An Approach to Pediatric ECGs – Part I

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Introduction:
Hello and welcome to the Pedscases podcast on an approach to pediatric ECGs. This is Part 1 of a 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:
By the end of this two-part podcast series, listeners will be able 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

The Approach
Interpreting any ECG can seem overwhelming at times, and without a systematic approach, it can be easy to miss things. This approach will help you stay organized and efficient when interpreting ECGs, so that you can correctly interpret them every time! In order to better benefit from this podcast, it would be advantageous for you to be familiar with the basic physics of ECGs, ECG lead axis orientation, common arrhythmias and conduction disturbances prior to listening to this podcast. Since this is a quite a visual topic, we will be working through an example as we go along and would encourage you to listen while viewing the corresponding video presentation available on the PedsCases website.
The basic approach in pediatric ECGs is similar to the approach for adult ECGs, and consists of:
1. ID and Calibration
2. Rate
3. Rhythm
4. Axis

5. Intervals
6. Voltages
7. Repolarization

While this approach is similar to ECG interpretation in adult patients, this podcast will highlight the unique features of pediatric ECGs. We will discuss the differences and summarize them as we go.

Case 1 – 4-week-old Boy

Let's begin with a clinical case. You are a third-year medical student on your peds rotation, and you are seeing a 4-week-old baby boy in clinic with his mother for a check-up. He was born at 37+2 weeks via spontaneous vaginal delivery and weighed 6lbs 4oz with APGAR scores of 8 and 9 at one and five minutes, respectively. The pregnancy and birth were uncomplicated. His mother states that he is exclusively breast fed and is feeding well. His growth charts reveal that his weight and length are tracking along the 25th percentile and his head circumference is tracking along the 50th percentile. On inspection today, he is pink in colour, slightly fussy when examined but in no distress. His heart rate is 160bpm, RR: 35, BP: 80/46, T: 37, O2 sat: 97%.

The rest of your physical exam is normal, so you move on to the cardiac exam. You observe no peripheral or central cyanosis, and no chest wall deformities or visual impulses. You note a 2 sec cap refill peripherally, no palpable thrills, and a 1 cm apical impulse at the 5th intercostal space and midclavicular line. On auscultation, you hear a normal S1 and S2, but note a loud grade 3 high pitched systolic, crescendo-decrescendo, murmur. It is heard at the upper left sternal border and radiates to both axillae and to the back. The murmur was not documented at birth. In discussion with your preceptor, you suspect the murmur to be a benign pulmonary flow murmur of the newborn, however you decide to order a 12 lead ECG to screen for a more concerning cause of the murmur.

ID and calibration

Later that day, the ECG is completed, and it looks like this.
The first step in our approach is to check the identification and calibration. Identifying information can be found at the top of the ECG. It is extremely important to make note of the age of the patient, as you need to use age-appropriate norms for all pediatric ECGs. The calibration for speed and voltage can be found at the beginning or end of each row, in our case, its at the end.
In standard calibration, each 10 mm upward deflection in the recording represents 1 mV, and each 25 mm in the x axis represents 1 second. The calibrations may be adjusted by the technician for various reasons, so you must recognize these adjustments to correctly interpret the ECG.

ECG Leads

Lets quickly review the leads used in 12 lead ECGs
The electrical forces of the heart in the frontal plane are detected by the 6 limb leads, which are labeled I, II, III, aVR, aVL and aVF. The frontal plane is the vertical plane that

divides the body into anterior and posterior portions. So, the superior-inferior and vertical right to left forces of the heart are detected by limb leads.

The precordial leads are labeled as V1-V6. They capture the electrical forces of the heart in the horizontal plane. The horizontal plane is the imaginary plane that divides the body into superior and inferior portions and is perpendicular to the frontal plane. The anterior-posterior, and horizontal right to left forces of the heart are detected here. In pediatric patients, two additional leads may be placed on the right side of the chest, opposite and symmetrical to lead V3 and V4 and are labeled V3R and V4R. This is to get a better indication of the right sided forces of the heart, which as we will see, is very important in pediatric patients. Such is called a 14-lead ECG.
On the bottom of the recording is the rhythm strip, which is a continuous recording of lead II.

Standardized Norms
Before we get into the steps of interpreting the tracing, it's important to understand how we determine what normal values are for pediatric patients.

Normative data was initially collected by Davidgnon et al. on over 2000 Caucasian children, and are established based on age.[1] "Within normal limits" refers to values between the 2nd and 98th percentiles in each age range.[1] You may find that some reference tables group the data into broader age categories, leading to slightly different values. In 2001, Rijnbeek and colleagues published new age and gender-based ECG normative data that are now used in clinical practice and will be used for the majority of this podcast.[2] Theses norms are available for free online. Regardless of which reference you use; normative data should always be referred to when interpreting pediatric ECGs.

Rate
The next step in the approach is to calculate the heart rate. The heart rate of pediatric patients varies with age, and the normal ranges are quite large, so referral to the norms is essential. As mentioned, there are several reference ranges published for heart rate, including the normative ECG data by Rijnbeek, as well as the PALS guidelines.[3] We will use the PALS guidelines here, as they were previously referenced on the podcast "Pediatric Vital Signs" on PedsCases.com.[4]

Using the PALS ranges, at birth, the heart rate can range from 90-205 bpm. This range is acceptable until about 3 months, where the heart rate slowly starts to decrease. From 3 months to 1 year, a range of 100-190 is acceptable and after 2 years of age, a range of 80-120 is normal. The rate approaches the adult norms of 60-100bpm at around 12-16 years of age.[3] Factors that should also be considered when interpreting the rate, are whether the patient was awake, crying, sleeping or whether the patient appeared generally unwell such as being febrile or dehydrated during the time of the recording. The ECG machine automatically calculates the heart rate and it is shown at the top of the ECG recording and can be used for confirmation.

There are several methods to calculate the rate and we will review each briefly. They include: 1. The Count off method 2. R-R distance 3. 6/10 second method and 4. an ECG ruler.

1. The count-off method is a quick way to approximate the rate. This method works by counting off the number of large boxes between 2 consecutive R waves, in the sequence of 300-150-100-75-60-50 bpm. This method only works if the rhythm is regular.
    a. In our patient we see that there are just under 2 large boxes between consecutive R waves. So, we know that the rate must be just over 150 bpm, we'll say roughly 165bpm, which is normal for our patient's age.
2. A more accurate way to calculate the rate is the R-R distance method. In this method, we divide 60 seconds by the measured R to R distance in seconds. We know that 1 mm is equal to 0.04 sec, therefore the measured R-R wave distance in mm is multiplied by 0.04 to give the R-R time in seconds. Dividing 60 by this time equals the heart rate.
   In our patient, the R to R wave distance is 9mm, so we multiply 9mm/beat by 0.04 sec/mm, this gives you 0.36 seconds/beat. You can then divide 60 seconds by 0.36 seconds/beat to get 167 bpm.
   $(9\frac{mm}{beat}\ x\ 0.04\ \frac{sec}{mm} = 0.36\ \frac{sec}{beat} \qquad 60\ \frac{sec}{min} \div 0.36\ \frac{sec}{beat} = 167\ \frac{beats}{min}$
   This method also requires a regular rhythm to be accurate.
3. The 6 or 10 second method, is a method that works for irregular rhythms as well. In this method, the number of full R-R segments in 30 large boxes (6 seconds) is multiplied by 10. This can also be done for 50 large boxes (10 seconds) and multiplying by 6.
   In our patient, we can count 28 full R-R segments in 10 seconds. If we multiply this by 6, we get 168 bpm, which is within normal limits.
4. Finally, an ECG ruler is another quick and easy way to measure the rate, if it is available.

Rhythm
The next step is to check the rhythm of the ECG strip.
The normal rhythm for all ages is sinus rhythm, where the heart rate is paced by the sinoatrial, or SA node. The SA node is located in the right atrium, at the junction of the superior vena cava. As the SA node paces the heart, it sends an impulse that travels from the right atrium to the left atrium and down towards the AV node, resulting in atrial depolarization and a P wave on the ECG.

In sinus rhythm, every P wave should be followed by a QRS, every QRS should be preceded by only one P wave, and the P axis should be between 0 and +90 degrees, at all ages.[5] Therefore, a normal P axis can be confirmed by checking leads I, II, and aVF for upright P waves, and lead aVR for negative P waves. Every P and QRS on the rhythm strip should also be inspected so that no arrhythmias are missed. An abnormal or changing P axis, absent P waves, or an abnormal P to QRS ratio indicates non-sinus rhythm. It should be noted, however, that premature atrial contractions are common in healthy children and may have no significance.[5] Discussion of specific rhythm abnormalities is beyond the scope of this podcast.

Case 1 - Rhythm
Going back to our case, we see that there are upright P waves in leads I, II and aVF and negative P waves in aVR, indicating a normal P axis between 0 and +90 degrees. Looking at the rhythm strip, we can see that every P wave looks the same and is followed by a QRS, and every QRS is preceded by only one P wave. Therefore, we can conclude that there is normal sinus rhythm, as it fulfills all the criteria.

Axis
We have analyzed the rate and rhythm so far, which means that the next step is to calculate the mean QRS axis. However, before we go through this, we will take a moment to review fetal circulation to appreciate why pediatric ECGs progress the way they do.

Since fetal blood is oxygenated through the placenta in utero, there is little need to direct blood through the pulmonary circulation. Instead, oxygenated blood is shunted from the right side of the heart to the left side, through the foramen ovale and the ductus arteriosus. This allows the oxygenated blood from the placenta to bypass pulmonary circulation and go straight to systemic circulation. High pulmonary resistance and low systemic resistance in utero is what allows these shunts to function. Because of this larger afterload on the right side of the heart, the right ventricle is much thicker and stronger than the left at birth. After birth, the lungs fill with air and the increase in PaO2 causes the pulmonary vascular resistance to drop, allowing blood to flow into the lungs. At the same time, the systemic resistance rises to maintain systemic blood pressure, and the ductus arteriosus and foramen ovale close. These changes cause a reversal in the pressure loads of the heart, where the left ventricle is now under a higher demand than the right. In the weeks to months following birth, there is an ongoing drop in pulmonary vascular resistance and consequentially a progressive change from right ventricular dominance to left ventricular dominance. These changes are reflected in different components of the pediatric ECGs including axis and forces.

The QRS axis represents the overall mean direction of ventricular depolarization and is important in supporting a diagnosis of ventricular hypertrophy and other conduction disturbances or congenital heart lesions. It is routinely calculated in the frontal plane, using the limb leads. The norms for mean QRS axis by age are shown in the slides.[2] Note how the axis gradually progresses from right to left with age.

An easy and quick method to approximate the QRS axis, is by looking at the overall polarity of the limb leads. By looking at the net vector of the QRS complex in leads I and aVF, we can localize the QRS axis to the appropriate quadrant. We can then use the remaining limb leads to approximate the QRS axis to a 30-degree sector, by noting which leads show positive, negative or iso-electric QRS complexes. An Iso-electric QRS

complex has equiphasic R and S complexes and shows no polarity, therefore the mean direction of the QRS vector must be perpendicular to that lead.
Let's try this with our case.

Case 1 - Axis
Our patient is 4 weeks old, so based on the Rijnbeek norms for boys between 0 to 1 month old, the mean QRS axis should be between +75 and +140 degrees.[2] First, we look at leads I and avF to localize the axis to a quadrant. We see that lead I has negative QRS complexes and lead aVF has positive QRS complexes, therefore, the QRS axis must fall between +90 and +180. Now that we know the appropriate quadrant, we can look for the most iso-electric lead, as the mean QRS axis should be roughly perpendicular to that lead. In our case the closest and most isoelectric limb lead is Lead aVR, even though it has slightly positive QRS complexes. Perpendicular to lead aVR is +120 degrees. Since in our example, lead aVR has slightly positive QRS complexes, we will estimate that the mean QRS axis is roughly +130 degrees.
Therefore, there is a rightward axis in keeping with the age of the infant, and it is within normal limits for age.

Intervals
The next step in our approach is to measure the intervals of the cardiac cycle to look for conduction disturbances. This section relies heavily on the norms for age, as certain intervals change throughout development. The changes seen here are largely due to the age differences in heart rate and cardiac size. I will briefly discuss how these intervals progress, and which leads are the best for each measurement.

PR Interval
The PR interval is measured from the start of the P wave to the start of the Q wave and is best seen in lead II. It gradually increases from a mean of 100ms at birth until it reaches adult norms of 120 to 200 ms, at age 16.[2] Prolongation of the PR interval typically indicates an abnormal delay in the conduction through the atrium and AV node, and may be seen in myocarditis, congenital heart defects (such as an atrial septal defect), hyperkalemia, and ischemia.[5] A short PR interval may be seen in Wolff-Parkinson White, among other conditions.

Our patient is 4 weeks old, so based on the Rijnbeek norms, the PR interval should be between 77 and 120ms.[2] The PR interval in our patient is 80ms measured in Lead II, which is within normal limits.

QRS Duration
The QRS duration is the duration from the start of the Q wave to the end of the S wave and is best measured in V5. It increases slowly from 50-80ms at birth, to the adult norms of 80 to 110ms at age 16.[2] A wide QRS duration indicates that there is a ventricular conduction disturbance, where the impulse is delayed or abnormally

transmitted across the ventricles. It can be seen in right or left bundle branch block, and in ventricular arrhythmias.[5]

Going back to our case, the normal QRS duration for a 4-week-old is between 50 to 85ms. Our QRS duration measured in lead V5 is 60ms, which is normal.

QT Interval

Finally, the QT interval is measured from the start of the Q wave to the end of the T wave and is best measured in V5 or lead II. It varies with heart rate, so it is interpreted using the corrected QT interval, which accounts for the heart rate. The corrected QT interval remains relatively stable in all pediatric age groups at 0.44 seconds as the upper limit of normal. The only exception is in early infancy where it is slightly longer up to 0.47 seconds as the upper limit of normal.[2] A long QT interval is associated with serious ventricular arrhythmias, with the potential for sudden death, so it is an essential part of evaluating an ECG and should not be overlooked.[5]

Based on the Rijnbeek norms, the QTc duration for 4 weeks is between 380ms-450ms.[2] In our patient, the QT duration, measured in V5 is 240ms. To calculate the QTc, you divide the QT duration by the square root of the preceding R-R interval. In our patient, the calculated QTc is 0.4 seconds, which is normal.

Case 1 – Summary

To summarize our case so far; our patient is a 4-week-old male with a new systolic murmur at the left upper sternal border. We are interpreting his ECG by using the approach: ID and calibration, Rate, Rhythm, Axis, Intervals, Voltages and Repolarization. In this podcast, we determined that this ECG shows standard calibration, normal sinus rhythm at a rate of 167 bpm, a normal mean QRS axis of +130 degrees, and no conduction disturbances.

Learning Objectives

This concludes part 1 of our two-part series on an approach to interpreting pediatric ECGs.

Our learning objectives for this 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

Thank you for viewing this podcast. In part 2, we will return to our case and complete the ECG interpretation. Tune in to find out what happens next!

References:

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