Correlation between manual measurements and an automated algorithm in measuring muscle thickness, pennation angle and fascicle length

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Introduction

Running is one of the most popular sports in the Netherlands (1). During running a lot of muscles are used to generate enough force to move the body and keep it in balance (2). Although a lot is know about the muscles in isometric conditions, little is know about the muscles in dynamic conditions (3). Studying the muscle is dynamic conditions is time consuming and prone to human error (4). At the Technical University of Eindhoven an automated algorithm is being developed to track muscle thickness, pennation angle and fascicle length in dynamic conditions. This algorithm could significantly reduce time needed to process ultrasound images of the muscles. However, little is known about the effectiveness of this algorithm.

The aim of this graduation project was to find out if there is a correlation between the automated and manual tracking of muscle thickness, pennation angle and fascicle length in healthy volunteers.

Methods

Study design
This was a retrospective cross-sectional quantitative measurement study. In this study an automatic algorithm was compared to a manual processing method. From the images the muscle thickness (MT), pennation angle (PA) and fascicle length (FL) were measured. These variables were used to determine the correlation between the automatic algorithm and the manual method.

Image selection
- 5 random patients chosen from the dataset of a previous study

Data gathering
- 5 patients randomly selected from a database with 201 frames of the medial gastrocnemius
- Images were processed manually in MATLAB (figure 1A)
- 5 points were made on the superior aponeurosis and 5 points on the inferior aponeurosis
- 3 fascicles traced as long as they were visible. (figure 1A)
- Repeated until all 201 images from all 5 patients were finished
- Automated algorithm performed measurements (figure 1B)
- Both processing methods were timed to determine the average time it took for 1 frame
- Results from transformed from .mat files to excel files
- Data exported from excel and imported to SPSS where statistical analysis was performed

Data analysis
- Shapiro Wilk and Kolmogorov Smirnov test of parametricity
- Two way mixed intraclass correlation coefficient(ICC) of each patient and of all data combined

Ethics
- No approval required for this study, all the data was anonymised

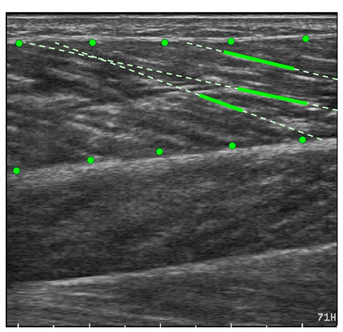

Figure 1 A) Manual measurements of the aponeurosis and fascicles. The continuous lines represent the fascicle traced by the operator, the dotted line is the extrapolated fascicle length from inferior to superior aponeurosis.

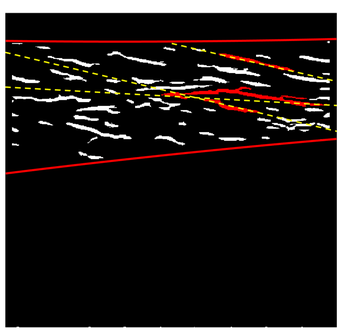

Figure 1 B) Automatic measurements on the same image. The two horizontal lines represent the aponeurosis selected by the algorithm. The three linens in between represent the fascicles traced by the algorithm. The dotted lines are the extrapolated fascicle lengths.

Results

Test population
Table 1 shows the description of the subjects that participated in this study.

Table 1 description of the participants

	Age (Y)	Gender	Height (cm)	Weight (kg)	Dominant leg
Patient 1	24	male	184	77.8	right
Patient 2	29	male	188	82	left
Patient 3	25	female	167	60.2	right
Patient 4	24	female	175	72	right
Patient 5	24	male	179	58.2	right

Obtained variables
After image processing the data was extracted from MATLAB were the following values were obtained
The medians of the MT, PA and FL of all subjects combined were 15.22 mm, 15.30 degrees (°) and 6.35 cm respectively with an IQR of 3.11 mm, 5.37° and 2.04 cm respectively for the manual method. For the automatic algorithm the medians of the MT, PA and FL were 15.25 mm, 13.56° and 7.39 cm respectively with an IQR of 3.32 mm, 5.43° and 2.47 cm respectively

Data analysis
Results from the tow way mixed ICC can be seen in table 2. The ICC for the individual patients can be seen in table 3 With the data from the MT, PA, FL graphs were made to show the correlation (figure 2).
According to to Koo and Li (5) the variables showed the following reliability scores:
- **MT** showed **excellent reliability** with an **ICC of 0,990**
- **PA** showed **good reliability** with an **ICC of 0,766**
- **FL** showed **poor reliability** with an **ICC of 0,372**

- Manual processing took 26s per image
- The Automatic algorithm took 0,6s per image

Table 2 ICC values with statistical significants and the mean error.

	ICC	p-value	Mean error
MT (mm)	0.990	0.00	0,19
PA (degree)	0.766	0.00	2,24
FL (mm)	0.372	0.00	1,04

Table 3 ICC values from each individual patient.

	Patient 1		Patient 2		Patient 3		Patient 4		Patient 5	
	ICC	P-value	ICC	P-value	ICC	P-value	ICC	P-value	ICC	P-value
MT	0.966	0.00	0.936	0.00	0.774	0.00	0.991	0.00	0.944	0.00
PA	0.733	0.00	0.573	0.00	0.617	0.00	0.712	0.00	0.695	0.00
FL	0.124	0.03	0.346	0.00	0.388	0.00	0.533	0.00	0.298	0.00

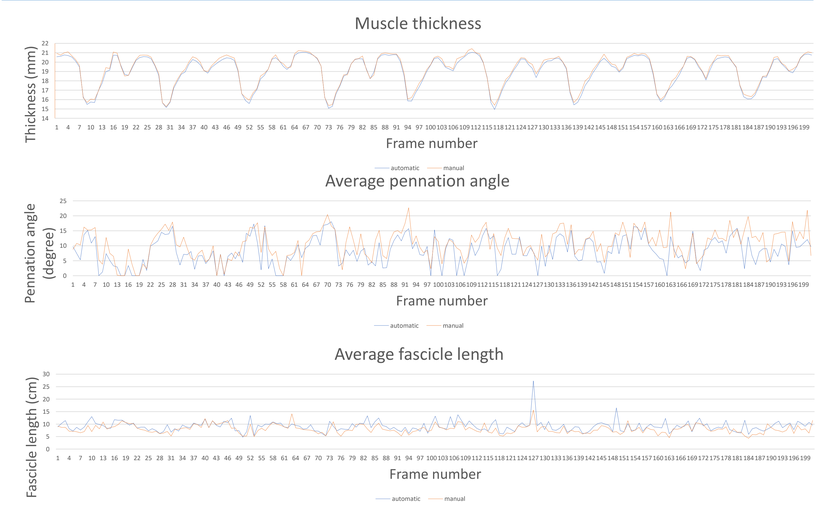

Figure 2) Graphs showing the muscle thickness, pennation angle and fascicle length for patient 4.

Discussion

Summary
The results showed that the muscle thickness had an excellent reliability with an ICC value of 0.990, the pennation angle had a good reliability with an ICC of 0.766 and the fascicle length had a poor reliability with an ICC of 0.372. The automated algorithm was 43 times faster in processing the images than the operator.

Unexpected results
- Lower ICC scores for the PA and FL than expected → The lower scores for the PA and FL are attributed to the shortcoming of the algorithm in detecting the right fascicle (figure 1B).
- Big difference between ICC value for MT for patient 3 compared to other patients → The difference of the ICC for patient 3 is attributed to an outlier in the dataset where the fascicle length that the algorithm measured was close to 80 cm.
- Big difference between ICC value for FL for patient 1 compared to other patients →The difference of the ICC for patient 1 is attributed to the smaller size of the muscle.

Comparison with similar studies
- MT is comparable with other studies (errors of 0,30mm, 0,25mm and -0,05mm)(6-8)
- PA and FL are worse than in other studies (ICC of 0,88 – 0,95)(9-11) → These differences can be attributed to the way that the current algorithm filters the images. Each study used a different form of filter for the images.

Strong points
- 1005 images used
- Tested on multiple subjects

Weak points
- No inter and intra rater reliability for both the automated algorithm and manual measurements
- Tested on only 1 muscle

Recommendations for future studies
- Intra and interrater reliability for the algorithm and manual measurements
- Test the algorithm on different muscles and different image planes
- Investigate different filter methods (LGIF, Lucas-Kenade optical flow, Gabor wavelet)

Application for the practice
The algorithm could be used in it's current form to quickly gather information about the muscle thickness of the medial gastrocnemius muscle. This could save time when researching muscle architecture in the biomedical field. When the algorithm is optimised for PA and FL it could be used in a clinical setting to determine the MT, PA and FL quickly. This can then be used to develop improved training schedules for athletes or people that are rehabilitating.

Conclusion

This study showed that there was a high correlation between automated and manual tracking of muscle thickness in the medial gastrocnemius in healthy volunteers. Although the algorithm detects fascicles and calculates the pennation angle, the correlation between automated and manual tracking is not as high as it should be to be interchangeable with an human operator. Further development of the algorithm is required for it to work as reliable as manual processing to be used in a clinical setting to provide an advantage in training and rehabilitation schedules.

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