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ORIGINAL ARTICLE

Asymmetric evolution of anterior chest wall blood supply in female adolescents with progressive right-convex thoracic idiopathic scoliosis

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Abstract Breast asymmetry was believed to be related to asymmetry of anterior chest wall blood supply and subsequently to aetiology of idiopathic thoracic scoliosis in female adolescents. Recent investigations on the anterior chest wall blood supply with Colour Doppler Ultrasonography (CDU) in such individuals did not show anatomical and hemodynamic abnormalities. The present study investigated the evolution of anterior chest wall blood supply in these individuals over a 2-year period. Twenty female adolescents with progressive right-convex idiopathic thoracic scoliosis (scoliotics), who were during the study in therapy with horacolumbosacral orthosis (TLSO) and 20 age-matched girls, without spine deformity (controls) were studied with CDU [internal mammary artery (IMA)] twice within the 2-year period. IMA-anatomical parameters [lumen diameter (D) and cross sectional area (AR)] as well as hemodynamic flow parameters [time average mean flow velocity and flow volume per minute (FV)] were measured. In the 2-year-period of observation, TLSO prevented scoliosis progression ($P = 0.004$), while IMA-AR decreased bilaterally in the individuals of both groups ($P < 0.03$). In the last evaluation: in scoliotics right IMA FV decreased ($P < 0.04$), while in controls IMA FV decreased bilaterally ($P < 0.03$); left IMA FV was significantly higher ($P < 0.05$) in scoliotics than in controls. The significant, within the 2-year period, decrease of IMA-diameter, cross-sectional area, and flow volume seems to be a physiological ageing process because it was observed in all individuals (scoliotics and controls), and thus these anatomic and hemodynamic changes seem not to have been affected by bracing. The maintenance of left flow volume of IMA in the pre-brace levels in scoliotics was the most significant finding of this investigation. In conclusion, this study provided evidence for abnormalities in the evolution of anterior chest wall blood supply in female adolescents with progressive right-convex female thoracic scoliosis. Further studies are needed to investigate if this asymmetric blood evolution contributes to the development of this pattern of scoliosis in girls.

Keywords Etiology idiopathic scoliosis · Adolescent thoracic scoliosis · Chest blood supply · Internal mammary artery · Color Doppler Ultrasonography

Introduction

Breast asymmetry in female adolescents with right-convex idiopathic scoliosis was believed to be related to asymmetry in anterior chest wall blood supply [1, 2]. Internal mammary artery (IMA) is anatomically the main blood distributor to the anterior thorax wall. Recent, comparative Colour Doppler Ultrasonography (CDU)-studies of IMA-anatomic and hemodynamic parameters in scoliotics with right thoracic curves

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versus non-scoliotic female adolescents did not disclose any differences or even IMA side-asymmetry [3–5].

All previously published studies on the anterior chest wall blood supply [1–5] were based on single observations and thus had the limitation of lack of follow up.

To the authors' knowledge, there is no data regarding correlative evolution of anterior chest wall blood supply and right-convex adolescent idiopathic scoliosis in female scoliotics.

The purpose of this prospective comparative study was to investigate the possible correlation between evolution of thoracic idiopathic scoliosis and anterior chest wall blood supply in female adolescents treated with thoracolumbosacral orthosis (TLSO).

Methods

Patients

This series includes twenty consecutive female adolescent scoliotics with radiologically documented progressive mild right-convex thoracic idiopathic scoliosis and skeletal maturity Risser I-II in the initiation of treatment with TLSO. These patients were simultaneously examined radiographically for evolution of the scoliosis and with CDU to investigate the evolution of anatomic and hemodynamic parameters of IMA. Two radiographic and CDU measurements were made over a 2-year period.

All girls wore TLSO 18–23 h daily, under their parents' observation. The age of the scoliotics was 13 ± 2 and 15 ± 2 years in the first and second observation, respectively. The scoliosis before application of TLSO was 30 ± 9°. No individual with scoliosis had any previous treatment for scoliosis, spinal trauma, spinal surgery, or heart-vessel disease. Twenty female individuals, aged (average ± SD) 13 ± 1 and 15 ± 1 years in the first and second observation, respectively, without spine deformity and were used as controls and examined with CDU (IMA) as the scoliotics.

Anatomy

Blood supply to the anterior chest wall is mainly derived from IMAs. 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 lateral 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 intercostals junctions [6].

Method

All individuals, scoliotics and controls, were examined twice over the 2-year period with CDU by the first author, who is senior radiologist with experience in performing CDU in small arteries [6–9]. This radiologist measured several anatomic and hemodynamic flow parameters of IMA close to its origin at the first intercostal space lateral to the margin of the sternum. The anatomic parameters were: arterial lumen diameter (D), measured perpendicularly to vessels' longitudinal lumen axis; and arterial lumen cross-sectional area (AR), measured perpendicularly to vessels' longitudinal lumen axis. The hemodynamic flow parameters were: time average mean velocity (TAM), which was derived from a complex mathematical calculation of the average blood flow velocity per second through the vessel's cross sectional area calculated by the device's software, in cm s^{-1} and blood flow volume per minute (FV), which is the result of multiplication of AR (cm^2) × TAM (cm s^{-1}) 60 s, in ml.

Each hemodynamic flow parameter was calculated on the basis of the average vessel (IMA) activity for at least six complete cardiac beats. The Doppler sample volume had the width of the vessel lumen and the angle between the longitudinal axis of the vessels' lumen and the ultrasound beam at the sampling point was always at ≤60°, range 30°–60°.

Three repeated measurements for each CDU-parameter and both IMAs were made in each individual and the average value of each parameter was taken for further statistical analysis.

A HDI-3000 (ATL, Bothel, WA, USA) CDU device, equipped with a 5–12 MHz linear sector was used in this study. The first CDU measurement was made immediately before starting the treatment with TLSO and the second 2 years later. The second CDU measurement was made after the patient remained unbraced for an hour.

Whole spine standing AP-roentgenograms were taken in scoliotics. The magnitude of scoliosis was measured by the Cobb's method. All controls were clinically examined with the use of Scoliometer [Axial trunk rotation (ATR)] to exclude individuals with scoliosis (ATR cut off >5°) and to avoid unnecessary radiation exposure.

Statistics

T test, paired *t* test and correlation coefficient were used to compare the CDU-parameters and scoliosis angle. The intra-observer agreement for the ultrasonographic measurements was tested with the use of one-way ANOVA. $P \leq 0.05$ was considered as the lowermost level of significance.

Results

The reliability and repeatability of the CDU method was high ($P = 0.94$).

The results obtained from this study are summarized in the Tables 1, 2 and 3.

Controls (changes between the two observations)

R IMA-D and L IMA-D were reduced at an average 26% ($P = 0.0002$) and 17.5% ($P = 0.002$), respectively. R IMA-AR and L IMA-AR were reduced at 31.6% ($P = 0.001$), and 19% ($P = 0.02$), respectively (Table 1).

R and L IMA-FV were reduced at an average 45% ($P = 0.025$), and 34.6% ($P = 0.014$), respectively (Table 1).

Scoliotics (changes between the two observations)

R IMA D and L IMA-D were reduced at an average 20.6% ($P = 0.001$) and 17.1% ($P = 0.003$), respectively; R IMA-AR and L IMA-AR were reduced at an average 23.7% ($P = 0.01$) and 18.6% ($P = 0.026$), respectively.

R IMA-FV was significantly reduced at an average 36% ($P < 0.04$), while L IMA-FV not significantly reduced at an average 23.6 % ($P = 0.2$) (Table 1).

Thoracic scoliosis was significantly reduced in brace ($P = 0.004$) (Table 1).

Cobb angle significantly correlated ($P < 0.05$) with IMA-FV bilaterally in the second evaluation (Table 3).

Controls versus scoliotics

In scoliotics, L-IMA FV was statistically significantly higher ($P = 0.045$) than in controls in the second observation (Table 2).

Discussion

Recent studies [3–5] measured with CDU anatomic and hemodynamic parameters of IMA, in an attempt to shed light in the aetiology of thoracic right-convex idiopathic female scoliosis [6]. The blood supply to the anterior chest wall, besides IMA, is also derived from several other arteries which however cannot be

Table 1 Cumulative anthropometric, anatomic, and hemodynamic data and changes in all individuals

Parameters	First observation Mean ± SD	Second observation Mean ± SD	Change (%)	*P*, *t* test
Controls				
Age (years)	13 ± 1	15 ± 1		
R IMA-D (cm)	0.245 ± 0.04	0.181 ± 0.023	–26	0.0002*
R IMA-AR (cm^{2})	0.038 ± 0.01	0.026 ± 0.005	–31.6	0.001*
R IMA-TAM (cm s^{-1})	19.29 ± 9.64	15.3 ± 3.36	–20.7	0.13
R IMA-FV (ml min^{-1})	44 ± 28.41	24 ± 8.04	–45	0.025*
L IMA-D (cm)	0.22 ± 0.04	0.19 ± 0.02	–17.5	0.002*
L IMA-AR (cm^{2})	0.034 ± 0.01	0.0275 ± 0.005	–19	0.02*
L IMA-TAM (cm s^{-1})	16.6 ± 5.62	13.655 ± 3.89	–17.74	0.15
L IMA-FV (ml min^{-1})	34.3 ± 14.35	22.47 ± 7.06	–34.6	0.014*
Scoliotics				
Age (years)	13 ± 2	15 ± 2		
R IMA-D (cm)	0.25 ± 0.06	0.2 ± 0.035	–20.6	0.001*
R IMA-AR (cm^{2})	0.04 ± 0.01	0.03 ± 0.01	–23.7	0.01*
R IMA-TAM (cm s^{-1})	17.9 ± 8.23	15.9 ± 5.84	–11.17	0.24
R IMA-FV (ml min^{-1})	49 ± 35.12	31.4 ± 14.67	–36	0.035*
L IMA-D (cm)	0.25 ± 0.06	0.20 ± 0.03	–17.1	0.003*
L IMA-AR (cm^{2})	0.04 ± 0.016	0.034 ± 0.01	–18.6	0.026*
L IMA-TAM (cm s^{-1})	16.89 ± 8.05	16.04 ± 5.69	–5.03	0.67
L IMA-FV (ml min^{-1})	45.35 ± 38.73	34.65 ± 17.51	–23.6	0.2
Scoliosis angle (degrees °)	30 ± 9	24 ± 10		0.004*

All values are shown as mean ± SD (standard deviation of mean value)

R, L IMA = Right, left internal mammary artery, *D* = diameter, *AR* = area, *TAM* = Time average mean blood velocity, *FV* = Blood flow volume per minute

*Significant *P* values (paired *t* test)

Table 2 Comparative data (anthropometric, anatomic, and hemodynamic) between controls and scoliotics

	Scoliotics Mean ± SD	Controls Mean ± SD	*P*, *t* test
First observation			
Age (years)	13.32 ± 2.47	13.6 ± 1.17	0.74
R IMA-D (cm)	0.25 ± 0.06	0.25 ± 0.042	0.76
R IMA-AR (cm^2)	0.042 ± 0.015	0.038 ± 0.009	0.41
R IMA-TAM ($cm\ s^{-1}$)	17.9 ± 8.23	19.29 ± 9.64	0.68
R IMA-FV ($ml\ min^{-1}$)	49.1 ± 35.13	44.11 ± 28.4	0.7
L IMA-D (cm)	0.25 ± 0.058	0.23 ± 0.039	0.34
L IMA-AR (cm^2)	0.041 ± 0.016	0.034 ± 0.01	0.16
L IMA-TAM ($cm\ s^{-1}$)	16.89 ± 8.05	16.64 ± 5.62	0.93
L IMA-FV ($ml\ min^{-1}$)	45.35 ± 38.73	34.33 ± 14.35	0.4
Second observation			
Age (years)	15.159 ± 2.54	15.6 ± 0.84	0.6
R IMA-D (cm)	0.2 ± 0.034	0.18 ± 0.023	0.13
R IMA-AR (cm^2)	0.03 ± 0.01	0.026 ± 0.005	0.09
R IMA-TAM ($cm\ s^{-1}$)	15.86 ± 5.84	15.31 ± 3.36	0.79
R IMA-FV ($ml\ min^{-1}$)	31.4 ± 14.7	24.28 ± 8.04	0.17
L IMA-D (cm)	0.2 ± 0.033	0.19 ± 0.02	0.14
L IMA-AR (cm^2)	0.03 ± 0.011	0.027 ± 0.005	0.076
L IMA-TAM ($cm\ s^{-1}$)	16.04 ± 5.69	13.65 ± 3.9	0.25
L IMA-FV ($ml\ min^{-1}$)	34.65 ± 17.51	22.47 ± 7.06	0.045*

All values are shown as mean ± SD (standard deviation of mean value)

*Significant *P* values (*t* test) $P < 0.05$

R, L IMA = right, left internal mammary artery, *D* = diameter, *AR* = area, *TAM* = Time average mean blood velocity, *FV* = Blood flow volume per minute

measured with the existed CDU methods because of their fine anatomy and thus they were not included in the present study.

Sevastik et al. [1, 2] suggested the asymmetric increase of blood supply to the left anterior chest wall as a possible cause of right-convex idiopathic scoliosis in girls, while recent studies with CDU [3–5] in these individuals doubted this theory of asymmetry because they did not find any asymmetry in blood supply to the anterior chest wall. However, all these studies did not investigate the evolution of blood supply to the anterior chest wall of the female adolescent scoliotics. The present study is advantageous to previous studies [3–5] because it is prospective, controlled, and used radiographic and CDU-data derived from two consequent measurements within a 2-year period.

The authors of the present study believe that the observed significant decrease of diameter, cross-sectional area and flow volume of IMA within the 2-year period, should be a physiological maturity process that occurs in adolescence. The latter conclusion was based to the observation that the decrease of the anatomic and functional IMA-parameters occurred in the same period in all individuals (scoliotics and controls) in a similar amount and thus it seems not to have been affected by bracing.

The present study supports a new theory for the evolution of the right-convex thoracic adolescent scoliosis: Right-convex idiopathic thoracic scoliosis may be due to an asymmetry of blood supply to the anterior chest that is characterized by decreasing blood supply on to the right anterior hemithorax with simultaneous maintenance of blood supply on to the left anterior hemithorax. This combined abnormality may result in a relative increase of blood supply on to the left anterior chest wall, increased temperature on the left sterno-costal cartilaginous junction, and subsequent elongation of the left ribs.

The observed asymmetrical changes of blood supply to the anterior chest wall in a 2-year period in the female adolescents with right-convex idiopathic scoliotics should support the hypothesis that this particularly scoliosis may be closely related to some "disturbance" in the mechanism regulating the blood supply to the left anterior half of the chest wall.

The last observation regarding "disturbance" in the blood supply to the anterior chest wall half may seems to justify the results of a recent theory for the etiology of idiopathic scoliosis [13], which claimed that the progression of the idiopathic thoracic scoliosis was related to a disturbance of the underlying autonomous nerve system blood flow regulating mechanism to the anterior chest wall.

In the present study, no comparison was made regarding CDU data between scoliotics with progressive versus non-progressive scoliosis, because the number of patients in each subgroup was small.

There are three limitations in this study: first, the authors could not investigate the natural history of evolution of blood supply to the anterior chest wall in non braced patients, because it is unethical to leave patients with curves of such a magnitude untreated [10–13]; second, bracing may have contributed to the observed IMA flow abnormalities; and third scoliotics with small curvatures did not need bracing, and were not included as controls because they were unwilling to undergo CDU examination.

This investigation provided anatomic and hemodynamic evidences for asymmetry in the evolution of anterior chest wall blood supply in female adolescents with progressive right-convex female thoracic scoliosis.

Further comparative studies over longer period are needed to investigate if these blood flow abnormalities could contribute to the development of this pattern of scoliosis in girls.

Table 3 Correlation matrix between IMA Colour Doppler Ultrasonography parameters in controls and scoliotics (including scoliosis angle in scoliotics)

r	R IMA-D	R IMA-AR	R IMA-TAM	R IMA-FV	L IMA-D	L IMA-AR	L IMA-TAM	L IMA-FV
Controls								
First observation								
R IMA-AR	0.77***	1						
R IMA-FV			0.89***	1				
L IMA-AR					0.96^	1		
L IMA-FV						0.72**	0.77***	1
Second observation								
R IMA -AR	0.93**	1						
R IMA-FV	0.77***	0.82***	0.87***	1				
L IMA-AR					0.94^	1		
L IMA-FV							0.82***	1
Scoliotics								
First observation								
R IMA-AR	0.94^	1						
R IMA-TAM	0.48*	0.50*	1					
R IMA-FV	0.67***	0.72	0.94^	1				
L IMA-AR	0.55**	0.6**	0.46*	0.59***	0.86^	1		
L IMA-FV			0.76	0.77	0.51*	0.67***	0.93^	1
Scoliosis angle						0.52*		
Second observation								
R IMA-AR	0.94^	1						
R IMA-FV	0.58***	0.48*	0.81^	1				
L IMA-D	0.69***	0.61***		0.5*	1			
L IMA-AR	0.66***	0.62***			0.96^	1		
L IMA-TAM			0.8	0.81	0.54**	0.53**	1	
L IMA-FV	0.5*		0.59**	0.71	0.79	0.8	0.9^	1
Scoliosis angle				0.46*	0.52*			0.49*

Correlation coefficient (*r*); level of significance (*P*) *<0.05, **<0.02, ***<0.01, ^<0.001; *R, L IMA* = right, left internal mammary artery; *D* = diameter; *AR* = area; *TAM* = Time average mean blood velocity; *FV* = Blood flow volume per minute

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