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Colour Doppler ultrasonography for evaluation of anterior chest blood supply: the possible role of arterial blood supply to the costosternal junction in the aetiology of idiopathic scoliosis in female adolescents

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Abstract This prospective comparative study was carried out to investigate the blood supply to the anterior chest wall by measurement of several anatomical and haemodynamic flow parameters of the internal mammary artery, with the use of colour Doppler ultrasonography, in female scoliotics with idiopathic right convex scoliosis in adolescence. Previous investigations have postulated that asymmetry of the breasts in female adolescents may be linked with the development of right convex thoracic scoliosis. This breast asymmetry is supposed to be linked with anatomical and functional asymmetry of the internal mammary artery that is the main supplier to the mammary gland. However, no measurements of anatomical and haemodynamic parameters of the internal mammary artery have been made to justify or reject the hypothesis of asymmetric blood flow volume to the breasts and costosternal junction in female adolescent scoliotics. Twenty female adolescents with right convex thoracic scoliosis and 16 comparable female individuals without spine deformity were examined with roentgenograms (scoliotics only) to measure scoliosis curve, vertebral rotation and concave and convex rib–vertebra angle at three vertebrae (the apical, one level above and one below the apical vertebra). Doppler ultrasonography was used to measure, at the origin of the internal mammary artery, its lumen

diameter, cross-sectional area, time average mean flow and flow volume per minute in scoliotics and controls, which were compared with each other. The roentgenographic parameters were compared with the ultrasonographic parameters in the scoliotics to disclose any relationship. The reliability of colour Doppler ultrasonography was high and the intra-observer variability low (ANOVA, $P=0.92-0.94$). There was no statistically significant difference in the ultrasonographic parameters of the internal mammary artery between right and left side in each individual as well as between scoliotics and controls. In scoliotics the right mammary artery time average mean velocity increases with the convex ($P<0.05$) and concave ($P<0.01$) rib–vertebra angle one level above the apical vertebrae and with the apical convex rib–vertebra angle ($P<0.05$). The right internal mammary artery flow volume per minute increases with convex ($P<0.01$) and concave ($P<0.01$) rib–vertebra angle one level above the apical vertebrae and with the apical convex rib–vertebra angle ($P<0.05$). Left internal mammary artery cross-sectional area increases with convex apical rib–vertebra angle ($P<0.01$) and concave rib–vertebra angle one level above the apical vertebra ($P<0.01$). Conclusively, this investigation showed that haemodynamic flow parameters of the right internal mammary artery and anatom-

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ical parameters of the left internal mammary artery are significantly correlated with the magnitude of rib-vertebra angles close to the apex of right thoracic scoliosis in female adolescents. This study did not find

any evidence for side-difference in vascularity of the anterior thorax wall and, thus, it could not clearly justify previous theories for development of right thoracic scoliosis in female adolescents.

Keywords Aetiology · Thoracic idiopathic scoliosis · Internal mammary artery

Introduction

Asymmetric development of the breasts in female adolescents has been documented [11]. Normeli et al. [12] and others [4] found a significantly higher vascularity of the left breast than the right in scoliotics and, particularly, in scoliotics with right convex thoracic scoliosis and concluded that unilateral stimulation of rib growth due to a greater vascularity of the left breast and the ipsilateral costosternal junctions might be one initiating factor in the development of right convex thoracic idiopathic scoliosis in adolescent girls. Previous studies [10, 16] had shown that asymmetry of rib length can, in some cases, be a primary cause of idiopathic scoliosis in adolescence.

On the assumption that longitudinal growth of the rib is stimulated by unilaterally increased local blood supply to the costosternal junction provided by the internal mammary artery, which is the main blood supplier to this area, we undertook the present study to investigate, with the use of colour Doppler ultrasonography, whether there is clear evidence for anatomical and haemodynamic asymmetry in the internal mammary artery in scoliotics and non-scoliotics. To our knowledge there is no other study dealing with this subject.

Material and methods

In this prospective study 20 female adolescents with right thoracic scoliosis and 16 non-scoliotic individuals used as controls were examined with colour Doppler ultrasonography (CDU) so that we could measure anatomical and haemodynamic parameters of the internal mammary artery (IMA). The scoliotics, who were first found, were selected. Then the controls were selected to be comparable in age, height and weight. All controls were examined clinically with the Adam's test and with the use of the scoliometer by the first senior author (P.K.). Controls with evidence of axial trunk asymmetry shown in the Adam's test associated with axial trunk rotation (ATR) that was measured (more than 3°) with the scoliometer were excluded from the study. Thus, no roentgenograms were taken of any individual who was used as control for ethical reasons and because the scoliometer has been proven to be a reliable measure for detecting even minor scoliosis with high accuracy. In addition, individuals with known congenital anterior chest deformity, chest trauma or previous operation, breast atrophy or acquired breast anomaly or disease (mastitis, adenoma) were excluded from the study. The scoliotics were additionally examined radiographically with a standing posteroanterior roentgenogram of the whole spine. The parameters that were measured were vertebral rotation and rib-vertebrae angle (RVA) (Table 1). Vertebral rotation was measured at the apical vertebra and one vertebra above (superior) and one below (inferior) the apical vertebra of the thoracic

scoliosis by the method of Perdriolle and Vidal [13]. Convex-RVA and concave-RVA, as well as RVA-differences (RVADs), were measured at the apical, superior and inferior vertebrae by the Mehta [8] method.

Anatomy

The arteries supplying the breast derive from the thoracic branches of the axillary artery (AXA) and from the IMA and anterior intercostal arteries [3]. The IMA passes downward and inward behind the first rib to the inner surface of the anterior wall of the chest, resting against the costal cartilages approximately 1.2 cm from the margin of the sternum. The main branches of the IMA are the sternal (supply the triangularis sterni and the posterior surface of the sternum), anterior intercostal (supply the intercostal muscles) and the perforating (supply the pectoralis major and the integument).

The intercostal arteries, which are branches of the IMA, also supply the anterior part of the intercostal spaces, including the intercostal junctions [3]. The superior intercostal arteries arise from the subclavian artery and supply the posterior spinal muscles.

The AXA supplies, by its superior thoracic branches, the anterior chest muscles pectoralis minor and major and the anterior chest wall, anastomosing with the IMA and intercostal arteries.

The arteries supplying the mammae are derived from the thoracic branches of the AXA, the intercostals, and the IMA.

Method

In this study we used CDU to study, bilaterally, both the IMAs. In addition, we bilaterally measured the same anatomical and haemodynamic parameters of the AXA in all individuals, to establish any variability between right and left side as well as between scoliotics and controls. The ultrasound device that was used in this study was an HDI-3000 (ATL, Bothel, Wash., USA) equipped with a 5–12 MHz linear sector. All ultrasonographic measurements were made by the

Table 1 Roentgenographic parameters in scoliotics. Mean (range) values are in degrees

Parameter	Mean	SD	Range
Scoliosis angle	27	10	(12–52)
RVA convex apical	67	12	(50–90)
RVA convex superior	70	14	(50–93)
RVA convex inferior	67	14	(48–102)
RVA concave apical	74	11	(60–98)
RVA concave superior	80	13	(60–110)
RVA concave inferior	65	11	(50–82)
RVAD apical	9	7	(1–23)
RVAD superior	11	7	(2–24)
RVAD inferior	8	7	(0–22)
Perdriolle apical	13	5	(5–25)
Perdriolle superior	12	8	(0–25)
Perdriolle inferior	12	7	(0–25)

second author, P.I., who is a senior radiologist with great experience in CDU examinations. P.I. made a blind radiological evaluation, since he did not know if the examined individual was scoliotic or a control, and he knew nothing about the results of the radiological examination of the scoliotics and, thus, was an unbiased observer. No other radiologist was involved in the CDU measurements because the relative high inter-observer variability and low inter-observer agreement in CDU measurements are well known. The location for CDU application has been well established by previous authors as being between the first to the fifth intercostal space parasternally and bilaterally [14]. The measurements for the IMA were made bilaterally, with the patient in the supine position, at the sternal edge in the second and third intercostal spaces. Thus, six values were taken for each side. For each individual the radiologist took the average value of the CDU measurements for each side. Before initiation of the measurements we made several measurements for the IMA at intercostal spaces 2 to 6, but the values were inconstant and not reliable because the diameter of the IMA decreased from the emergence of the IMA from the subclavian artery downwards. Thus, we performed all CDU measurements solely at the second and third intercostal spaces, to examine the IMA values as close as possible to its emergence from the subclavian artery, where the IMA has its greatest diameter, great enough to be measured with high repeatability and reliability by the CDU transducer. In addition, scoliosis is a deformity that affects more than one vertebral level and, subsequently, more than one rib. Thus, although the major deformity is located at the apex of the thoracic scoliosis, CDU measurement differences depend on the side, not on the level, where the measurement was made. The AXA was identified immediately after its emerge from the subclavian artery, laterally to the anterior border of the axillary cavity. The CDU parameters which were measured included (1) anatomical: arterial lumen diameter (DIAM) and arterial lumen cross-sectional area (AREA),

and (2) haemodynamic flow parameters: time average mean velocity (TAMV), which was derived from a complex mathematical calculation of the average blood flow velocity per second through the vessel's cross sectional area and is calculated by the device's software, and blood flow volume per minute (VF), which is $AREA (cm^2) \times TAMV (cm/s) \times 60 s$. Three consecutive CDU measurements were made for each of the examined vessels bilaterally, and the average value was taken for analysis and comparison with other variables. These values for all three measurements were then tested for intra-observer variability. Each measurement was the average value of vessel activity for at least six complete cardiac beats. The sample volume had the width of the vessel lumen and the angle between the vessel, and the ultrasound beam during examination was always at 60° in relation to the surface of the thorax of the examined individual.

Statistics

We used the *t*-test and the correlation coefficient to compare the CDU parameters in both groups of individuals and the radiographic data in the scoliotics. The intra-observer agreement for the ultrasonographic measurements was tested with the use of one-way ANOVA.

Results

The probability (*P*, ANOVA) values for the CDU parameters between the three repeated examinations varied from 0.92 to 0.94.

Table 2 Physical and ultrasonographic data in controls and scoliotics (*RTM* right mammary artery, *LTM* left mammary artery)

Parameter	Controls		Scoliotics		Level of significance (<i>P</i> , <i>t</i> -test)
	Mean	SD	Mean	SD	
Age	13.5 years	1.7	14 years	1.85	0.332
Height	159 cm	9	164 cm	8	0.077
Weight	47 kg	7	51 kg	7.7	0.103
RTM AREA	0.041	0.01	0.04	0.01	0.12
RTM TAMV	18.67	7	20.5	8.64	0.46
RTM FV	47.7	31	60.8	34	0.2
LTM AREA	0.037	0.009	0.042	0.016	0.195
LTM TAM	19	6	18	7.7	0.68
LTM FV	43.65	19	49	36.76	0.562

Table 3 Ultrasonographic data for anatomical and haemodynamic flow parameters of mammary and axillary arteries in scoliotics

Parameter	Right		Left		Level of significance (<i>P</i>) ^a
	Mean	SD	Mean	SD	
Mammary artery					
DIAM	0.27	0.037	0.25	0.055	0.18
AREA	0.048	0.012	0.043	0.016	0.24
TAMV	20.52	8.64	18.3	7.34	0.38
FV	60.84	33.97	49.06	36.76	0.28
Axillary artery					
DIAM	0.55	0.072	0.57	0.078	0.25
AREA	0.209	0.045	0.21	0.044	0.32
TAMV	21.26	12.7	20.7	12.65	0.45
FV	284.99	224.54	245.46	166.03	0.3

^aPaired *t*-test

Table 4 Correlation matrix between radiographic parameters in scoliotics (*superior* adjacent vertebra above the apical, *inferior* adjacent vertebra below the apical, *Perdriolle* vertebral rotation, correlation coefficient)

Parameter	1	2	3	4	5	6	7	8	9
1. RVA convex apical	1.00								
2. RVA convex superior	0.89**	1.00							
3. RVA convex inferior	0.7**	0.75**	1.00						
4. RVA concave apical	0.7**	0.77**	0.83**	1.00					
5. RVA concave superior	0.65*	0.77**	0.83**	0.85**	1.00				
6. RVA concave inferior	0.56*	0.68**	0.6*	0.69**	0.7**	1.00			
7. Perdriolle apical			0.62*			0.32	1.00		
8. Perdriolle superior						(-0.01)	0.7**	1.00	
9. Perdriolle inferior						0.1		0.77**	1
10. Scoliosis angle	(-0.2)	(-0.04)	0.31	0.18	0.2	0.12	0.43	0.08	0.24

* $P < 0.01$, ** $P < 0.001$ **Table 5** Correlation matrix between roentgenographic and ultrasonographic parameters in scoliotics (*RTM TAMV* right internal mammary artery time average mean velocity, *RTM FV* right internal mammary artery blood flow volume per minute, *LTM AREA* left internal mammary artery cross sectional area)

Parameter	RVA convex apical	RVA convex superior	RVA concave superior
RTM TAMV	0.51*	0.55*	0.64**
RTM FV	0.55*	0.58**	0.65**
LTM AREA	0.59**		0.59**

Correlation coefficient, * $P < 0.05$, ** $P < 0.001$

The IMA CDU parameters (AREA, TAMV and FV) did not show any statistically significant difference between right and left sides either in controls or in scoliotics (Table 2).

No CDU differences were found between scoliotics and controls (Table 2).

There was no significant correlation between magnitude of scoliosis and CDU parameters.

The diameter of the AXA was approximately twice that of the IMA, and the AREA was fourfold (Table 3).

The correlations between RVAs and vertebral rotation are shown in Table 4.

In scoliotics, the right IMA TAMV increased with convex apical RVA ($P < 0.05$) as well as with convex and concave superior RVA ($P < 0.01$) (Table 5).

The right IMA FV increased with convex apical RVA ($P < 0.05$) as well as with convex and concave superior RVA ($P < 0.01$) (Table 5).

Left IMA AREA increased with convex apical RVA ($P < 0.01$) and concave superior RVA ($P < 0.01$) (Table 5).

No significant correlations were shown between RVADs and CDU parameters.

Discussion

Right convex thoracic idiopathic scoliosis in adolescence often presents almost simultaneously with the development

of the mammary glands. The temperature of the skin reflects the vascularity of the underlying tissues and mammary glands. Ventral thermograms of the thorax have occasionally been used in connection with examination of scoliosis and have indicated marked asymmetry of the anterior aspect of the thorax in scoliosis [4]. Asymmetric growth of the thorax is possibly an initiating factor in the development of scoliosis [10, 11, 16].

This study, which was conducted in adolescent female scoliotics with right convex thoracic scoliosis, was planned by means of plain radiology and CDU to test the hypothesis of apical rib asymmetry due to right-to-left asymmetry of blood supply. Experimental studies have shown that the longitudinal growth of the ribs in animals occurs mainly in the growth zone of the costosternal junction [15], which is mainly supplied by the IMA. If the blood supply to the breasts in human beings is similar to that in animals, then the increased thermal emission provided by increased blood supply derived from the main branches of the IMA to the left costosternal junction should be followed by longitudinal overgrowth of the left ribs and development of right convex thoracic scoliosis. However, it is questionable as to how well blood flow and vessel anatomy of the IMA, measured at its origin, reflects the vascularity at the costochondral junction. The IMA is large enough for CDU measurements to be applied only at its origin, and, probably, flow differences below the third intercostal space cannot reliably be detected.

The use of CDU for evaluation of anatomical and flow parameters of the IMA at its origin did not disclose, in the present study, any side asymmetry in blood supply to the breasts and anterior thorax in scoliotics. However, the most significant observation that was derived from this study was the correlation that was demonstrated between juxta-apical RVAs and right IMA flow parameters in scoliotics.

In idiopathic scoliosis in adolescence, RVAs have no prognostic value [6] as in infantile idiopathic scoliosis [5, 8]. On the contrary, juxta-apical RVAs are important elements of thorax and trunk asymmetry, which are associated with cosmesis in adolescents with idiopathic scoliosis.

The results of this study let us assume that juxta-apical frontal rib deformity may be in some way linked with blood flow to the right anterior thorax solely. The anatomy of the left IMA, measured by CDU, seems to be correlated with juxta-apical frontal rib deformity. However, these preliminary results derived from the present study do not allow us to make any definitive conclusion about the validity of these significant observations.

Over the past decade CDU became well established and the best non-invasive method for assessing the vessels' haemodynamics [1, 2, 7, 9, 14, 15]. In the beginning, the main problem of this method was the inter- and intra-observer variability. This problem can be avoided by co-training the examiners [2]. The problem with intra-observer variability was solved in this study by the examiner's experience in performing this examination. Internal mammary and axillary arteries are easily detected with modern CDU methods. Many studies have been performed, mainly by cardiologists on adult populations, in an effort to establish the condition of IMAs before and after coronary artery

bypass surgery [1, 9, 14]. This study showed that CDU is a very reliable method for investigation of anatomical and haemodynamic parameters of both the IMA and the AXA in adolescents. In the literature there are studies that justify the use of measurement of IMA parameters in adults, as it is non-invasive, safe, sensitive and reliable [1, 2, 5, 9, 15, 16]. Ehram et al. [2] showed in adults that the sensitivity of CDU in measuring anatomical and haemodynamic parameters of the IMA was 100%, while its specificity was 58%.

Further, repeated, CDU studies, together with observation of the evolution of right thoracic scoliosis, are in progress by the authors to investigate the significance of the above-mentioned hypothesis for the progression of right convex idiopathic scoliosis in adolescence.

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