This is a text version of a podcast/video from Pedscases.com on "**An Approach to Pediatric ECGs – Part 2"** These podcasts are designed to give medical students an overview of key topics in pediatrics. The audio versions are accessible on iTunes or at www.pedcases.com/podcasts.

An Approach to Pediatric ECGs – Part II

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Introduction:

Welcome back to the PedsCases podcast on "An Approach to Pediatric ECGs". This is part 2 of our two-part series. My name is Eric King and I am a medical student at the University of Alberta. This podcast was developed with the help of pediatric hospitalist and medical educator Dr Karen Forbes, pediatric cardiologist Dr. Joseph Atallah and the help of the PedsCases team.

Learning Objectives

Our objectives for this two-part podcast series are to:

1. Outline a systematic approach to interpreting pediatric ECGs
2. Describe how the forces within the heart change and progress after birth
3. Recognize a normal pediatric ECG at different points in childhood, and explain why differences are seen at different ages
4. Recognize common pediatric ECG abnormalities

In part 1 of the approach, we discussed the steps rate, rhythm, axis, and intervals, and we worked through a case of a 4-week-old boy with a new grade 3 systolic murmur. It is recommended that you listen to part 1 prior to moving on to part 2. In this podcast, we will discuss the last 2 steps of the approach: voltages, and repolarization. Since this is a visual topic, we encourage you to view the corresponding video presentation to this podcast, available on the PedsCases website.

Voltages

The 6th step is to evaluate the voltages of the heart, which can provide clues to whether there is abnormal ventricular mass, or hypertrophy. Hypertrophy of the myocardium is one of the most common abnormalities seen in pediatric ECGs. It can result from anything that causes volume and/or pressure overload in the heart and can impact the atria and the ventricles. Once again, referral to the normative data is very important. We will look at voltages of both the atria and the ventricles.

Voltages – Atrial Hypertrophy Criteria
Let's first discuss the criteria for atrial hypertrophy.
Right atrial hypertrophy is characterised by tall P waves, which are 3 mm or greater, in any lead.[5] It is most commonly seen as a tall p-wave in lead II, V1 and V2. The p wave represents atrial depolarization, so if we think about an impulse travelling from the SA node through the right atrium to the AV node, it makes sense that an enlarged right atrium would result in a taller p wave.

Left atrial hypertrophy is characterised by prolonged P waves, which are 0.10 seconds or longer in any lead, or longer than 0.08 seconds in infants.[5] Again, thinking about the impulse travelling from the SA to the AV node, if the left atrium is enlarged one can imagine that an impulse going through both atria will take longer to reach the AV node resulting in a longer p wave. Broad, notched P waves in the limb leads, and a biphasic P wave in V1 with a dominant negative terminal segment, may raise your suspicion for LAH.

Bi-atrial hypertrophy may also be seen and is characterised by a combination of an increased amplitude and duration of P waves.

Case 1 – Atrial Voltages
Let's go back to our case. The length and height of the P waves in Leads II, V1 and V2 are shown in the slides. The p waves are less than 3mm in height and under 0.08 seconds long. There are no broad, notched p waves, and there are no biphasic waves in lead V1. Therefore, there is no atrial hypertrophy in our patient.

Voltages – Ventricular Hypertrophy Criteria
Now moving on to the criteria for ventricular hypertrophy. Since a hypertrophied ventricle is larger and/or thicker than normal, the forces within that ventricle are amplified.
This causes the following key ECG findings:[5x]

1. large QRS complexes outside of the normal ranges in the precordial leads that reflect the hypertrophied ventricle
2. An abnormal R/S wave ratio in the precordial leads that favor the hypertrophied ventricle
3. QRS axis deviation towards the hypertrophied ventricle, mainly seen in right ventricular hypertrophy

When we evaluate the voltages or forces within the heart, it is necessary to understand which leads reflect the forces of the right and left ventricles. The forces of the right ventricle will be primarily represented by the positive R waves in right sided precordial leads (V1, V2 and V4R), as well as, limb leads III and aVR. While, the forces of the left ventricle will be primarily represented by the positive R waves in left sided precordial leads (V5 and V6), and limb leads I, II and aVL. A hypertrophied ventricle would show large R waves, outside the upper limit of normal, in the groups of leads that reflect that ventricle. It is, therefore, important to understand which leads reflect the forces of which ventricle.

We can also compare the amplitude of the R and S waves in these leads to assess the relative forces of each ventricle. The S waves provide insight into the forces in the other ventricle, since the forces on the opposite side of the heart record as negative deflections.

With this in mind, we can look at the R/S wave progression in the precordial leads as another way to assess the relative forces of the right and left ventricles, in addition to the axis. As we discussed in part 1, the right ventricle is dominant at birth, and in the months to years following, there is a progressive shift to left ventricular dominance. If we look at lead V1, infants in the first months of life should have a high R/S ratio, where the R wave is greater than the S wave. This is because lead V1 reflects the right ventricle, which is dominant at this age. As the axis shifts, so too will the R/S ratio, and often by 2-3 years of age, the amplitude of the R and S waves are equal. After age 3, the ratio typically drops below 1, so that the R wave is now smaller than the S wave. The R/S wave ratios in lead V6 essentially show the opposite trend. Typically, the R/S ratio's in leads V1 and V6 are used to assess for proper ventricular development.

Case 1 – Ventricular Voltages

Let's look at the ventricular voltages to determine if hypertrophy is present in our case. The first major finding we look for are large QRS complexes outside of the normal ranges in the precordial leads that detect the hypertrophied ventricle. To do this, we will measure the R and S waves in leads V1 and V6 and compare them to normative data for age. As we just discussed, lead V1 represents the right ventricle, and lead V6 represents the left ventricle. In our case, lead V1 shows an R wave of 16mm and an S wave of 4mm. These are both within normal limits for age.[2]

Lead V6 shows an R wave of 4mm and an S wave of 1mm which is also within normal limits.[2] Therefore, we can infer that as expected, the magnitude of voltages in the right ventricle are higher than in the left and all values are within normal ranges.

The next major finding we look for in ventricular hypertrophy is an abnormal R/S wave ratio in the precordial leads, that favor the hypertrophied ventricle. To do this, you measure the R and S wave, typically in V1 and V6, and then divide the R wave by the S wave to get a ratio.

Based on the Rijnbeek tables, the normal R/S wave ratio from 0 to 1 month in V1 is 0.8 to 3.7 and 1.0 to 3.7 in V6.[2] Interestingly, in our patient the R/S wave ratio in both leads V1 and V6 is 4, which is slightly above the upper limit of normal for age in both leads. This finding does not fulfill our criteria for ventricular hypertrophy however, as the ratios do not favor a specific ventricle. In ventricular hypertrophy, we would expect the R/S wave ratios to be higher on the dominant side and lower on the non-dominant side. In our case, the R/S wave ratios are slightly high in both the right and left sided leads and are therefore non-specific to either ventricle.

Finally, we look for QRS axis deviation towards the hypertrophied ventricle. We already measured the QRS axis in step 4 of our approach, at +130 degrees, which was normal for our patients age.[2] If we suspected ventricular hypertrophy based on voltages or R/S ratios, we would expect an axis corresponding to that ventricle.

So, to conclude our findings; our patient has normal QRS complex voltages, slightly high but non-specific R/S wave ratios, and a QRS axis that is appropriate for his age. Although the R/S ratios are slightly abnormal, he does not meet criteria for ventricular hypertrophy.

Repolarization

The last step in our approach is to look at the ST segment and T wave for repolarization abnormalities. There are several ST/T changes in pediatric ECGs that are considered normal but may be more alarming if they were seen in an adult ECG. Pathologic ST/T changes are less frequent in pediatric patients, because ischemic heart disease and infarction are rare in this population.[5] Nevertheless, certain ST/T changes may signify serious myocardial disease, so proper identification of these changes is important.
The T wave is a recording of ventricular repolarization, and the amplitude and vector of the wave are important indicators of cardiac function. Because the axis of the heart starts to change drastically after birth, the axis of repolarization of the ventricles is also affected. The T waves in leads V1, V2, and V4R are typically upright from birth until day 7, where they flip and become inverted. They should remain inverted for the next 8 to 10 years. After these years of gradual axis development, they then flip back and remain as upright T waves from then on. Positive T waves in leads V1, V2 and V4R from day 7 to 8-10 years old, may suggest right ventricular hypertrophy.[5] The normal ranges of the T wave axis and the T wave amplitude in leads V5 and V6, are available in the normative data.[2] In general, the T wave axis should be the same or within 90^{o} of the QRS axis.[5]

The ST segment is the phase after ventricular depolarization and before repolarization. In healthy adult ECGs, this segment should return to baseline before the T wave. In pediatric ECGs however, a slight elevation or depression of 1 mm in the limb leads, and up to 2 mm in the precordial leads is common and within the normal limits.[5] Detailed discussion of ST/T changes are beyond the scope of this podcast, however, some common pathologies that cause ST/T changes include myocarditis, pericarditis, LVH or RVH, cardiomyopathy, digitalis effect, hypothyroidism, and although rare, myocardial ischemia, and myocardial infarction.[5]

Another normal ST variation in pediatric ECG's to be aware of, is something called early repolarization. In early repolarization, leads with upright T waves have elevated ST segments, leads with negative T waves have depressed ST segments, and the T waves are taller than normal.[5] It usually involves the inferior (II, III, aVF) and lateral leads (V4, V5, V6) . You may also see a small positive deflection immediately following the QRS complex which is called a J wave. Although it may look concerning, the ST segment shift is stable and is quite common in healthy adolescents.

Case 1 - Repolarization
Let's complete our approach and look for repolarization abnormalities in our case. Recall that between 7 days to 8-10 years old, the T waves in the right sided precordial leads will be inverted. In our ECG, we can see that the T waves in V1 are negative, and all other T waves in the ECG are positive, which is expected.
Looking through the ST segment for elevation or depression, we see that leads V2 and V3 show ST elevation of 1 mm. As we discussed, an ST elevation or depression of 1-2 mm in the precordial leads is normal.
Therefore, there are no concerning findings in terms of repolarization in our patient.

Case 1 - Summary
Now that we've gone through the ECG in detail, let's review our case. In summary, our patient was a 4-week-old male with a new systolic murmur at the left upper sternal border. We interpreted his ECG by using the following approach: ID and calibration, Rate, Rhythm, Axis, Intervals, Voltages, and Repolarization. By working systematically, we determined that this ECG shows normal sinus rhythm at a rate of 167 bpm, a normal mean QRS axis of +130 degrees, no conduction disturbances, normal voltages, and no repolarization abnormalities. We can conclude that this is a normal ECG. With the reassurance from the ECG, our patient was followed clinically with regular check-ups. The murmur was determined to be a benign systolic pulmonary flow murmur of infancy as we suspected and disappeared by 6 months of age. He remained asymptomatic from a cardiac perspective and continued to thrive.

Learning Objectives
This concludes our PedsCases podcast on an approach to pediatric ECGs. To review our learning objectives:

1. We outlined a systematic approach to interpreting pediatric ECGs.
2. We described how the forces within the heart change from right sided dominance to left sided dominance shortly after birth.
3. We discussed what normal pediatric ECGs look like at different points in childhood and why these differences are seen
4. And with this approach, the viewer should now be able to recognize common abnormal pediatric ECGs

Becoming familiar with normal ECGs will allow you to more easily identify abnormal findings in pediatric ECGS. We recommend practicing this approach whenever the opportunity arises.

Thank you for listening, please refer to the self-assessment questions that are available on the PedsCases website.

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