

## ELECTROCARDIOGRAPH

<ul style="list-style-type: none"> <li>• General</li> <li>• Heart Rate</li> <li>• QRS Axis</li> <li>• T Wave Axis</li> <li>• PR Interval according to Heart Rate &amp; Age</li> <li>• P Wave Duration and Amplitude</li> <li>• QRS Duration according to Age</li> <li>• QT Interval</li> <li>• R &amp; S voltages according to Lead &amp; Age</li> <li>• R/S ratio according to Age</li> <li>• Q voltage according to Lead &amp; Age</li> <li>• Q wave duration</li> </ul>	<ul style="list-style-type: none"> <li>• ST segment</li> <li>• T wave</li> <li>• Criteria for Right Ventricular Hypertrophy</li> <li>• Right Ventricular Hypertrophy in the Newborn</li> <li>• Criteria for Left Ventricular Hypertrophy</li> <li>• Criteria for Combined Ventricular Hypertrophy</li> <li>• Right Bundle Branch Block</li> <li>• Wolff-Parkinson-White Syndrome</li> <li>• References</li> </ul>
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### General

A systematic approach considering rhythm, rate, axes, intervals, wave abnormalities, R/S ratios, and ST segment changes is recommended. Modern ECG machines may calculate intervals, durations and axes but these should be seen as an aid and not relied on.

If you are not confident of your findings seek senior review. It is good practice to document your findings either on the ECG itself or in the notes including the date, your name and your signature.

**Time:** Generally the recording speed of the paper is 25mm per second so that 1 small square (1mm) = 0.04 seconds, 1 large square (5mm) = 0.2 seconds and 5 large squares (25mm) = 1 second.

**Amplitude:** In general 1 mV = 10mm. Amplitudes should be measured from the upper (or lower) margin of the baseline to the very top of the positive (or negative) deflection.

**Developmental changes:** Most age related changes in paediatric ECGs are related to changes in ratio of left to right ventricular muscle mass. The RV is larger than the LV at birth (less so for premature babies), by one month the reverse is true, by six months the ratio is 2:1 L:R and by adulthood 2.5:1. Changes with age include decreasing heart rate, increased interval durations, changes in R/S ratio in the precordial leads in consequence of increasing left ventricular mass, and changes in T wave axis.

### Heart Rate

Age	Mean Heart Rate (beats/min)	Range
Newborn	145	90 - 180
6 months	145	106 – 185
1 year	132	105 – 170
2 years	120	90 – 150
4 years	108	72 – 135
6 years	100	65 – 135
10 years	90	65 – 130
14 years	85	60 - 120

## ELECTROCARDIOGRAPH

### Tachycardia – consider:

Sinus tachycardia  
Supraventricular tachycardia  
Ventricular tachycardia  
Atrial Fibrillation  
Atrial Flutter

### Bradycardia – consider:

Sinus bradycardia  
Nodal rhythm  
Second degree AV block  
Third degree AV block

An estimate of heart rate can be obtained by dividing 300 by the number of large squares between R waves.

“Sinus rhythm” implies the sinoatrial node is the pacemaker for the entire heart. There must be a P wave in front of each QRS complex and the P wave axis must be in the range 0 to +90 degrees (upright in II and usually I and aVF).

## QRS Axis

### Mean and Ranges of Normal

QRS axis may be determined by limb lead vectors. The net positive deflection in lead I indicates a vector toward the 3 o'clock position. The net positive deflection in lead aVF indicates a vector in the 6 o'clock direction. Summing the two vectors produces an approximate axis.

1 week to 1 month	+ 110° (+30 to + 180)
1 to 3 months	+ 70° (+10 to +125)
3 months to 3 years	+ 60° (+10 to +110)
Older than 3 years	+ 60° (+20 to +120)
Adults	+ 50° (-30 to +105)

## T Wave Axis

Usually upright in V1 at birth but negative by day 4. Persistence of upright T wave in V1 suggests right ventricular hypertension. Remains negative (posterior and leftward) for the first 4-5 years (highly variable) and then becomes progressively more anterior. T waves in V2-V6 should be upright by adulthood.

## PR Interval according to Heart Rate and Age

### Mean (and ULN)\*

Rate	0-1 mo	1-6 mo	6-12mo	1-3 yr	3-8 yr	8-12 yr	12-16yr	Adult
< 60						0.16 (0.18)	0.16 (0.19)	0.17 (0.21)
60-80					0.15 (0.17)	0.15 (0.17)	0.15 (0.18)	0.16 (0.21)
80-100	0.10 (0.12)				0.14 (0.16)	0.15 (0.16)	0.15 (0.17)	0.15 (0.20)
100-120	0.10 (0.12)			(0.15)	0.13 (0.16)	0.14 (0.15)	0.15 (0.16)	0.15 (0.19)
120-140	0.10 (0.11)	0.11 (0.14)	0.11 (0.14)	0.12 (0.14)	0.13 (0.15)	0.14 (0.15)		0.15 (0.18)
140-160	0.09 (0.11)	0.10 (0.13)	0.11 (0.13)	0.11 (0.14)	0.12 (0.14)			(0.17)
160-180	0.10 (0.11)	0.10 (0.12)	0.10 (0.12)	0.10 (0.12)				
> 180	0.09 (0.11)	0.09 (0.11)	0.10 (0.11)					

From Park MK, Guntheroth WG *How to read pediatric ECGs*, ed 3, St Louis, 1992, Mosby. ULN, Upper limits of normal

## ELECTROCARDIOGRAPH

PR interval is measured (usually in lead II) from the onset of the P wave to the beginning of the QRS complex (i.e. actually the PQ interval).

**Prolonged PR interval** (1<sup>st</sup> degree AV block) indicates delayed conduction through the AV node and may be seen in myocarditis, certain congenital lesions, toxicities, hyperkalaemia, and ischaemia. It may be normal.

**Short PR interval** may be seen in Wolff-Parkinson-White & Lown-Ganong-Levine syndromes and in glycogen storage disease.

**Variable PR** intervals occur in second degree AV blockade (Type I) and with a wandering pacemaker.

### P wave duration and amplitude

Normally the P amplitude is less than 3 mm. Tall waves indicate right atrial hypertrophy or “P-pulmonale”. The maximum duration of P waves is ≤ 0.10 second in children and 0.08 second in infants. Prolonged P waves indicate left atrial hypertrophy or “P-mitrale”.

### QRS duration according to Age

Mean (& ULN\*)

Measured from the onset of the Q wave to the termination of the S wave usually in lead II.

	0-1 mo	1-6 mo	6-12mo	1-3 yr	3-8 yr	8-12 yr	12-16yr	Adult
Seconds	0.05 (0.07)	0.055 (0.075)	0.055 (0.075)	0.055 (0.075)	0.06 (0.075)	0.06 (0.085)	0.07 (0.085)	0.08 (0.10)

\*Upper limit of normal refers to the 98<sup>th</sup> percentile. Derived from Davignon A et al *Pediatr Cardiol* 1979/80;1:133-152

### QT interval

Measured from the onset of the Q wave to the end of the T wave usually in lead II (or other leads with visible Q waves). The QT interval varies primarily with heart rate and may be corrected (QTc) by using Bazett's formula.

$$QTc = \frac{QT \text{ measured}}{\sqrt{RR \text{ interval}}}$$

At heart rates over 120bpm, the formula is increasingly unreliable. The QTc interval should not exceed 0.46 seconds in males and 0.47 seconds in females. Measure and report the QT interval in Lead II and V5 and consider the longest to be representative.

## ELECTROCARDIOGRAPH

### R and S Voltages according to Lead and Age

Mean (and ULN)\*

	Lead	0-1mo	1-6mo	6-12mo	1-3yr	3-8yr	8-12yr	12-16yr	Young adults
<b>R Voltage</b>	I	4 (8)	7 (13)	8 (16)	8 (16)	7 (15)	7 (15)	6 (13)	6 (13)
	II	6 (14)	13 (24)	13 (27)	13 (23)	13 (22)	14 (24)	14 (24)	9 (25)
	III	8 (16)	9 (20)	9 (20)	9 (20)	9 (20)	9 (24)	9 (24)	6 (22)
	aVR	3 (8)	2 (6)	2 (6)	2 (5)	2 (4)	1 (4)	1 (4)	1 (4)
	AVL	2 (7)	4 (8)	5 (10)	5 (10)	3 (10)	3 (10)	3 (12)	3 (9)
	aVF	7 (14)	10 (20)	10 (16)	8 (20)	10 (19)	10 (20)	11 (21)	5 (23)
	V4R	6 (12)	5 (10)	4 (8)	4 (8)	3 (8)	3 (7)	3 (7)	
	V1	13 (24)	10 (19)	10 (20)	9 (18)	8 (16)	5 (12)	4 (10)	3 (14)
	V2	18 (30)	20 (31)	22 (32)	19 (28)	15 (25)	12 (20)	10 (19)	6 (21)
	V5	12 (23)	20 (33)	20 (31)	20 (32)	23 (38)	26 (39)	21 (35)	12 (33)
	V6	5 (15)	13 (22)	13 (23)	13 (23)	15 (26)	17 (26)	14 (22)	10 (21)
<b>S Voltage</b>	I	5 (10)	4 (9)	4 (9)	3 (8)	2 (8)	2 (8)	2 (8)	1 (6)
	V4R	4 (9)	4 (12)	5 (12)	5 (12)	5 (14)	6 (20)	6 (20)	
	V1	7 (18)	5 (15)	7 (18)	8 (21)	11 (23)	12 (25)	11 (22)	10 (23)
	V2	18(35)	15 (26)	16 (29)	18 (30)	20 (33)	21 (36)	18 (33)	14 (36)
	V5	9 (17)	7 (16)	6 (15)	5 (12)	4 (10)	3 (8)	3 (8)	
	V6	3 (10)	3 (9)	2 (7)	2 (7)	2 (5)	1 (4)	1 (4)	1 (13)

From Park MK, Guntheroth WG *How to read pediatric ECGs*, Ed 4, St Louis, 2006, Mosby

\* Voltages are measured in millimetres, when 1 mV = 10 mm paper. ULN = upper limits of normal refers to 98<sup>th</sup> percentile

### R/S Ratio according to Age

Mean, LLN\*, and ULN\*

Lead		0-1mo	1-6mo	6-12mo	1-3yr	3-8yr	8-12yr	12-16yr	Adult
<b>V1</b>	LLN	0.5	0.3	0.3	0.5	0.1	0.15	0.1	0.0
	Mean	1.5	1.5	1.2	0.8	0.65	0.5	0.3	0.3
	ULN	19	S=0	6	4	2	1	1	1
<b>V2</b>	LLN	0.3	0.3	0.3	0.3	0.05	0.1	0.1	0.1
	Mean	1	1.2	1	0.8	0.5	0.5	0.5	0.2
	ULN	3	4	4	1.5	1.5	1.2	1.2	2.5
<b>V6</b>	LLN	0.1	1.5	2	3	2.5	4	2.5	2.5
	Mean	2	4	6	20	20	20	10	9
	ULN	S=0	S=0	S=0	S=0	S=0	S=0	S=0	S=0

From Guntheroth WB *Pediatric Electrocardiography*, Philadelphia, 1965, Saunders

\*LLN, Lower limits of normal; ULN, upper limits of normal

### Q Voltages according to Lead and Age

Mean (and ULN)\*

Lead	0-1mo	1-6mo	6-12mo	1-3yr	3-8yr	8-12yr	12-16yr	Adult
III	1.5 (5.5)	1.5 (6)	2.1 (6)	1.5 (5)	1.0 (3.5)	0.6 (3)	1.0 (3)	0.5 (4)
aVF	1.0 (3.5)	1.0 (3.5)	1.0 (3.5)	1.0 (3)	0.5 (3)	0.5 (2.5)	0.5 (2)	0.5 (2)
V5	0.1 (3.5)	0.1 (3)	0.1 (3)	0.5 (4.5)	1.0 (5.5)	1.0 (3)	0.5 (3)	0.5 (3.5)
V6	0.5 (3)	0.5 (3)	0.5 (3)	0.5 (3)	1.0 (3.5)	0.5 (3)	0.5 (3)	0.5 (3)

From Park MK, Guntheroth WB *How to read Pediatric ECGs*, 4<sup>th</sup> Ed Mosby 2006.

Voltages are measured in millimetres, when 1 mV = 10 mm paper.

\*ULN = upper limits of normal or 98<sup>th</sup> percentile

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## ELECTROCARDIOGRAPH

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### Q wave duration

The average Q wave duration is 0.02 second and does not exceed 0.03 second. Q wave abnormalities include their absence in V6, presence in V1, very deep Q's or deep and wide Q's .

### ST segment

The normal ST segment is iso-electric. However, in the limb leads, elevation or depression of the ST segment up to 1 mm may be normal in infants and children. A shift of up to 2mm is considered normal in the precordial leads.

### T Wave

**Tall, peaked T waves:** hyperkalaemia, LVH (volume overload), CVA, posterior MI

**Flat or low T waves:** newborns (normal), hypothyroidism, hypokalaemia, hypo/hyperglycaemia, pericarditis, myocarditis, ischaemia, digitalis (reversed tick)

### Criteria for Right Ventricular Hypertrophy

Some or all of the following criteria are present. In general, the greater the number of positive, independent criteria, the greater probability of an abnormal degree of RVH.

- RAD for the patient's age
- Increased rightward and anterior QRS voltages (in the presence of a normal QRS duration):  
R in V1, V2 or aVR > ULN for age; S in I and V6 > ULN for age
- Abnormal R/S ratio in favour of the RV (in the absence of bundle branch block):  
R/S ratio in V1 and V2 > ULN for age; or R/S ratio in V6 < 1 after 1 month of age,  
Upright T in V1 older than 3 days provided that the T is upright in V5 and V6. An upright T in V1 is not abnormal in patients 6 years or older.
- A qR pattern in V1 suggests RVH (make sure there is not a small r in an rsR' configuration)
- In the presence of RVH, a wide QRS-T angle with T axis outside the normal range (usually in the 0 to -90 degree quadrant) indicates "strain" pattern

### Right Ventricular Hypertrophy in the Newborn

This is difficult because of the normal RV dominance in neonates. The following clues may be helpful

- S waves in Lead I,  $\geq 12$  mm
- R waves in aVR,  $\geq 8$  mm
- Important abnormalities in V1 such as: pure R waves (without S)  $\geq 10$  mm; R waves  $\geq 25$  mm; qR pattern in V1 (also seen in 10% of normal neonates); upright T waves in V1 in neonates more than 3 days old (with upright T in V6)
- QRS axis > +180 degrees

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## ELECTROCARDIOGRAPH

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### Criteria for Left Ventricular Hypertrophy

- LAD for the patient's age
- QRS voltages in favour of the LV (in the presence of a normal QRS duration): R in I, II, III, aVL, AVF, V5 or V6 > ULN for age; S in V1 or V2 > ULN for age
- Abnormal R/S ratio in favour of the LV; R/S ratio in V1 and V2 < LLN for age
- Q in V5 and V6, 5 mm or more, plus tall symmetric T waves in the same leads ("LV diastolic overload")
- In the presence of LVH, a wide QRS-T angle with the T axis outside the normal range indicates "strain" pattern; this is shown by inverted T waves in I or AVF.

### Criteria for Combined Ventricular Hypertrophy

- Positive voltage criteria for RVH *and* LVH in the absence of bundle branch block or pre-excitation
- Positive voltage criteria for RVH or LVH and relatively large voltages for the other ventricle
- Large equiphasic QRS complexes in two or more of the limb leads and in the mid-precordial leads (i.e. V2 through V5), called Katz-Wachtel phenomenon.

### Right Bundle Branch Block

- RAD, at least for the terminal portion of the QRS complex
- QRS duration > ULN for age
- Terminal slurring of the QRS complex directed to the right and usually, but not always, anteriorly: wide and slurred S in I, V5 and V6; terminal, slurred R' in aVR and the right ventricular leads (V4R, V1, V2)
- ST segment shift and T wave inversion are common in adults, but not in children

It is difficult to make a diagnosis of ventricular hypertrophy in the presence of RBBB.

**Note that the rsR' pattern in V1 is *normal* in infants and young children provided that the QRS duration is not prolonged and the voltage of the primary or secondary R waves is not abnormally large.**

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## ELECTROCARDIOGRAPH

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### Wolff-Parkinson-White Syndrome

1 Short PR interval, (less than the lower limit of normal for age) +.

Younger than 12 months	0.075 sec
1 to 3 years	0.080 sec
3 to 5 years	0.085 sec
5 to 12 years	0.090 sec
12 to 16 years	0.095 sec
Adults	0.120 sec

LLN of PR interval for age derived from Davignon et al Pediatric Cardiol 1979/80;1:133-152

2 Delta wave (initial slurring of the QRS complex) +

3 Wide QRS duration beyond the upper limits of normal

In the presence of WPW syndrome, the diagnosis of ventricular hypertrophy is unreliable.

### References

Park MK, Guntheroth WG, *How to read pediatric ECGs*, Ed 4, 2006 Mosby

Davignon A., Rautaharju P, Boisselle E et al Normal ECG standards for Infants and Children  
Pediatric Cardiology 1;133-152 1979/80