K. M. Diab
A. Shalabi
J. A. Sevastik
P. Güntner

A method for morphometric study of the intercostal muscles by high-resolution ultrasound

Received: 24 March 1997
Revised: 8 November 1997
Accepted: 27 November 1997

K. M. Diab · J. A. Sevastik (✉)
Department of Orthopaedic Surgery,
Huddinge, University Hospital,
Karolinska Institute,
S-141 86 Huddinge; Stockholm, Sweden

A. Shalabi · P. Güntner
Department of Diagnostic Radiology,
Huddinge University Hospital,
Karolinska Institute, Stockholm, Sweden

Abstract Besides their main function of assisting in breathing, the intercostal muscles also play an important role in maintaining the balance of forces acting on the thoracic cage including the thoracic spine. Since it is virtually impossible to conduct a morphometric evaluation of these muscles, a study was undertaken to standardize an ultrasound method for accurate determination of the area of the intercostal muscles and hence, indirectly, their function. In a pilot study, the area of the intercostal muscles was determined on the torso of a fresh specimen of a grown-up lamb, using high-resolution ultrasound and CT, and by direct measurements of the intercostal space at two points equidistant from the midline on the left and the right sides of the back of the specimen. The size of the intercostal muscles was determined either by tracing or from the perpendiculars of the area of the muscles both on sonographs and on CT scans. The re-

sults showed that measurements derived from the perpendiculars of the muscle area on the sonographs give better estimates than those derived from CT scans, and were in good accordance with the direct measurements of the corresponding intercostal space on the specimen. To evaluate the applicability of the method in vivo the area of the intercostal muscles at maximal inhalation and exhalation was determined in one adult person. It was found that measurements at maximal inhalation were more accurate than those taken at maximal exhalation. It is concluded that ultrasonography is a reliable, safe, easy to apply and high-resolution method for measurements of the area and, indirectly, of the activity of the intercostal muscles in humans, and that the measurements are more accurate at maximal inhalation.

Key words Intercostal muscles · Morphometry · Ultrasonography

Introduction

The intercostal muscles constitute an integral part of the thoracic cage. Their main function is to assist in breathing. Breathing exercises are largely included in physiotherapy programmes for treatment of cardiopulmonary impairment.

The intercostal muscles also play an important role in maintaining the balance of forces acting on the thoracic

cage including the thoracic spine. Their importance in the development of thoracospinal deformity in scoliosis has been documented by several experimental studies [10, 11, 13, 14, 18, 22]. Moreover, it has been found that arm movements are a powerful cause of reflex contraction of the intercostal muscles and that these can be used in the treatment of scoliosis [16]. It has also been reported that breathing exercises have a beneficial effect not only on the vital capacity and rib mobility in idiopathic scoliosis

[20], but also on the progression of the scoliotic curve [21].

In view of the accumulated evidence regarding the importance of the intercostal muscles in the function of the thoracic cage and in the maintenance of the normal alignment of the thoracic spine, and considering that reliable morphometric evaluation of these muscles *in vivo* is virtually impossible, it was considered useful to examine the possibilities for measuring the cross-sectional area of the intercostal muscles and hence, indirectly, their functional state. It is believed that development of an adequate method for this purpose would improve future research related not only to the aetiology, the pathogenesis and the pathomechanism, but also to the evaluation of the results of treatment of scoliosis.

Real ultrasound imaging has been widely used for measuring muscular thickness [3, 5–8, 12] and can give high resolution [17]. The method does not involve ionising radiation, is not expensive and is easily available [9]. The aim of this study was to standardise an ultrasound method for morphometric studies of the intercostal muscles in one animal specimen and to compare the results with CT measurements and with direct measurements of the intercostal space on the specimen. Furthermore, to examine the bearing the results of the model study had on *in vivo* applications the method was tried in one adult person.

Material and methods

Pilot study

The torso of a fresh specimen of a grown-up lamb, including the scapulae and the overarms, was skinned and the subcutaneous fat and the viscera were removed, the thoracic cage being kept intact.

The midline over the spinous processes was marked with a marking pen and points were also marked symmetrically from the midline on both sides on the back of the specimen over the intercostal spaces, between the 5th and 12th ribs at 7 cm from the midline and then a further 5 cm lateral to it, approximately on the dorsal axillary line (Fig. 1).

The specimen was placed lying down on the movable CT table with its longitudinal axis parallel with the CT beam. Then the specimen was rotated around its longitudinal axis until the X-ray beam fell perpendicular to the chest wall. Four longitudinal scans were conducted on the specimen at the level of the previously marked points. An area of six to seven intercostal spaces (usually seven spaces at 7 cm and five at 12 cm from the midline) was then selected and the surface area of the muscle image of each intercostal space was evaluated. The mean values of the measurements from each side were then computed and finally the difference between the means of the right and left sides was calculated (Fig. 2).

For the ultrasound technique, an Acuson 128 XP/4 computed sonograph machine with a 5-MHz probe was used. Measurements of the intercostal muscle area on the left and right sides of the specimen were performed on the same points previously determined for the vertical CT scanning. The surface area of each intercostal muscle at each rib interspace was measured either by tracing or from the perpendiculars on the sonographs as in the CT scans (Fig. 2).

The expanse of the muscular surface was computed by the ultrasound and the CT machines respectively.

Fig. 1 Predetermined lines drawn on the specimen: *a* mid-line, *b* at 7 cm lateral on each side, *c* at 12 cm lateral on each side

Fig. 2 Methods of measurement of the intercostal muscle surface area by CT and sonography: *A* measurement from the perpendiculars and *B* by tracing

Finally, the real distance between the relevant ribs, corresponding to the longitudinal diameter of the intercostal muscle area, was measured directly on the specimen with a Vernier calliper.

Human trial

To evaluate the applicability of the ultrasound method for *in vivo* measurements of the area of the intercostal muscles in humans, one normal man was examined, according to the principles of the pilot study, during maximal inhalation and exhalation with the subject prone in neutral position.

The same ultrasound machine as in the pilot study was used. The 5-MHz probe was placed perpendicular to the chest wall and parallel to the longitudinal axis of the body, after applying an echogenic gel on the skin. The probe was passed over a line at the medial border of the left and right scapulae. Measurements started in an upwards direction from the intercostal spaces between the 11th and 12th ribs to those between the 5th and 6th ribs.

For estimation of the interobserver repeatability, measurements of the sonographic image of the area of the intercostal muscles at

full inhalation and exhalation was evaluated from the perpendiculars separately by two independent observers. The intraobserver repeatability was tested for six measurements by one observer. At least 1 day (mean 4 days) elapsed between each measurement.

Statistical analysis

ANOVA was used to test the significance of the recorded differences between the right and the left sides, between the three different methods of examination and between the two methods of measurement used in the pilot study and in the human trial.

Results

Pilot study

The area of the intercostal muscles as measured on the sonographs showed no significant difference between the right and left sides at either 7 or 12 cm from the midline whether measured from the perpendiculars or by tracing (Table 1).

The muscular area measured on the CT scans either from the perpendiculars or by tracing showed no significant difference between left and right sides at 12 cm from the midline. At 7 cm lateral of the midline, there was a significant difference in area between the two sides in measurements from the perpendiculars (Table 1).

Comparison of measurements of the sonographs and on the CT scans disclosed no significant difference in the area of the intercostal muscles at any level for either side, when the area of interest was derived from the perpendiculars (Table 2).

Table 1 Mean difference between the left and right intercostal muscle area at 7 and 12 cm respectively from the midline of the specimen computed from the perpendiculars and by tracing on sonographs and CT scans (left minus right, mm²)

Method	Sonographs		CT-scans	
	7 cm	12 cm	7 cm	12 cm
Perpendiculars	-0.50	-10.78	-12.43*	-14.00
Tracing	0.57	-2.50	-16.43	-26.25

* Significant at 95%

Table 2 Difference between the sonograph and CT scan values of the area of the right and left intercostal muscles at 7 and 12 cm respectively from the midline of the specimen computed from the perpendiculars and by tracing (mean difference, mm²)

Side	Perpendiculars		Tracing	
	7 cm	12 cm	7 cm	12 cm
Right	3.78	3.92	-24.86**	-9.00
Left	15.71	6.98	-7.86	-10.40*

* Significant at 95%; ** Significant at 99%

Table 3 Comparison of values for the longitudinal axes of the intercostal muscle obtained by direct measurements on the specimen, by ultrasound (US) and by CT at 7 and 12 cm respectively from the midline of the specimen (mean difference, mm)

	US vs real distance	CT vs real distance	US vs CT
Right at 7 cm	0.64	-0.93	1.57
Left at 7 cm	1.10	-0.43	1.53
Right at 12 cm	0.06	0.70	-0.64
Left at 12 cm	2.12**	0.1	2.02*

* Significant at 95%; ** Significant at 99%

When the tracing method was used, there was a significant difference between the values obtained by the two methods on the right side at 7 cm and on the left side at 12 cm from the midline (Table 2).

Direct measurements of the concerned intercostal distances on the specimen showed no significant differences between the right and the left side either at 7 cm or at 12 cm from the midline. The mean difference was -0.36 mm ($P > 0.05$) at 7 cm from the midline and -0.2 mm ($P > 0.05$) at 12 cm.

Comparisons between direct measurements of the intercostal distance on the specimen and corresponding measurements on sonographs and CT scans showed no significant differences at 7 cm from the midline. At 12 cm lateral to the midline on the left side, the ultrasound values were significantly higher than the CT or the direct measures (Table 3).

Human trial

The intraobserver variability of the values for the difference in the area of the intercostal muscle between the left and right side at full inhalation and at full exhalation was not significant except at the levels 7 to 8, where the difference was significant both at full inhalation and at full exhalation. Variability in measurements of the difference in the area of the intercostal muscles at full inhalation compared to full exhalation was significant on the right side at the level between the 7th and the 8th ribs (Table 4).

Interobserver variability in measurements of the left side during full inhalation and full exhalation was not significant except at three levels during full exhalation (Table 5). There were no significant differences between the measurements of the two observers on the right side either at full inhalation or at full exhalation except at one level during full inhalation (Table 5).

As a whole there was no significant interobserver variability in measurements of the difference between the left and right side either at full inhalation or at full exhalation, and there was no significant variability in measurements of the difference between full inhalation and full exhalation for either side (Table 6).

Table 4 Intraobserver variability in measurements of the difference between left and right intercostal muscle area (left minus right) at full inhalation and full exhalation, and between inhalation and exhalation on the left and the right side, evaluated from the perpendiculars on the sonographs of the examined person (mean difference, mm²)

* Significant at 95%; ** Significant at 99%

Level	Full inhal L – R	Full exhal L – R	Inhal – exhal Left	Inhal – exhal Right
5th– 6th	11.48	16.80	–4.60	0.72
6th– 7th	16.02	34.48	–20.11	–1.65
7th– 8th	55.05**	40.16*	0.79	–14.10*
8th– 9th	25.38	22.11	9.63	6.36
9th–10th	–4.35	2.74	–8.34	–1.26
10th–11th	2.40	–19.96	11.85	–10.52
11th–12th	19.75	–15.74	–1.64	–37.13

Table 5 Interobserver variability in values for the left and right intercostal muscle area, evaluated from the perpendiculars at seven intercostal spaces during full inhalation and full exhalation (mean difference, mm²)

Level	During full inhalation		During full exhalation	
	Left	Right	Left	Right
5th– 6th	8.77	–6.98	30.52	–2.33
6th– 7th	34.65	3.75	37.10*	1.86
7th– 8th	45.68	–32.05	54.15**	–13.38
8th– 9th	14.52	40.38	21.31*	–1.49
9th–10th	34.50	14.63	10.83	15.94
10th–11th	45.08	13.18*	24.55	45.98
11th–12th	29.74	–76.45	8.25	7.54

* Significant at 95%; ** Significant at 99%

Table 6 Interobserver variability in measurements of the difference between the left and right intercostal muscle area as derived from the perpendiculars on sonographs of the examined person at full inhalation and full exhalation and in measurements of the difference between full inhalation and full exhalation on the left and right sides (means of differences at all spaces, mm²)

Observer	Full inhal L – R	Full exhal L – R	Inhal – Exhal Left	Inhal – Exhal Right
Observer 1	10.11	11.51	–1.78	–0.37
Observer 2	–19.21	–16.36	4.26	7.11

Discussion

Evaluation of morphometric and functional changes in the muscles is of paramount importance in studies of dysfunction of the locomotor system. This is particularly valid with regard to the mechanisms responsible for the development of idiopathic scoliosis.

Several reports presented over the years have shown morphometric and histochemical changes [2, 4, 9, 19, 23] or changes in myoelectric activity [1, 15, 24] of the dorsal muscles in scoliotic patients. However, despite the documented role of the intercostal muscles in the maintenance of normal alignment of the thoracic spine and in the de-

velopment of scoliosis, because of special anatomical relations, existing methods cannot be applied for morphometric or functional studies of these muscles. Therefore, the derived method paves the way for evaluation of the area of the intercostal muscles and, indirectly, of their function.

The results of the model study indicated that there are no significant differences between the area of the right and left intercostal muscles at a distance of 7 or 12 cm from the midline of the spine whether measured on sonographs or on CT scans by tracing or from the perpendiculars. Similarly, direct measurements of the intercostal spaces on an animal specimen yield equal values for both sides.

Moreover, it has been found that, both on sonographs and on CT scans, evaluation of the area of the intercostal muscles from the perpendiculars is an easier and safer method than tracing of the area. This is in accordance with an earlier report that there is no significant difference between the two methods of measurement [6]. Good agreement was also found between the measurements made on CT scans, those made on sonographs and direct measurements of the corresponding intercostal spaces on the specimen.

The human trial was performed to ascertain the applicability of the ultrasound method *in vivo* and to study the influence of the respiratory movements on the area of the intercostal muscles in humans.

The intra- and interobserver measurements of the intercostal muscle area on sonographs in this isolated trial showed good repeatability on both sides at almost all intercostal spaces between the 5th and 12th ribs. The results also showed that, under normal circumstances, there is symmetrical expansion of the intercostal muscle area and indirectly of muscular activity at maximal inhalation and maximal exhalation. This finding emphasises the role of the intercostal muscles in keeping the chest wall in balance during breathing.

The observation that the interobserver difference, except at three levels on the left side at maximal exhalation, was not significant either for the left or the right side indicates that measurements of the intercostal muscle area are more accurate at full inhalation than at full exhalation. This observation was noted by the observers during sono-

graphic examination of the intercostal muscles. No significant differences were found between the left and right sides during full inhalation or full exhalation.

As a whole, the results of these studies indicate that ultrasonography is a reliable, safe, easy to apply and high-resolution method for measurement of the area in question which, indirectly, reflects the activity of the intercostal muscles. Moreover, the results of the human trial showed

that measurements of the intercostal muscle area between the 5th and 12th ribs approximately at the medial scapular line computed from the perpendiculars of the area at maximal inhalation give more reliable results.

Acknowledgement This study was supported by research grants from the Karolinska Institute and King Oscar II and Queen Sofia's Golden Anniversary Foundation, Stockholm, Sweden.

References

- Alexander MA, Season EH (1978) Idiopathic scoliosis: an electromyographic study. *Arch Phys Med Rehabil* 59: 314–315
- Bylund P, Jansson E, Dahlberg E, Eriksson E (1987) Muscle fiber types in thoracic erector spinae muscles. *Clin Orthop* 214: 222–228
- Gershuni DH, Gosink BB, Hargens AR, Gougl RN, Forsythe JR, Mubarak SJ, Akeson WH (1982) Ultrasound evaluation of the anterior musculofacial compartment of the leg following exercise. *Clin Orthop* 167: 185–190
- Green RJA (1981) Histochemistry and ultrastructure of the paraspinal muscles in idiopathic scoliosis and in control subjects. *Med Lab Sci* 38: 197–216
- Heckmatt JZ, Pier N, Dubowitz V (1988) Measurement of quadriceps muscle thickness and subcutaneous tissue thickness in normal children by real-time ultrasound imaging. *J Clin Ultrasound* 16: 171–176
- Hides JA, Cooper DH, Stokes MJ (1992) Diagnostic ultrasound imaging for measurement of the lumbar multifidus muscle in normal young adults. *Physiother Theory Pract* 8: 19–26
- Hides JA, Stokes MJ, Saide M, Jull GA, Cooper DH (1994) Evidence of lumbar multifidus muscle wasting ipsilateral to symptoms in patients with acute/subacute low back pain. *Spine* 19: 165–172
- Kennelly KP, Stokes MJ (1993) Pattern of asymmetry of paraspinal muscle size in adolescent idiopathic scoliosis examined by real-time ultrasound imaging. *Spine* 18: 913–917
- Khosla S, Tredwell SJ, Day B, Shinn SL, Ovalle WK (1980) An ultrastructural study of multifidus muscle in progressive idiopathic scoliosis. *J Neurol Sci* 46: 13–31
- Langenskiöld A, Michelsson JE (1961) Experimental scoliosis in the rabbit. *J Bone Joint Surg Br* 43: 116–120
- Langenskiöld A, Michelsson JE (1962) The pathogenesis of experimental scoliosis. *Acta Orthop Scand Suppl* 59
- Martinson H, Stokes MJ (1991) Measurement of anterior tibial muscle size using real-time ultrasound imaging. *Eur J Appl Physiol* 63: 250–254
- Monticelli G, Ascani E, Salsano V, Salsano A (1975) Experimental scoliosis induced by prolonged minimal electrical stimulation of the paravertebral muscles. *Ital J Orthop Traum* 1: 39–54
- Olsen GA, Rosen H, Hohn RB, Slocum B (1977) Electrical muscle stimulation as a means of correcting induced canine scoliotic curves. *Clin Orthop* 125: 227–235
- Reuber M, Schultz A, McNeill T, Spencer D (1983) Trunk muscle myoelectric activities in idiopathic scoliosis. *Spine* 8: 447–456
- Roaf R (1976) The intercostal muscles and conditioned reflexes in the control of spinal posture. *Proc R Soc Med* 69: 177–178
- Sakai F, Sone S, Kiyono K, Imai S, Izuno I, Oguchi M, Okazaki Y, Kasuga T, Ehara T (1990) High resolution ultrasound of the chest wall. *Rofo Fortschr Geb Rontgenstr Nuklearmed* 153: 390–394
- Silva JF (1969) Experimental scoliosis on monkeys. *Proceedings of the Eleventh Congress of SICOT, Mexico*, pp 305–313
- Slager UT, Hsu JD (1986) Morphometry and pathology of the paraspinal muscles in idiopathic scoliosis. *Dev Med Child Neurol* 28: 749–756
- Weiss HR (1991) The effect of an exercise program on vital capacity and rib mobility in patients with idiopathic scoliosis. *Spine* 16: 88–93
- Weiss HR, El Obeidi N, Lohschmidt K (1997) The in patient scoliosis rehabilitation. A “worst-case” analysis. In: Sevastik JA, Diab KM (eds) *Research into spine deformities*, 1. IOS Press, Amsterdam, pp 361–364
- Willers U, Sevastik B, Hedlund R, Sevastik JA, Kristjansson S (1995) Electrical muscle stimulation on the spine: three-dimensional effects in rabbits. *Acta Orthop Scand* 66: 411–414
- Wright J, Herbert MA, Velazquez R, Bobechko WP (1992) Morphologic and histochemical characteristics of skeletal muscle after long-term intramuscular electrical stimulation. *Spine* 17: 767–770
- Zetterberg C, Björk R, Örtengren R, Andersson GBJ (1994) Electromyography of the paravertebral muscles in idiopathic scoliosis. *Acta Orthop Scand* 55: 304–309