Neonatal Electrocardiogram (Interpretation of)

The Task Force for the Interpretation of the Neonatal Electrocardiogram of the European Society of Cardiology

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Task Force Report

Guidelines for the interpretation of the neonatal electrocardiogram

A Task Force of the European Society of Cardiology

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Objectives

- Adult cardiologists
  - Guidelines for the interpretation of neonatal ECG
    - Clinically most relevant abnormalities
    - Management and referral options
- Paediatricians/neonatologists
  - Updated information of clinical relevance that can be detected from neonatal ECG
Normal ECG in newborn

- Normal ECG changes from birth to adult life
- Major changes in ECG occur in first year
- Intervals should be hand measured
  - Computerized systems often inaccurate in newborn
- Intervals in children increase with age
  - Reach most of adult normal values by 7–8
## Normal Neonatal ECG Standards

<table>
<thead>
<tr>
<th>Age Group</th>
<th>Heart Rate (bpm)</th>
<th>Frontal Plane QRS Axis # (degrees)</th>
<th>P Wave Amplitude [mm]</th>
<th>P-R Interval # (sec)</th>
<th>QRS Duration # [mm]</th>
<th>O III ^</th>
<th>QV6 ^</th>
<th>RV1 * [mm]</th>
<th>SV1 * [mm]</th>
<th>R/S V1 ^</th>
<th>RVs * [mm]</th>
<th>SVs * [mm]</th>
<th>R/S V1 ^</th>
<th>RVs ^</th>
<th>SVs ^</th>
<th>R + S V1 ^</th>
<th>R + S V5 [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-1 day</td>
<td>93-154 (123)</td>
<td>+59 to +192 (135)</td>
<td>2.8</td>
<td>0.06-0.16 (0.11)</td>
<td>0.02-0.08 (0.05)</td>
<td>5.2</td>
<td>1.7</td>
<td>5-26</td>
<td>0-22.5</td>
<td>9.8</td>
<td>0-11</td>
<td>0-9.8</td>
<td>10</td>
<td>28</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 days</td>
<td>91-159 (123)</td>
<td>+64 to +197 (134)</td>
<td>2.8</td>
<td>0.08-0.14 (0.11)</td>
<td>0.02-0.07 (0.05)</td>
<td>5.2</td>
<td>2.1</td>
<td>5-27</td>
<td>0-21</td>
<td>6</td>
<td>0-12</td>
<td>0-9.5</td>
<td>11</td>
<td>29</td>
<td>52</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-7 days</td>
<td>90-166 (129)</td>
<td>+77 to +187 (132)</td>
<td>2.9</td>
<td>0.08-0.14 (0.10)</td>
<td>0.02-0.07 (0.05)</td>
<td>4.8</td>
<td>2.8</td>
<td>3-24</td>
<td>0-17</td>
<td>9.7</td>
<td>0.5-12</td>
<td>0-9.8</td>
<td>10</td>
<td>25</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-30 days</td>
<td>107-182 (149)</td>
<td>+65 to +160 (110)</td>
<td>3.0</td>
<td>0.07-0.14 (0.10)</td>
<td>0.02-0.08 (0.05)</td>
<td>5.6</td>
<td>2.8</td>
<td>3-21.5</td>
<td>0-11</td>
<td>7</td>
<td>2.5-16</td>
<td>0-9.8</td>
<td>12</td>
<td>22</td>
<td>47</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-3 months</td>
<td>121-179 (150)</td>
<td>+31 to +114 (75)</td>
<td>2.6</td>
<td>0.07-0.13 (0.10)</td>
<td>0.02-0.08 (0.05)</td>
<td>5.4</td>
<td>2.7</td>
<td>3-18.5</td>
<td>0-12.5</td>
<td>7.4</td>
<td>5-21</td>
<td>0-7.2</td>
<td>12</td>
<td>29</td>
<td>53</td>
<td></td>
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</tr>
</tbody>
</table>


# 2nd–98th percentile (mean); * 2nd–98th percentile (1 mm = 100 μV); ^ 98th % tile (1 mm = 100 μV).
Normal ECG in newborn: characteristics (1)

- Heart rate
  - normal neonates may have rates of 150–230 bpm especially if crying or agitated

- P-wave
  - Generally pointed in lead II and aVF
  - More rounded in other leads
  - Lead V₁ may be diphasic

- PR interval
  - Increases with age
  - Decreases with heart rate
  - Mean 100 ms (range: 70–140 ms)
Normal ECG in newborn: characteristics (2)

- **QRS complex**
  - Normal axis is between 55° and 200° at birth
  - By 1 month, normal upper limit is < 160°
  - May have more notches than in older children/adults
  - Q wave duration > 30 ms is abnormal
  - Secondary r waves in right chest leads is frequent in normal neonates

- **ST segment and T wave**
  - Better to consider as the isoelectric line the TP segment instead of the PQ segment
  - T waves are normally quite variable in first week
  - T wave is negative in lead V₁ and positive in V₅–V₆ after week 1
Normal ECG in newborn: characteristics (3)

- QT interval
  - Duration changes with rate and is usually corrected (QTc) with Bazett’s formula/using charts to match QT and RR interval*
  - Mean QTc on day 4 is 400 ± 20 ms; no gender differences are present
  - Upper limit of normal is 440 ms on day 4
  - By month 2 there is a physiological prolongation of QTc, followed by progressive decline
  - By month 6, QTc returns to values recorded in week 1

Abnormal ECG in the Newborn

Recommendations for work-up are in yellow font
Heart rate (1)

- **Sinus arrhythmia**
  - Differentiate from wandering pacemaker
  - No work-up should be done unless significant brachycardia exists

- **Sinus tachycardia**
  - Sinus rhythm with heart rate above normal limit for age
  - May be caused by fever, infection, anaemia, pain, dehydration, hyperthyroidism, myocarditis, beta-adrenergic agonists, theophylline
  - Perform evaluation according to underlying condition
  - Perform echocardiogram if myocarditis is suspected
  - Consider appropriate acute treatment of causes of tachycardia
Heart rate (2)

- Sinus bradycardia
  - Sinus rhythm with heart rate below normal limit
  - May be caused by CNS abnormalities, hypothermia, hypopituitarism, increased intracranial pressure, meningitis, drugs passed to the infant from the mother, obstructive jaundice, typhoid fever, hypothyroidism
  - 24-hour Holter monitoring may be helpful when heart rate < 80–90 bpm
  - Perform evaluation for underlying conditions

- Other bradycardias
  - Abnormal sinus pauses (> 2 s)
  - Apparent life-threatening events may manifest as sinus pauses or abrupt bradycardia
  - Assess with 24-hour Holter monitoring
  - Eliminate long pauses (secondary to excessive vagal tone) with atropine
  - Undertake treatment of underlying conditions
P wave

- May be seen in infants with atrial enlargement or non-sinus origin of P wave
  - Right atrial enlargement produces P wave enlargement with normal duration
  - Left atrial enlargement produces increased and prolonged negative terminal deflection of P wave
- Perform echocardiogram when clinically indicated
Atrioventricular (AV) conduction (1)

- Complete (3rd degree) AV block
  - Complete absence of conduction from atrium to ventricle
  - Most cases due to presence of anti-Ro/SSA and La-SSB antibodies in the mother
  - Acquired complete AV block is rare; caused by infections or related to tumours
- 1st and 2nd degree AV block
  - Neonates with LQTS may show 2:1 AV block due to fast atrial rate and the P wave falls within the very prolonged T wave
  - If prolonged QT interval, may be caused by cisapride, diphenamid or doxapram
- Determine clinical history of autoimmune disease
- Assess plasma titre of maternal anti-Ro/SSA and La-SSB antibodies
- If no antibodies, perform ECG on parents and siblings
- 1st degree AV block: perform ECGs in following months
- 2nd or 3rd degree AV block: complete paediatric cardiology work-up
- Only effective treatment for complete block is permanent artificial pacing

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**Atrioventricular (AV) conduction (2)**

- **Bundle-branch block (BBB)**
  - Congenital isolated complete right and left BBB are very rare
  - Hereditary BBB is an autosomal dominant genetic disease
    - Induces right BBB, left or right QRS axis deviation, or AV block
- **Non-specific intraventricular conduction abnormalities**
  - Very rare/ may be caused by myocarditis/endocarditis
  - Complete paediatric cardiology work-up
  - Evaluate underlying causes/ perform ECG on parents and siblings
- **Wolf-Parkinson-White syndrome (WPW)**
  - Prevalence is high in the presence of 2 of the following:
    - PR interval ≤ 100 ms
    - QRS duration ≥ 80 ms
    - Lack of Q wave in $V_6$
    - Left axis deviation
  - Perform complete 2-dimensional echocardiography
  - Assess conduction properties of accessory pathway by tranoesophageal programmed simulation in selected patients for risk stratification

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ECG in neonate showing subtle signs of Wolf-Parkinson-White syndrome

Note delta waves in V5 and V6 with absence of Q waves.
QRS axis and amplitude

- Right ventricular hypertrophy
  - QR complex in V₁
  - Upright T wave in V₁ (normal in 1st week)
  - Increased R wave amplitude in V₁
  - Increased S wave in V₆
- Left ventricular hypertrophy
  - T wave abnormalities in V₅ and V₆
  - Increased R wave amplitude in V₆
  - Increased S wave amplitude in V₁
  - Combination of the last two variables
- Low QRS voltage
  - In limb leads, total amplitude of R+S in each lead ≤ 0.5 mV may indicate myocarditis or cardiomyopathy
- Evaluate underlying causes
- Perform echocardiogram when clinically indicated
Ventricular repolarization (1)

- QT interval prolongation
  - In general, the longer the QTc interval, the greater the likelihood of its clinical significance
  - QTc ~ 500 ms implies clear abnormality
  - May be caused by:
    - Hypocalcaemia – distinct lengthening of ST segment
    - Hypokalaemia/hypomagnesaemia – decrease of T wave amplitude and increase in U wave amplitude
    - CNS abnormalities – T wave inversion
    - Macrolide antibiotics, trimethoprim, cisapride
  - Neonate from mothers who are anti-Ro/SSA antibody positive may show QT interval prolongation in the first 6 months
Ventricular repolarization (2)

- Long QT syndrome (LQTS)
  - Characterized by occurrence of syncopal episodes due to torsades de pointes ventricular tachycardia
  - High risk of sudden cardiac death if left untreated
  - Genetic disease due to mutations of several genes encoding ionic currents involved in control of ventricular repolarization
    - Low penetrance implies gene carriers may not show the clinical phenotype
    - 30% cases are de novo mutations
  - Beta-blockers are first choice therapy
  - If beta-blockers do not prevent cardiac events, consider additional drug therapy, left cardiac sympathetic denervation, pacemakers or implantable cardioverter defibrillator
ECG tracings of 3 newborns with LQTS

Mutations in the potassium channel gene \( KvLQT1 \) (panel A) and in the sodium channel gene \( SCN5A \) (panel B) were identified.
Electrolytes, echocardiogram, intracranial ultrasound are recommended in the appropriate clinical situation. In cases of positive genetics and QTc > 440 ms, therapy is indicated. # In cases of a positive family history (Hx) for LQTS
* 24-hour Holter monitoring should be obtained to look for T wave alternans, complex ventricular arrhythmias or marked QTc prolongation, and the ECG should be periodically checked during the first year.
Ventricular repolarization (3)

- ST segment elevation
  - May be caused by:
    - Pericarditis (most frequent)
    - Hyperkalaemia
    - Intracranial haemorrhage
    - Pneumothorax and pneumopericardium
    - Subepicardial injury due to anomalous left coronary artery
    - Kawasaki disease with cardiac involvement
  - Treat after identifying the underlying cause
  - Brugada syndrome: identified by ST segment elevation with right bundle-branch block pattern in the right precordial leads
    - High incidence of sudden cardiac death secondary to ventricular fibrillation in the absence of cardiac structural abnormalities
  - Collect family history; obtain 24-hour Holter monitoring; refer to specialist
Atrial/junctional arrhythmias (1)

- Premature atrial beats
  - Premature P wave: usually have different morphology and mean vector from sinus P waves
  - Blocked atrial bigeminy: blocked premature atrial beats occur in bigeminal sequence
  - Perform follow-up ECG at 1 month
- Supraventricular tachycardia (SVT)
  - Rapid regular tachyarrhythmia: results from abnormal mechanism originating proximal to bifurcation of bundle of His
  - Extremely regular R-R interval after the first 10–20 beats, most often at rates 260–300 bpm
  - Document SVT with 12-lead ECG before attempting conversion of rhythm, unless infant is critically ill
  - Treatment to prevent further episodes of SVT in infancy is recommended
  - Perform echocardiogram to determine ventricular function or congenital heart disease
Atrial/junctional arrhythmias (2)

- Atrial flutter
  - Characterized by rapid, regular form of atrial depolarization: the ‘flutter’ wave
  - Variable AV conduction from 1:1 to 4:1 causing an irregular ventricular rate
  - QRS complex is usually same as in sinus rhythm
  - Attempt to convert to sinus rhythm
  - Perform echocardiogram to determine ventricular function and congenital heart disease
ECG tracings of a newborn with blocked atrial bigeminy which simulates sinus brachycardia

Blocked P waves are present when examining the T waves.
# Distinguishing tachyarrhythmias in infants

<table>
<thead>
<tr>
<th></th>
<th>Sinus tachycardia</th>
<th>SVT</th>
<th>Atrial flutter</th>
<th>VT</th>
</tr>
</thead>
<tbody>
<tr>
<td>History</td>
<td>Sepsis, fever, hypovolaemia, etc</td>
<td>Usually normal</td>
<td>Most have a normal heart</td>
<td>Many with abnormal heart</td>
</tr>
<tr>
<td>Rate</td>
<td>Almost always &lt; 230 bpm</td>
<td>Most often 260–300 bpm</td>
<td>Atrial 300–500 bpm. Vent 1:1 to 4:1 conduction</td>
<td>200–500 bpm</td>
</tr>
<tr>
<td>R-R interval variation</td>
<td>Over several seconds, may get faster and slower</td>
<td>After first 10–20 beats, extremely regular</td>
<td>May have variable block (1:1, 2:1, 3:1) giving different ventricular rates</td>
<td>Slight variation over several beats</td>
</tr>
<tr>
<td>P wave axis</td>
<td>Same as sinus, almost always visible P waves</td>
<td>60% visible P waves, P waves do not look like sinus waves</td>
<td>Flutter waves (best seen in LII, LIII, aVF, V₃)</td>
<td>May have sinus P waves continuing unrelated to VT (AV dissociation), retrograde P waves, or no visible P waves</td>
</tr>
</tbody>
</table>
| QRS                  | Almost always same as slower sinus rhythm | After first 10–20 beats, almost always same as sinus | Usually same as sinus, may have occasional beats different from sinus | Different from sinus (not necessarily ‘wide’)

SVT = supraventricular tachycardia; VT = ventricular tachycardia.
Ventricular arrhythmias (1)

- Premature ventricular beats (PVBs)
  - Diagnosis of PVB if the complex has different morphology from sinus and is not preceded by premature P wave
  - Measure QT interval
  - 24-hour Holter monitoring in complex cases
  - Perform echocardiogram to determine ventricular function or structural abnormalities

- Accelerated ventricular rhythm
  - Also known as ‘slow VT’ – generally rate is < 200 bpm
  - Occurs at same rate as infant's sinus rate
  - Rhythms tend to alternate
  - Work-up as for ‘ventricular tachycardia’
Ventricular arrhythmias (2)

- **Ventricular tachycardia (VT)**
  - Series of > 3 repetitive complexes originating from the ventricles
  - SVT in infants with a different QRS beyond the first 10–20 beats is rare
    - Diagnosis of VT should be strongly considered
  - Rate of VT may be 200–500 bpm
  - May be sinus P waves unrelated to VT (AV dissociation), retrograde P waves or no visible P waves
  - Infants with VT may have underlying cardiac or CNS abnormality
    - Measure QT interval
    - Obtain 24-hour Holter monitoring and echocardiogram
  - Treatment is generally indicated