SUMMARY The frontal chest film as a means of suspecting transposition complexes is discussed. The first step is recognizing the normal relationships formed by the ascending aorta, an aortic knob-descending aorta, and pulmonary trunk. The concept of which ventricle is connected to which atrium is developed—the terms ventricular noninversion and inversion being utilized. Frontal chest film signs of transposition are summarized as follows: 1) in the majority of transposition complexes, absence of the pulmonary trunk is the premier sign; 2) patients with ventricular noninversion tend to show the ascending aorta and aortic knob-descending aorta in normal position. Patients with ventricular inversion usually show absence of all three great artery relationships. 3) In ventricular inversion, the left heart border shows a low septal notch or a diffuse convex bulge (two ventricles), or a discrete bulge high up on the left heart border (single ventricle).

In utilizing the posterior-anterior (PA) chest film, the observer must first recognize its limitations as well as the relative limitations of his other clinical findings. It is intriguing that the PA chest film and electro-vectorcardiographic data complement each other in a unique manner. Basically, cardiac auscultation and electro-vectorcardiographic techniques reflect the intracardiac findings (e.g., presence or absence of a ventricular septum, atretic valve etc.) while yielding little data regarding the position and course of the great arteries. On the other hand, the chest film yields little information about intracardiac pathology but does determine the position and course of the aorta and/or pulmonary artery. This is because these are exterior or border-forming cardiac structures outlined by the lungs.

Normal Great Artery Relationships

In analyzing the chest film in a patient suspected of having congenital heart disease, information regarding the possibility of a transposition complex resides primarily in an analysis of the great artery region—the mediastinum. Therefore, knowledge of the roentgenological anatomy of the normal great artery relationships is fundamental to determining the presence or absence of transposed or malpositioned great arteries.

In the patient with normally related great arteries, the superior mediastinum often shows what we term a "triad of densities." In the PA or frontal view, this includes 1) the ascending aorta, 2) the transverse arch (aortic knob) and proximal descending aorta continuum, and 3) the pulmonary trunk or main pulmonary artery segment (fig. 1). These normally formed densities seen on the PA chest film can be explained angiographically, as follows. The aortic valve is in reality an intracardiac structure and thus cannot be seen; the ascending aorta arises from within the left ventricle, posterior to the pulmonary trunk. The right outer margin of the ascending aorta is convex to the right. This may produce a slight convex density in the right superior mediastinum. As the transverse aortic arch courses posteriorly and to the left of the trachea, the outer wall of the upper descending thoracic aorta forms a curvilinear density termed the "aortic knob" (fig. 1). The proximal thoracic...
aorta continues inferiorly, superimposed on the cardiac silhouette as the descending thoracic aorta (fig. 1).

Just below the aortic knob is the most important density — the pulmonary trunk itself (fig. 1). Angiocardiographically, it is seen to arise anterior to the aorta, originating from the anteriorly situated right ventricular infundibulum. The pulmonary trunk produces a slight convex bulge with its upper margin beginning just below the aortic knob and its lower margin ending abruptly at the left cardiac border where the inconspicuous left atrial appendage begins (fig. 1).

Variations in the Triad of Densities with Age

Of the triad of densities (the ascending aorta, the aortic knob — descending aorta, and the pulmonary trunk), all but the ascending aorta are usually well defined in older children, teenagers, and young adults. In the normal newborn, infant, and young child, however, thymic tissue often obscures both great arteries (fig. 2). Fortunately, most infants with stressful forms of congenital heart disease, especially those entities falling within the constellation of “transposition complexes,” show relatively little if any thymic tissue and thus, the great artery region can be evaluated.

In the normal middle-aged and elderly individual, the pulmonary artery density is rarely apparent (fig. 2B). On the other hand, the ascending aorta is almost invariably visible in this age group, and the aortic knob-descending aorta continuum may be quite prominent (fig. 2B). It follows that the aortic knob-descending aorta density is the only member of the triad of densities visible in most patients, regardless of age (fig. 2). Therefore, when one analyzes the mediastinal relationships of the great arteries, the presence or absence of these densities assumes a certain significance depending on the age of the patient.

A Plain Chest Film Definition of Transposition

From a plain chest film viewpoint, transposition of the great arteries can be defined as an alteration of both great arteries from their previously described normal relationship. In other words, the pulmonary trunk and ascending aorta no longer arise from the right ventricular infundibulum and left ventricle respectively. In the vast majority of transpositions, the pulmonary trunk arises from the left ventricle and the ascending aorta from the right ventricular infundibulum.

It must be understood that the term transposition of the great arteries, as used herein, is a general one. It does not indicate a specific condition. It does not, for example, indicate whether the patient has, in association with “transposition,” two functioning ventricles or a single or common ventricle. It does not define which anatomic type of ventricle is connected to the right or left atrium; nor does it give information about associated atresia of the tricuspid or mitral valve. Furthermore, it does not tell whether the anatomic situation creates an admixture cyanotic condition or one showing normal physiology. Lastly, this definition does not include the classical varieties of “double outlet

![Figure 1](image-url)
Figure 2. A) PA chest film in a normal infant showing how normal thymic tissue (arrows) may obscure the great vessels. B) Posteroanterior chest film of an elderly male without known heart disease. The ascending aorta (AA) and aortic knob (AK) are prominent and the pulmonary trunk is not distinguished — all features normally found in this age group.

Figure 3. Schematic representation of the embryologic development of the ventricles in ventricular noninversion. In this schema, there is situs solitus of the atria (atria in usual position). A) Initially, the cardiac tube begins as a straight line structure (7 somite stage). B) At approximately the 11 somite stage, the tube bends with its convexity directed anteriorly and to the right (so-called "d-loop"). Following this, the ventricular mass develops in a leftward direction so that the apex will ultimately reside in the left chest as shown in C through E (7mm embryo). C) The resulting atrioventricular arrangement (anatomic right ventricle aligned with the anatomic right atrium and anatomic left ventricle with the left atrium), may be termed ventricular noninversion. It is important to realize that the cardiac mass may become arrested at the stage shown in C (dextrocardia), or at the stage shown in D (mesocardia). In the schema F-H, the ultimate anatomic positions of the right and left ventricles relative to the right and left atria are shown. In the basic definition of noninversion, the division of the truncus (T) plays no role. In this schema we show the great arteries to be normally related (F-H). However, the aorta (A) could just as easily arise from the right ventricular infundibulum (RV — black irregular border) and the pulmonary trunk (P) from the left ventricle (LV — smooth dotted border). This common condition is known as complete transposition of the great arteries. A = aorta; AS = aortic sac; BC = bulbus cordis; LA = left atrium; LV = left ventricle; RA = right atrium; RV = right ventricle; T = truncus arteriosus; V = ventricle. (A, B, C redrawn after Van Mierop and Davis).
right ventricle,” (also termed “partial transposition”) in which the pulmonary artery arises in a normal position above a right ventricular infundibulum. Fortunately, this latter condition is extremely uncommon.

**Development of the Ventricles**

In order to better understand the great artery relationships in the transposition complexes, the clinician must have some understanding of the basic embryology regarding the development of the ventricles. As a means of classifying the various entities which fall within the broad scope of “transposition complex,” researchers have categorized them based upon which way the *originally straight* embryonic cardiac tube bends.

**Ventricular Noninversion ("d-loop")**

In the vast majority of individuals, the originally straight embryonic cardiac tube (fig. 3A) bends initially to the right (fig. 3B). Following this, the embryonic ventricles usually develop in a leftward direction so that the cardiac apex will ultimately come to rest on the left (figs. 3C, D, E). The initial rightward bend of the cardiac tube is a normal phenomenon and is termed “d-loop” by some investigators.

As a result of this bend to the right, the anatomic right ventricle aligns itself with the right atrium (fig. 3C). Another term used to describe the resulting atrioventricular arrangement is ventricular noninversion — a term which will become more logical following the description of ventricular inversion. Rarely, following the initial rightward bend, the embryonic ventricular mass may fail to migrate to the left and remain arrested in this position (figs. 3C and 3F). As a result, the patient with ventricular noninversion or d-loop may present roentgenologically with dextrocardia (fig. 3F). Another alternative is that ventricular migration may arrest with final development in the midline — a situation termed mesocardia (figs. 3D and G). However, in the majority of individuals with ventricular noninversion, the ventricular mass migrates and develops so that the cardiac apex is on the left — a situation referred to as levocardia (figs. 3E and H). The important clinical-roentgenologic implication of all this is that the cardiac apex in ventricular noninversion may vary in position.

**Ventricular Inversion ("l-loop")**

In a few rare instances, the originally straight embryonic cardiac tube (fig. 4A) bends initially to the left (fig. 4B). The normal migration and development of the embryonic ven-

**FIGURE 4.** Schematic representation of the embryonic development of the ventricles in ventricular inversion. In this schema there is situs solitus of the atria (atria in usual position). A) As in figure 3A, the cardiac tube begins as a straight line structure (? somite stage). B) In contrast to noninversion, the initial bend of the cardiac tube in inversion is to the left (so-called "l-loop"). The normal development is for the cardiac mass to migrate in a rightward direction so that the cardiac apex resides in the right chest (C-E). The primitive right and left atria (RA and LA) arise in an identical fashion to that in ventricular noninversion (fig. 3). C) The resulting atrioventricular arrangement (anatomic right ventricle aligned with the anatomic left atrium and anatomic left ventricle with the right atrium) is termed ventricular inversion. The basic definition of inversion and noninversion then relates simply to which ventricle is in continuity with which atrium. Just as with ventricular noninversion, the cardiac mass may show mesocardia (D) or dextrocardia (E). In this schema we show the truncus (T) dividing, so the aorta (A) arises from the anatomic right ventricle (RV — black irregular border) and the pulmonary trunk (P) from the anatomic left ventricle (LV — smooth dotted border). The division of the truncus in no way dictates the basic ventricular arrangement (i.e., inversion or noninversion of the ventricles). A = aorta; AS = aortic sac; BC = bulbus cordis; LV = left ventricle; T = truncus arteriosus; V = ventricle. (4A redrawn after Van Mierop and David11).
tricular mass in these patients is the opposite from those with ventricular noninversion or d-loop, that is, the ventricles may migrate to the right (figs. 4C, D, and E). The initial leftward bend of the cardiac tube is termed “l-loop” by some investigators. As a result of this bend to the left, the anatomic right ventricle is aligned with the anatomic left atrium, and the anatomic left ventricle aligns itself with the right atrium (fig. 4C). The ventricles, therefore, are inverted with respect to the atria. The resulting atroventricular arrangement may thus be termed ventricular inversion. It becomes apparent from figures 3F, G, H and figures 4F, G, and H that the ventricular arrangement in ventricular inversion (l-loop) is the mirror-image of the ventricular arrangement in ventricular noninversion (d-loop). The embryology, unfortunately, is not completely logical for following the initial leftward bend, the embryonic ventricular mass commonly fails to migrate to the right. As a result, the patient with ventricular inversion will usually present roentgenologically with levocardia (figs. 4C and F). Another alternative is that the ventricular mass may arrest and develop in the midline (mesocardia) (figs. 4D and G). However, in a small percentage of the cases the ventricular mass completes its migration so that the cardiac apex is on the right (dextrocardia) (figs. 4E and H). The clinical-roentgenologic implication of this is the same as for ventricular noninversion, that is, the cardiac apex in ventricular inversion may show variations in position.

As already indicated, patients with ventricular noninversion almost invariably show levocardia (fig. 3H). In our experience the majority of the patients with ventricular inversion also present with levocardia (fig. 4F). Therefore, to simplify this communication, the rare patient with dextrocardia will be excluded.

In addition, it must be clearly understood that the presence or absence of transposition of the great arteries plays no role in defining the type of basic ventricular arrangement. The former is a separate embryologic phenomenon which deals with the division of the truncus. The determination of whether ventricular inversion or noninversion exists depends ultimately upon which ventricle is connected to which atrium, not which great artery arises from which ventricle. This point is emphasized because some terminologies have developed highly involved and complex classifications of “transposition complexes” based upon relatively minor variations in the position of the great arteries. We feel this is unnecessary and only tends to confuse those unaccustomed to these conditions.

**Development of the Great Arteries**

The ultimate site of origin of the pulmonary trunk and aorta (excluding persistent truncus arteriosus) is dependent upon whether or not two embryonic pairs of truncus swellings develop in a correct or an incorrect manner. As mentioned, this phenomenon is independent of the ventricular development.

In all forms of transposition (regardless of the ventricular arrangement), there are three basic courses of the ascending aorta. These are 1) the ascending aorta with varying degrees of convexity to the right (figs. 5A and D); 2) a midline ascending aorta without a major convexity to the right or left (figs. 5B and E); and 3) an ascending aorta with varying degrees of convexity to the left (figs. 5C and F).

The importance and limitations regarding these aortic positions will be subsequently discussed. However, among transposition complexes, the more important great artery from an X-ray point of view is the pulmonary trunk itself.

**Figure 5.** Arteriographic and schematic demonstration of the three basic courses of the ascending aorta in transposition complexes, regardless of the presence of ventricular inversion or noninversion. A and D show the ascending aorta (AA) convex to the right — a similar appearance as that of the “usual” course of the aorta (fig. 1). The dotted lines indicate variations in the position of the ascending aorta (AA). B and E show the ascending aorta (AA) in the midline without a major convexity to the right or left. C and F show the ascending aorta (AA) convex to the left. This is the prevailing pattern of the aorta in transposition with ventricular inversion. The dotted lines indicate variations in the position of the ascending aorta (AA). RC = right coronary artery.
The Pulmonary Trunk in Transposition Complexes

In transpositions, (again, regardless of the ventricular arrangement), the pulmonary trunk arises from the anatomic left ventricle somewhat posterior to the anterior ascending aorta (fig. 6). As mentioned, considerable attention has been given to the types of interrelation between the great arteries in transpositions. From a plain film viewpoint, however, these are relatively unimportant when dealing with the pulmonary trunk. This is because the origin of the transposed posteriorly located pulmonary trunk prohibits it from being a border-forming structure in 99% of the cases. Therefore, the premier X-ray sign of transposition is absence of a distinct pulmonary trunk density on the PA chest film (fig. 7).

As mentioned previously, this sign by itself is of relative value and its significance depends on the clinical situation and the age of the patient. In an infant with thymic tissue covering the great arteries, it is worthless (fig. 2A). However, in an infant with heart disease (especially cyanotic heart disease), and minimal thymic tissue, absence of the pulmonary trunk density suggests a transposition complex until proven otherwise (fig. 7). Most importantly, its absence in this situation forces the physician to consider this diagnosis early in the interpretation.

In adults absence of the pulmonary trunk has little significance since most normal middle-aged and elderly patients show no pulmonary trunk on the plain chest film (fig. 2B). Moreover, the frequency with which a transposition complex reaches adulthood is extremely low. However, in a cyanotic adult, absence of a pulmonary trunk assumes added significance when correlated with the position of the thoracic aorta. This will be discussed in the next section.

Analyzing the pulmonary trunk from another viewpoint, what does its presence imply? Presence of a pulmonary trunk is of considerable value. This finding almost invariably indicates that the pulmonary trunk is arising from an anteriorly located right ventricular infundibulum. From this it can be extrapolated that 1) the great arteries are normally related (major forms of transposition are ruled out); 2) the patient has noninversion of the ventricles; and 3) the patient has two ventricles rather than a single or common ventricle. This last point is valid because in single or common ventricles, there is almost always transposition of the great arteries.

The Thoracic Aorta in Transposition Complexes

As mentioned previously, there are three basic configurations of the ascending aorta in transposition complexes (fig. 5). Embryologically, it has been decided that in patients with ventricular noninversion, the truncus divides in such a way that the transposed aorta has a tendency to show a rightward convexity (fig. 5A). When this occurs, the transposed aorta will yield all the plain film signs as the normally
related aorta. This includes not only the ascending component to the right, but the transverse aortic arch and descending aorta as well. The explanation for this is that the PA chest film does not show alterations in anterior-posterior relationships, but primarily alterations in lateral relationships of border-forming structures.

Because many normal individuals of all ages may present with the thoracic aorta in this manner, the rightward aortic configuration by itself does not indicate a transposition complex. Its primary value would be to suggest noninversion of the ventricles among patients in whom there was a high index of suspicion of transposition for other reasons (i.e., cyanotic child or adult, ECG findings, etc.).

Unfortunately, as many as one-fourth of patients with ventricular noninversion and transposition show the ascending aorta with no convexity or with slight-to-moderate convexity to the left (figs. 5B and C). In these patients, ventricular noninversion cannot be distinguished from ventricular inversion.

With ventricular inversion and transposition, the "prevailing pattern" of the ascending aorta is the opposite or mirror-image of noninversion. The tendency is for the truncus to divide in such a way that the ascending aorta shows varying degrees of convexity to the left (fig. 5C). However, patients with ventricular inversion may occasionally show an ascending aorta with no convexity or with varying degrees of convexity to the right, identical to the prevailing pattern seen in ventricular noninversion and transposition (fig. 5A and B).

When the transposed ascending aorta has no dominant convexity or is convex to the left, all the conventional plain film thoracic aortic densities are absent. In this situation, the ascending aorta produces a relatively straight or overtly convex density in the left superior mediastinum, supplanting the familiar pulmonary trunk and thoracic aortic densities (fig. 7B). Because of the posterior and medial orientation of the transverse aortic arch, the aortic knob and descending aorta usually lie over the spine (fig. 6C). They are, therefore, no longer border-forming structures adjacent to the lung. This explains why they are often absent on PA chest film among patients with ventricular inversion (fig. 7B). Obviously, the ascending aortic density will be absent in the upper right superior mediastinum as well (fig. 7B).

In summary, then, the plain film signs of transposition occurring with most cases of ventricular inversion are simply total absence of the normal triad of densities. The absent pulmonary trunk, of course, is the fundamental sign by which to relate the abnormal thoracic aortic density. Unfortunately, some patients with ventricular inversion will show the ascending aorta convex to the right (fig. 8). As mentioned, these patients are uncommon.

Once transposition of the variety occurring with ventricular inversion is suspected, there are additional signs involving the left cardiac border which may further substantiate that impression.

The Significance of the Left Heart Border in Patients with Ventriclel Inversion

When transposition with ventricular inversion is suspected from the PA chest film (absence of the normal triad of densities), the left heart border will often yield additional supporting data.
In patients with ventricular inversion and levocardia, it will be recalled that the anatomic right ventricle forms the left heart border (fig. 4F). Moreover, in the PA view the ventricular septum is oriented somewhat horizontally and is situated on end (fig. 4F). The inverted position of the right ventricle often results in a pronounced convexity to the left heart border (figs. 8A and 9A). Moreover, because of the position of the ventricular septum, a notch is formed immediately below the convex bulge of the right ventricle — the septal notch (fig. 9A and C).

Once the right ventricular bulge and ventricular septal notch are located, the ultimate size of the right ventricle should next be assessed. This is important because the observer is in the position of not only diagnosing a patient with transposition and ventricular inversion, but he may also determine whether the patient has two functioning ventricles (so-called "corrected transposition") or a single ventricle.

In patients with ventricular inversion and two ventricles, the convex bulge is diffuse, often reaching the diaphragm. If present, the septal notch in these cases is seen just above the diaphragm (fig. 9A and B). In some cases the septal notch may be absent, and the left heart border is overly convex or normal in contour.

In patients with ventricular inversion and a single ventricle, the anatomic right ventricle is by definition, rudimentary. This rudimentary right ventricle creates a small localized bulge confined to the upper one-half of the left heart border, the inferior portion of which represents the septal notch (fig. 9C and D).

As would be expected, patients with transposition and ventricular noninversion may present with a single ventricle as well. However, the plain film signs are identical to patients with complete transposition (noninversion and two ventricles, figs. 10 and 7A). This is because the rudimentary right ventricle is located anteriorly in a nonborder-forming position.

**Summary**

It now seems appropriate to summarize the PA chest film signs of the transposition complexes.

1) In the vast majority of conditions of the heart characterized by some form of transposition (regardless of the ventricular arrangement), the pulmonary trunk density is absent (figs. 7, 8, 9, and 10).

2) The presence of a pulmonary artery segment or the triad of normal densities almost invariably indicates a) both great arteries are normally interrelated (exceptions to this are rare), b) the ventricular arrangement is noninversion, and c) the patient has two functioning ventricles rather than a single ventricle. (It's amazing how much information can be derived from one curvilinear density!) (fig. 1).

3) In patients in whom the clinical setting creates a high index of suspicion for a transposition complex (cyanotic patient, certain ECG findings, etc.), and the pulmonary trunk is absent on the plain chest film, ventricular noninversion is favored if the ascending aorta, aortic knob, and descending aorta are in the usual position (figs. 7A and 10). Unfortunately, this does not rule out transposition with ventricular inversion. In acyanotic patients the absent pulmonary trunk and normal aorta are meaningless because many normal individuals of all ages, especially older adults, may present in this manner (fig. 2B).

4) In patients with total absence of the triad of normal mediastinal densities, a transposition complex should be suspected, regardless of age or clinical presentation. This situation is how most cases of ventricular inversion present, especially in adulthood (figs. 7B and 9).

5) If ventricular inversion is suspected, the left heart border should be analyzed for the ventricular septal notch. A
low-lying notch or a diffuse yet unusually convex left heart border suggests a normal-sized right ventricle which in turn suggests the two-functioning-ventricles form of ventricular inversion (figs. 9A and B). A superiorly located discrete bulge suggests a rudimentary right ventricle, which in turn suggests the single ventricle form of inversion (fig. 9C and D).
FIGURE 10.  A) PA chest film and B) diagram of a patient with transposition of the great arteries, ventricular noninversion, and single ventricle. In A, the pulmonary trunk is absent. Note the presence of an aortic knob and proximal descending aorta in their usual positions (oblique arrows). The ascending aorta is silhouetted by a right upper lobe infiltrate. Thus, in the appropriate clinical setting, the absent pulmonary trunk suggests a transposition complex and the aortic densities favor ventricular noninversion. Because the rudimentary right ventricle is in the anterior or noninverted position, it is nonborder-forming. Therefore, the plain film signs in single ventricle with noninversion are identical to patients with two ventricles and noninversion (fig. 7A).  

A = aorta;  
P = pulmonary trunk;  
RV = anatomic right ventricle;  
SV = single ventricle;  
"LV" = anatomic left ventricle.

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