slice thickness was 1 mm.

Contour of the phantom is jagged (left enlarged portion) and with this pixel size, spatial resolution is ≈2 mm (top right enlarged portion). Images of the holes were not circular but elliptic. Taking mean values of their small and large axes, measurement error on diameters ranged from 18% (11 mm holes) up to -44% (3 mm holes) as can be seen in Fig. 3.

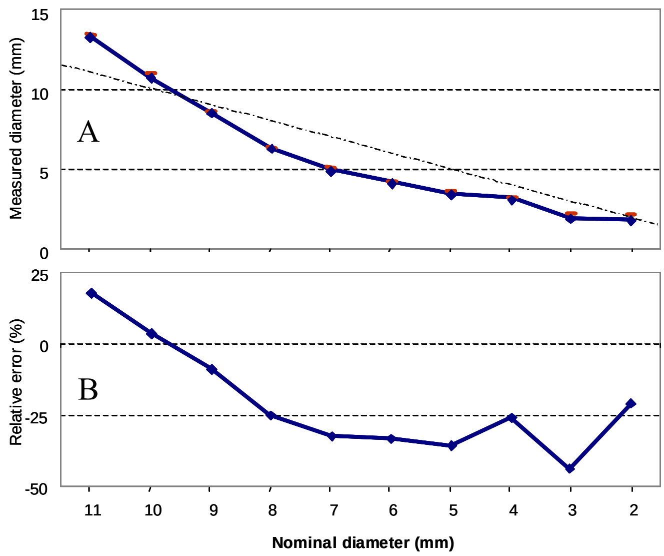

Fig. 3. A: Experimentally measured vs nominal hole diameter (dash-dotted line). B: estimated error on the holes diameter.

B. Characteristics of image processing softwares used

The two packages operate differently. While Amira is a multi-windows program, the other one is single window based. SliceOmatic provides more measurement tools (ruler, caliper, protractor, surface and perimeter of any region of interest (ROI)) and more statistics on the segmented areas than Amira. 3D reconstruction module of Amira offers the most contrasted views as a result of active contour capability during segmentation process. SliceOmatic smoothing module is more elaborated.

C. Inter- intra-operator variations

Images of deltoid muscle were segmented 3 times by each operator. Segmentation time was 78±6 min for O1 and 69±31 min for O2 with SliceOmatic, but only 43±10 (O1) and 46±3 (O2) min with Amira. Lower values were obtained with Amira because it offers active contour detection that greatly reduces segmentation time. Measurement of length, surface and volume obtained from segmented muscles were quite similar with both softwares. O1 had a slight tendency to under-evaluate the volume of the muscles compared to O2 (Fig. 4).

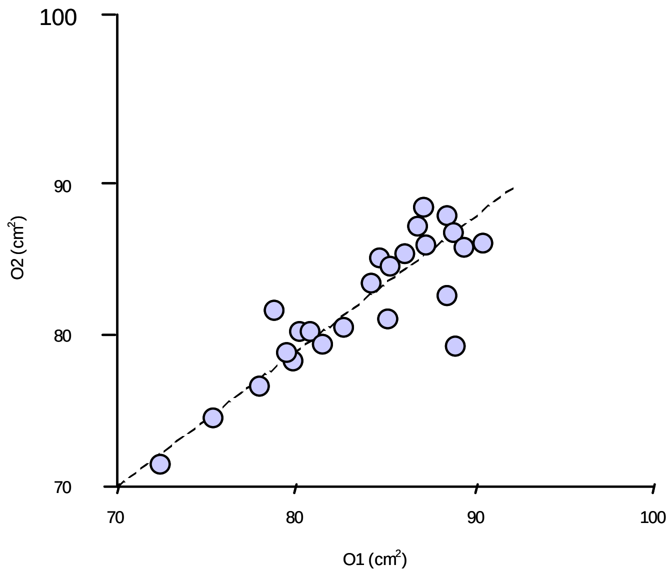

Fig. 4 Correlation between surface measurements obtained by both operators with SliceOmatic.

D. Optimal MRI acquisition sequence

Greater contrast was obtained with large slice thickness than with sub-millimetric ones. The best resolution was found for slice thickness of 1 mm but contrast was smaller than in 3 mm slices. Among the 9 sequences tested, the best compromise between trunk images acquisition time, resolution and contrast were obtained with the following parameters: TR 595 ms, TI: 0 s, TE: 14 ms, matrix 256x256, slice thickness 4 mm.

E. Sub-sampling effect

As long as slice thickness remain <4 mm, no major difference in the estimated volume of the erector spinae (ES) muscles was observed (Fig. 5A). When muscles of the upper limb were sub-sampled, similar results were obtained up to 7 mm (Fig. 5B).

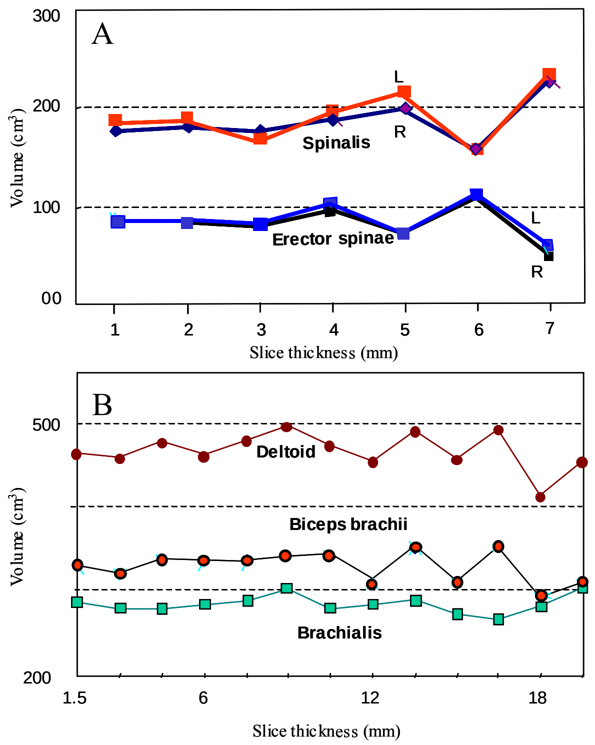

Fig. 5. Effect of sub-sampling ratio varying from 2 to 7. A: original images of the trunk were 1 mm thick. (R: right, L: left). B: thickness of original upper limb images was 1.5 mm.

IV. DISCUSSION

Measurement errors are associated with the ratio of the pixel size relative to the dimension of the measured structures. As lower ratios ensure more accurate measurements, FOV must be kept as small as possible.

While well-contrasted images are easy to segment, good resolution is required for accurate measurements. A best compromise between resolution (which affects acquisition time) and contrast is to be found. Sub-millimetric slice thickness offers a very good resolution but images are blurred and the acquisition time is long and may cause motion artifacts. In our case, the best compromise between contrast, and resolution was found for slice thickness varying between ≈1.5 and 4 mm.

Sub-sampling results indicate that slice thickness is to be linked to how importantly dimension of the muscles under study is changing in the plane of the image. Since the contour of the deltoid and biceps brachii muscles varies more than brachialis, fewer slices have to be taken for accurate measurements of the brachialis than for the two other muscles. Constant cross-sections are thus insensitive to slice thickness while small slice thickness is more appropriated to small anatomical structures. An optimal sub-milimetric slice thickness implies a long acquisition time during which the subject has to remain immobile. This could be possible for a short acquisition time when the volume of interest is very small.

Various commercial image processing softwares such as Volview®, 3D-Doctor®, AnalyzePC®, etc. have been evaluated. The particularity of SliceOmatic is direct biometry with electronic calipers while Amira has active contour segmentation capability. With both software programs used, segmentation can be done automatically by setting thresholds. This method can be applied for the detection of skin boundaries and the study of subcutaneous fat distribution. It is not appropriated for muscle segmentation where no clear threshold exists to detect the boundaries between muscles. Manual segmentation thus appears to be more appropriate for personalized biometry measurements where boundaries between muscles have to be identified with confidence.

Manual segmentation is usually carried out by an expert. However, by combining contours obtained from many planes, satisfactory results can be obtained with non-expert operators [5]. Initially, the use of an atlas was required but this need vanished quite rapidly as the operator gained experience. With the advent of newer MRI system, better image resolution and contrast can be expected. Manual segmentation procedures will then be easier.

V. CONCLUSION

The most important factor for manual segmentation is contrast between muscles. It was found optimal with slice thickness ≥1.5 mm. Development of a contrast agent to enhance boundaries between muscles could eventually lead to the use of automatic segmentation algorithms.

ACKNOWLEDGMENT

We acknowledge the contribution of Drs G. Beaudouin and H. Mallouche of the Centre hospitalier universitaire de Montréal, for the image acquisitions. During this work, A. Malanda was supported by a Spanish MEC grant.

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Work supported by NSERC and FCAR.