Comparison of Medial Growth of Human Thoracic and Abdominal Aortas

By Harvey Wolinsky, M.D., Ph.D.

ABSTRACT

Recent morphologic studies of adult mammalian thoracic and abdominal aortic segments have shown that the adult human abdominal aorta deviates significantly from the usual pattern of medial lamellar architecture. In the present study medial growth of these two aortic segments from prenatal life to adulthood was compared in terms of medial architecture and calculated tangential tension levels. During prenatal life, these parameters were very similar in the two segments. However, the postnatal increase in the medial thickness of the thoracic segment was due mainly to the addition of lamellar units which increased in number from 35 to 56; only a minor contribution was made by increased thickness of each unit which changed from 0.012 to 0.017 mm. The converse was true for the abdominal segment; the number of lamellar units increased only from 25 to 28, but lamellar unit thickness increased strikingly from 0.012 to 0.026 mm. Calculated wall stress was similar in the two segments throughout growth, but tension per lamellar unit became disparate in the segments during the first decade of life, culminating in unusually elevated values in the adult human abdominal aortic media.

ADDITIONAL KEY WORDS

lamellar unit fetus comparative anatomy wall stress
tension per lamellar unit compared to the abdominal segment of other species. It was not determined in that study how this deviation came about or when it appeared in this segment.

The present study compares the growth of the human abdominal aortic media to the thoracic aortic media from prenatal life to adulthood in terms of medial lamellar architecture and calculated tension levels. It will be shown that the characteristic structural deviation of the adult abdominal segment is not present at birth but appears during the first decade of postnatal life.

Materials and Methods

A total of 59 segments was studied, 37 thoracic and 22 abdominal. These included 19 fetal vessels, 5 newborn aortas, 18 segments from children and 17 from adults. The fetuses, products of spontaneous abortions, were not macerated, were free of obvious congenital diseases, and were of body weight and length appropriate for the estimated length of gestation. Newborn infants were born alive and died within 48 hours, though usually within minutes of birth. They were free of all obvious congenital diseases and had the body parameters of term infants. Children were free of chronic disease and had died from a trauma or an acute illness. Adults were between 20 and 50 years of age and had been free of apparent cardiovascular disease during life and had died from a trauma or a brief acute illness; only aortas with little or no gross atherosclerosis were used. All vessels were obtained within 24 hours of death; both segments were not obtained from every case either because thoracic segments alone had been obtained as part of another study (21) or because one segment had been damaged during removal and rendered unsuitable for distention.

The thoracic segment was defined as that portion delimited by the left subclavian artery and coeliac artery; the abdominal segment was that portion between the left renal artery and the iliac bifurcation. All segments except those of the fetuses were distended as follows: All branches of the segment were ligated in situ and the segment was distended so that only the lamellar complement of the media was measured in these vessels. Tissue shrinkage amounted to 14% after fixation and an additional 16% after dehydration and paraffin embedding; all reported values have been appropriately corrected.

The estimated tangential tension exerted on the wall at the midpoint of each segment was expressed both in terms of tension per lamellar unit as described previously (20) and as wall stress, using the following equation: \( T = \frac{P R}{\delta} \)

where \( T = \) wall stress in dyn/cm² at the site in the vessel wall, \( P = \) blood pressure in dyn/cm², \( r = \) radius in cm, and \( \delta = \) wall thickness in cm (25).

The significance of differences between means was determined by use of Student’s t-test; significance was considered to be present at the 5% level.
GROWTH OF HUMAN AORTIC MEDIA

AORTIC WALL THICKNESS AND DIAMETER

The relationships of diameter and wall thickness to body weight of thoracic and abdominal segments are compared in Figure 1. The diameters of both segments increased throughout the period from birth to adulthood; in general, diameter of the abdominal segment was 30 to 40% less than that of the thoracic segment (Fig. 1A). Medial thicknesses of both segments also increased steadily over the same period, though more scatter of points was seen (Fig. 1B); the relationship between thicknesses of the two segments at any age was similar to the relationship of their respective diameters.

LAMELLAR UNITS AND BODY WEIGHTS

The complement of medial lamellar units could be easily determined in undistended as well as distended aortic segments. In Figure 2 the relationship of medial lamellar units to body weight is shown for aortas of humans ranging in age from early fetal life to adulthood. During the prenatal period, the number of lamellar units appeared to increase at a similar rate for both segments. The relative number of lamellar units in the two segments at any point during this age period corresponded to their relative diameters and wall thicknesses as described above.

During the period of growth from birth to adulthood, however, the rate of increase of lamellar units for the two segments was disparate. The lamellar units of the thoracic aorta nearly doubled over this period of time, whereas the number of abdominal aortic

![Figure 1](image1.png)

**Figure 1**


**Results**

- **Aortic Wall Thickness and Diameter**

- **Figure 2**

Relationship of number of aortic medial lamellar units to body weight during human growth. The rates of growth in the two segments are similar during fetal life; over the period from birth (arrows) to adulthood, however, accretion of units is much more rapid in the thoracic segment than in the abdominal segment.
Relationship of calculated tangential tension per lamellar unit of thoracic and abdominal aortic segments to body weight during human growth from birth to adulthood. Over the range of body weights of 15 to 40 kg, corresponding to the ages of 4 to 10 years, values for tension per lamellar unit become greater in the abdominal than in the thoracic segments.

It was seen in Figure 1B that increases in wall thicknesses of thoracic and abdominal segments were generally similar during the period of postnatal growth. Taken together with the different rates of accretion of lamellar units in these two segments during the same period, a progressively greater difference in lamellar unit thickness would be expected. This is confirmed by calculations of lamellar unit thickness: This value is 0.012 ± 0.004 mm (SD) and 0.012 ± 0.002 mm in the newborn thoracic and abdominal aortic segments, respectively; in the adult it is increased to 0.017 ± 0.003 mm and 0.026 ± 0.001 mm for the same segments, respectively. The difference between lamellar unit thicknesses of newborn segments was not significant ($P > 0.9$); that between the adult values was highly significant ($t = 8.63, P < 0.001$).

**MEDIAL TENSION**

During postnatal growth, increases in calculated tangential tension reflected increases of both blood pressure and diameter (23). Calculated tension per lamellar unit was significantly elevated in the adult human abdominal aorta compared to other avascular aortas, thoracic or abdominal, of many adult mammalian species (20). The development of this unusual situation is traced in Figure 3. Newborn human thoracic and abdominal segments had comparable levels of tension per lamellar unit (arrows). As growth proceeded,
GROWTH OF HUMAN AORTIC MEDIA

**Semidiagrammatic representation of medial growth of human thoracic and abdominal aortic segments.** Adult wall thickness of the thoracic segment is attained mainly by elaboration of more lamellar units whereas final wall thickness of the abdominal segment is accomplished primarily by the thickening of existing lamellar units. See text for details. Nb = newborn; Ad = adult.

However, with its attendant increases in blood pressure and diameter, the points representing abdominal vessels separated from those representing thoracic segments, a clearcut difference in tension per lamellar unit was seen by about 10 years of age (or approximately 40 g body weight); the transition seemed to occur between approximately 4 years and 10 years of age (or between 15 kg and 40 kg body weight).

Unlike medial lamellar complements, wall thicknesses of the thoracic and abdominal segments were related to each other in a similar manner throughout the period from birth to adulthood. It would be expected, therefore, that tension levels per unit wall thickness, i.e., wall stress, would remain similar in both segments over the same period. This is confirmed in Figure 4, where wall stress is related to body weight. Points representing thoracic and abdominal segments overlapped at all ages; the regression coefficient between wall stress and body weight was 0.63 \( (P < 0.01) \) and was the same when calculated separately for abdominal vessels or for all segments.

### Discussion

The findings of the present study are summarized in the semidiagrammatic representation shown in Figure 5. Medial thicknesses of thoracic and abdominal aortic segments were increased more than twofold in the adult compared to the newborn. In the human thoracic segment growth is accomplished mainly by an increase in number of lamellar units with only a relatively minor contribution from an increase in the thickness of individual units. The converse is true for the abdominal segment; most of the increase in postnatal thickness of this segment results from prominent thickening of existing lamellar units; very few new units are added. Stated differently, of the net increment in wall thickness of the thoracic aorta which occurs after birth, two-thirds is due to more units, one-third to increased unit thickness; corresponding figures for the increase in abdominal segment thickness are one-fifth due to new units, four-fifths due to thicker units. Note also in Figure 5, that thoracic aortic segments of newborn and adult humans have an outer zone which contains vasa vasorum (dark ellipses). The inner avascular zone contains 28 lamellar units, regardless of age, and is about 0.5-mm thick in the adult; both of these values are characteristic for this zone in mammalian aortas as established previously (26). In contrast, the human abdominal aortic media normally contains no vasa vasorum at any age; the lamellar complement of 28 of this adult vessel, while appropriate for an avascular vessel, is at the maximum value found in totally avascular aortas or avascular zones of vascularized aortas. Thickening of the media which corresponds to somatic growth and which is associated with rising tension levels results in an avascular abdominal segment in the adult human which greatly exceeds the maximum thickness of the avascular zones of vascularized aortas of other mammals. The implications of this discrepancy in the adult abdominal vessel have been discussed recently (20). A striking finding of the present study is that this segmental difference in the nature of medial growth of the human aorta arises in...
the postnatal period of growth; no difference is morphologically detectable before birth.

One possible explanation for the different mode of growth of the avascular abdominal segment is that it reaches a total maximum lamellar complement of 28 shortly after birth; as tangential tension continues to rise, no outer vascularized zone is present to elaborate more units; the only alternative is to thicken each unit. Parenthetically, this same course is taken by the avascular rat aorta under conditions of hypertension (19). In contrast, the human thoracic aorta has an outer vascularized zone at birth; the postnatal increase in tension is attended by the elaboration of many more lamellar units in the outer vascularized zone, a zone which has been shown to be capable of more structural adaptation than avascular inner medial zones or completely avascular vessels (unpublished observations). In retrospect, it is apparent from a previous study by us of vasa vasaum in mammalian aortas that the totally avascular aortas of the several smaller species studied added few, if any, units during postnatal growth but that the lamellar unit complement of vascularized outer medial zones of larger species increased considerably at a rate characteristic for each species (26). The presence of an outer vascularized zone seems to confer an adaptability not seen in avascular aortas or avascular zones.

The findings of this study also confirm our previous observations that no species with fewer than 28 medial units at birth exceeded a total of 28 units at any time thereafter (26). Conversely, all species with more than 28 medial units, i.e., with a vascularized outer zone in a segment as an adult, already had at least 28 units present at birth. It is intriguing that others have reported that when complete elastin lamellae first appear in the fetal human aorta (14 weeks gestation), "30 to 33 definite concentric layers" are seen (27). The youngest fetuses in our study were also of about this age and similarly had approximately 25 medial lamellae in the thoracic aorta. An explanation for this finding might be either that the avascular inner zone forms as a unit in those portions of the vascular tree destined to have an outer vascularized zone, or that the vascularized outer zone is found only in those segments in which development of the avascular zone is completed at an early stage of gestation. The finding that a "limit" of 28 lamellar units is reached early in postnatal life and that tension per unit rises inordinately thereafter because no vascularized outer zone develops may reflect the well-described lag in human growth during the final 2 months of gestation (28), or the more general finding that all primates have a significantly slower rate of intrauterine growth than nonprimates (29).

Previous experimental work (30) and autopsy studies of acardiac infants (31) showed that two influences are operative in cardiovascular development: (1) differentiation, which is of genetic origin; and (2) functional adaptation, which is presumably regulated by chemical and mechanical factors. The sharp increase in number of medial lamellar units, wall thickness, and vessel diameter seen during pre- and postnatal periods can probably be attributed to several factors acting concurrently. During these periods of very rapid body growth, aortic dimensions would be expected to keep pace with increasing body mass. To this point, we have noted that total medial lamellar units reached adult levels in the late teens and certainly by age 20, by which time adult body configuration had been attained; no further increases were seen between 20 and 50 years of age in the adults studied.

The level of blood pressure may be an important mechanical factor which influences the relative degree of lamellar accretion during pre- and postnatal growth periods. The pictograms by Dawes and his associates of blood pressure levels of several mammals during intra- and extrauterine life indicate that each species has a characteristic rate and pattern of rise (32): Wall thickness has been shown to correspond closely to pre- and postnatal blood pressure levels in the pulmonary and systemic circulations (33). It has also been noted that thoracic aortic wall
thickness of man increases steadily from birth until death (9, 10); in middle life it is twice as thick as at birth and in advanced age nearly three times as thick (9). Humoral factors, including the dramatic changes in arterial oxygen saturation and levels of circulating estrogens and other hormones which are associated with birth (34) may also influence vascular development.

Studies of humans and other mammals have shown that the characteristically different adult patterns of elastin and collagen composition of thoracic and abdominal segments are already present to some degree at birth (16, 18). In the present study we found that the morphologic appearance of the two segments was very similar in the prenatal period and that calculated tension levels per lamellar unit were also very similar in the newborn. It is possible that these data are not conflicting and that fibrous protein composition reflects changes in amplitude of, rather than mean levels of, tension in these segments (16). However, the importance of eliminating adventitia completely before determining the “true” fibrous protein composition of the media and intima has recently become apparent (35); many chemical data obtained without this precaution, including the above, should therefore be accepted with reservation until they are confirmed.

Acknowledgment

The author gratefully acknowledges the excellence of the histological material prepared by the late Mrs. Anne Pratt Daleske and thanks Mrs. Faye Ricksy and Miss Phyllis Savacchio for their secretarial assistance.

References


Comparison of Medial Growth of Human Thoracic and Abdominal Aortas

HARVEY WOLINSKY

Circ Res. 1970;27:531-538
doi: 10.1161/01.RES.27.4.531

Circulation Research is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1970 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7330. Online ISSN: 1524-4571

The online version of this article, along with updated information and services, is located on the
World Wide Web at:
http://circres.ahajournals.org/content/27/4/531

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation Research can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation Research is online at:
http://circres.ahajournals.org/subscriptions/