The heart arises at the transverse confluence of two tubes, not from their lengthwise fusion.

Many textbook accounts state that the heart arises from the fusion of two tubes that are aligned longitudinally either side of the future cardiac region. Schematic illustrations (such as the one below from *Langman's Medical Embryology*, 2007) are commonplace.

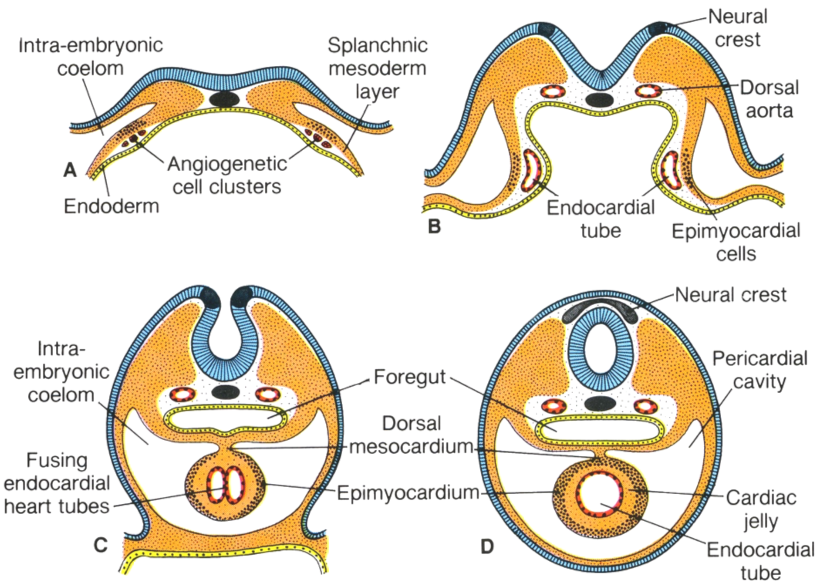
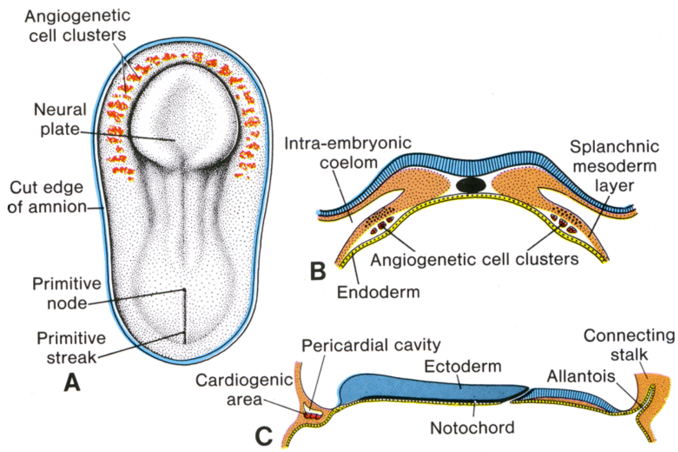
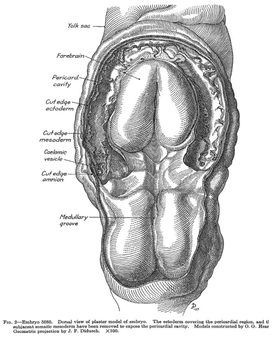


Figure 12-3. Schematic transverse sections through embryos at different stages of development, showing the formation of a single heart tube from paired primordia. (*A*) Early presomite embryo (approximately 17 days), (*B*) late presomite embryo (approximately 18 days), (*C*) at four somites (approximately 21 days), and (*D*) at eight somites (approximately 22 days) (adapted from several sources).

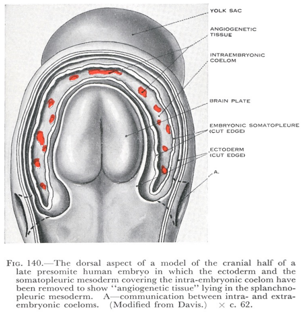
This idea arises partly from the incorrect concept that the early embryo has the form of a 'flat disc' in the shape of a 'sandal' (see A below, from *Langman*, 1985; B cross-section; C longitudinal).



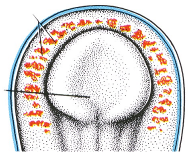
The sequence for the ‘flat’ embryo myth can be traced using the illustration below (sources: Davis CL, Development of the human heart from its first appearance to the stage found in embryos of twenty paired somites. *Carnegie Cont. Embryol.* 19, No. 107, 1927, 245–284; Hamilton WJ, Boyd JD, Mossman HW, *Human Embryology*. Cambridge: Heffer, 1964; Sadler TW, *Langman’s Medical Embryology*. Baltimore: Lippincott, 2007).



Davis (1927) - model of presomite human embryo



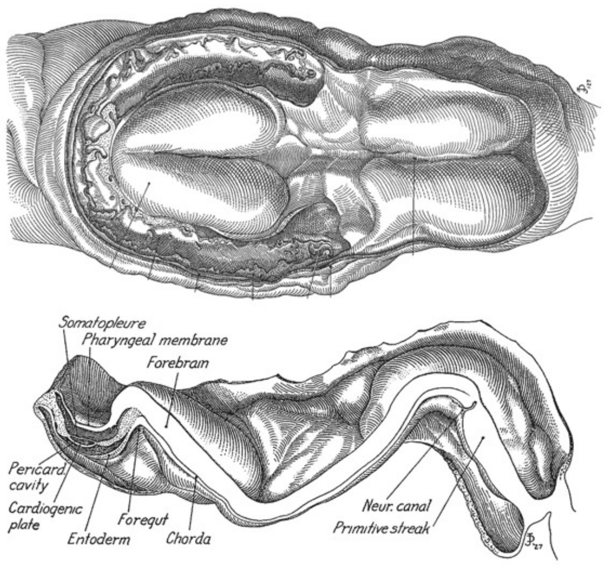
modified by Hamilton, Boyd, Mossman



modified by Langman as embryo of ‘18 days’

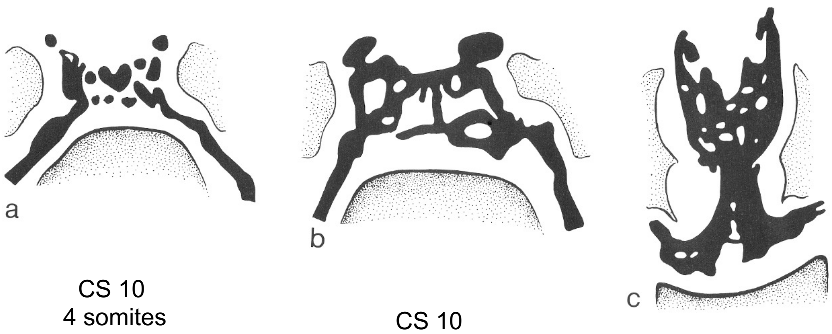
However, as soon as one views the 3D reconstruction by Davis (1927) from the side, it becomes obvious that the dorsal view (above) hides the fact that the brain bulges are already elevated above the horseshoe-shaped heart region. This heart region is labelled ‘cardiogenic plate’ in lower of two figures (below), based on a median section through the 3D reconstruction.

It is important to know that, at this time, there are two umbilical veins arising along the flanks of the embryo and that these veins already convey a flow of nutrients from the future placenta via the connecting stalk to the bulges of the growing brain, long before the heart itself arises. This is an important point: *flow precedes the heart*.



An illustration, which is closer to the reality of what happens in the heart region over time, is seen in the following compilation by students of Erich Blechschmidt, from older publications. From left to right, the three images represent a temporal sequence of development seen ventrally (head region at top), even though the Carnegie Stage (CS) is the same for each embryo (from: Steding G, Seidl W, Christ B, Chapter 10, in: Hinrichsen KV, *Humanembryologie*. Berlin: Springer, 1990).

all early vessels are plexiform and capillary-like



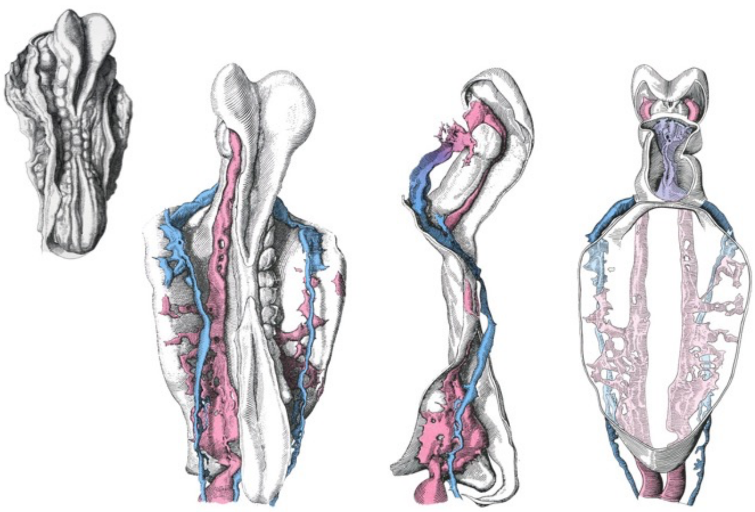
CS 10
4 somites
(Sternberg, 1927)

CS 10
4 somites
(Orts Lorca, 1934)

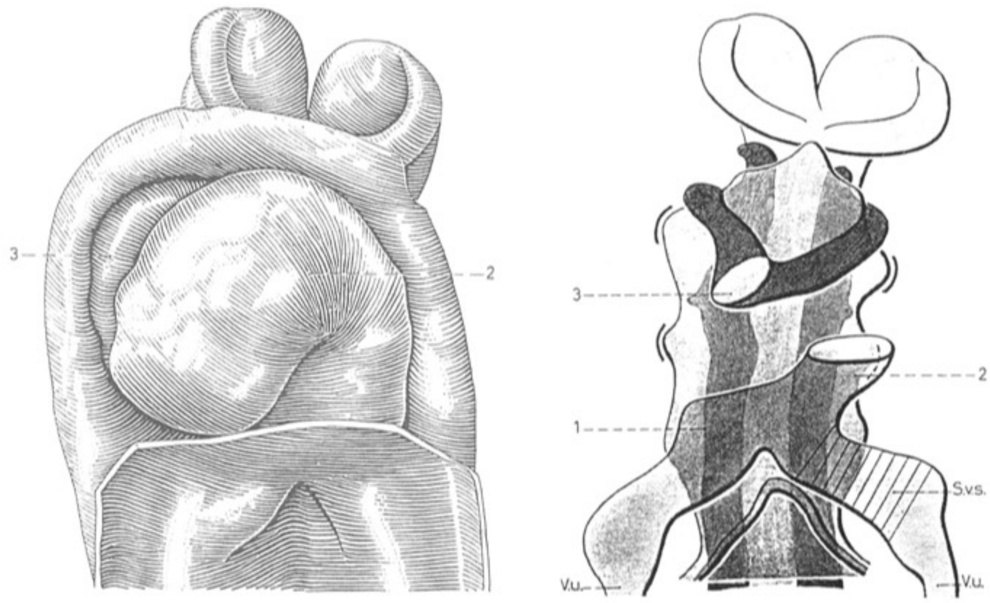
CS 10
2-3 somites
(Ingalls, 1920)

This process can be summarised as follows: the heart arises from a transverse collection of pools of percolating fluid at the cranial ends of two umbilical veins; the pools of fluid coalesce as their transverse alignment changes to longitudinal in the form of a 'tall' X, i.e., the X-heart (Ingalls, 1920 drawing, above).

This last stage leads into the next, illustrated using a reconstruction of the Payne embryo (2.2 mm; 7 somite pairs; CS 10; Carnegie Collection No. 4216; Blechschmidt E, *Vom Ei zum Embryo. Die Gestaltungskraft des Menschlichen Keims*. Stuttgart: Deutscher Bücherbund, 1969).



As the mid-region of the heart tube becomes surrounded by a 'lake' of fluid in the developing pericardial sac, the 'free' heart tube grows faster than the space it occupies. Thus, the heart tube arches ventrally as a loop, which Blechschmidt described as the Ω-heart, labelled 2 in the drawing on the left side of the next illustration (the Ω form is envisaged perpendicular to the plane of the paper and somewhat flexed with respect to the longitudinal axis of the embryo). The drawing on the right shows part of the atrium at 2 and the truncus arteriosus at 3, both remaining after the 'free' loop of the Ω-heart is removed (Blechschmidt E, Die Bedeutung der interzellulären Flüssigkeit für die Herzentwicklung; Flüssigkeitsstauungen als allgemeine Vorbedingungen für Differenzierungen. In: Heilmeyer L, Mazzei ES, Holtmeier HJ, Marongiu F (eds) *Diureseforschung*. *Fortschr Gebiete Inn Med, IV. Symp, Freiburg 1966*, Stuttgart: Thieme, 1967, pp. 60–85).



12 somites (Blechschmidt)

An anatomical mnemonic

The above process of transformation of the anlage of the heart from a transverse to a longitudinal orientation, can be mimicked using our body as follows:

1. Lay your forearms alongside one another across your chest, with each wrist near the opposite elbow.
2. Imagine that the forearms are fused to make a single common transverse region (containing multiple pools of fluid).
3. Raise the forearms above your head (the arms now represent each umbilical vein; the 'fused' forearms represent the anlage of the transverse heart tube).
4. Dorsiflex each hand at the wrist so that the hands point further up and away from the body (each hand represents the anlage of an aorta supplying the mesodermal surface of a brain bulge).

5. Slowly uncross your forearms but keep them 'fused' in the mid-region, so that the forearms make a tall X (i.e., the X-heart).
6. Continue to uncross the 'fused' forearms slowly until they become parallel; the hands (aortae) still diverge at the top; the arms (umbilical veins) supply blood to the base, where the zone of both elbows now represents the sinus venosus; the adjacent wrists at the opposite end can now be imagined as fused together to represent the truncus arteriosus; the intervening fused arms are the free part of the heart tube (the precursor of the Ω-heart) partly surrounded by a pericardial sac.

<u>Summary</u>

The human heart arises by elongation of a transverse region, initially containing plexiform pools of fluid that coalesce to create a tube with a single lumen. There is no fusion of so-called right and left 'endocardial' tubes.

Application of biomechanical human embryology to explain animal development (i.e., *reverse phylogeny*) reveals that the development of the heart in animals can be interpreted from similar biodynamics. Indeed, the conclusion of an important study of heart development in the mouse embryo is quite explicit: "...fusion of the left and right parts of the heart primordium does not occur" (De Ruiter MC, Poelmann RE, Van der Plas-de Vries I, Mentink MMT, Gittenberger-de Groot AC, The development of the myocardium and endocardium in mouse embryos. Fusion of two heart tubes? *Anat Embryol* 185, 1992, 461–473).

It remains to mention that the flow of nutrients in the young embryo before the heart starts to beat is probably not unidirectional, but tidal with flow and ebb and with a net flux from the chorion towards the brain bulges. Even after the heart starts beating, both anterograde and retrograde flows are still observed in the aorta and elsewhere.

The first event observed in the action of the embryonic heart is its *diastole,* which develops slowly over hours. This in turn leads to a slow *systole*; then the cycle frequency gradually increases. The heart rate in fetuses is very high compared with that of children or adults.