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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

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

Newborn	110 to 150 beats/min
2 years	85 to 125 beats/min
4 years	75 to 115 beats/min
Older than 6 years	60 to 100 beats/min

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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

“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 of 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. 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: With Rate and Age (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 (0.17)
160-180	0.10 (0.11)	0.10 (0.12)	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

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

Prolonged PR interval (1st 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.

QRS Duration: Average (and upper limits) for Age

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)	0.05 (0.07)	0.05 (0.07)	0.06 (0.07)	0.07 (0.08)	0.07 (0.09)	0.07 (0.10)	0.08 (0.10)

Modified from Guntheroth WG *Pediatric electrocardiography*, Philadelphia 1965, Saunders

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 :

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

The QTc interval should not exceed 0.44 second, except in infants. A QTc interval up to 0.49 second may be normal for the first six months of age. Lead II (usually with a visible q wave) is the best lead to measure the QT interval.

P wave duration and amplitude

Normally the P amplitude is less than 3 mm. Tall waves indicate right atrial hypertrophy or "P-pulmonale". The duration of P waves is ≤ 0.09 second in children and ≤ 0.07 second in infants. Prolonged P waves indicate left atrial hypertrophy or "P-mitrale".

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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
R Volts	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 (7)	3 (6)	3 (6)	2 (6)	2 (5)	2 (4)	2 (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	15 (25)	11 (20)	10 (20)	9 (18)	7 (18)	6 (16)	5 (16)	3 (14)
	V2	21 (30)	21 (30)	19 (28)	16 (25)	13 (28)	10 (22)	9 (19)	6 (21)
	V5	12 (30)	17 (30)	18 (30)	19 (36)	21 (36)	22 (36)	18 (33)	12 (33)
S Volts	V6	6 (21)	10 (20)	13 (20)	12 (24)	14 (24)	14 (24)	14 (22)	10 (21)
	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	10 (20)	7 (18)	8 (16)	13 (27)	14 (30)	16 (26)	15 (24)	10 (23)
	V2	20 (35)	16 (30)	17 (30)	21 (34)	23 (38)	23 (38)	23 (48)	14 (36)
	V5	9 (30)	9 (26)	8 (20)	6 (16)	5 (14)	5 (17)	5 (16)	
	V6	4 (12)	2 (7)	2 (6)	2 (6)	1 (5)	1 (4)	1 (5)	1 (13)

From Park MK, Guntheroth WG *How to read pediatric ECGs*, ed 3, St Louis, 1992, Mosby

* Voltages are measured in millimetres, when 1 mV = 10 mm paper. ULN = upper limits of normal

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
V1	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	2	2	1	1	1
V2	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
V6	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	2 (5)	3 (8)	3 (8)	3 (8)	1.5 (6)	1 (5)	1 (4)	0.5 (4)
aVF	2 (4)	2 (5)	2 (6)	1.5 (5)	1 (5)	1 (3)	1 (3)	0.5 (2)
V5	1.5 (5)	1.5 (4)	2 (5)	2 (6)	2 (6)	2 (4.5)	1 (4)	0.5 (3.5)
V6	1.5 (4)	1.5 (4)	2 (5)	2 (4.5)	1.5 (4.5)	1.5 (4)	1 (2.5)	0.5 (3)

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

* Voltages are measured in millimetres, when 1 mV = 10 mm paper. ULN = upper limits of normal

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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, or very deep (see table above) or deep and wide Q waves.

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, peak 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; R/S ratio in V6 < 1 after 3 days of age, provided that the T is upright in V5 and V6. An upright T in V1 is not abnormal in patients 6 years or older.
 - q wave in V1 (qR or qRs patterns) 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
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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, ≥ 12 mm
- R waves in aVR, ≥ 8 mm
- Important abnormalities in V1 such as: pure R waves (without S) ≥ 10 mm; R waves ≥ 25 mm; qR pattern (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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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.

Wolff-Parkinson-White Syndrome

- Short PR interval, less than the lower limit of normal for age. The lower limits of normal are as follows:

Younger than 3 years old	0.08 seconds
3 to 16 years old	0.10 seconds
Older than 16 years old	0.12 seconds

- Delta wave (initial slurring of the QRS complex)
- Wide QRS duration beyond the upper limits of normal

In the presence of WPW syndrome, the diagnosis of ventricular hypertrophy cannot safely be made.

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Lown-Ganong-Levine Syndrome

Short PR interval and normal QRS duration

Mahaim-type pre-excitation syndrome

Normal PR interval and long QRS duration with a "delta wave"

References

1. Park MK, Guntheroth WG, *How to read pediatric ECGs*, ed 3, St Louis, 1992, Mosby
2. Guntheroth WB, *Pediatric Electrocardiography*, Philadelphia, 1965, Saunders