Electrocardiogram

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Pediatric Cardiology
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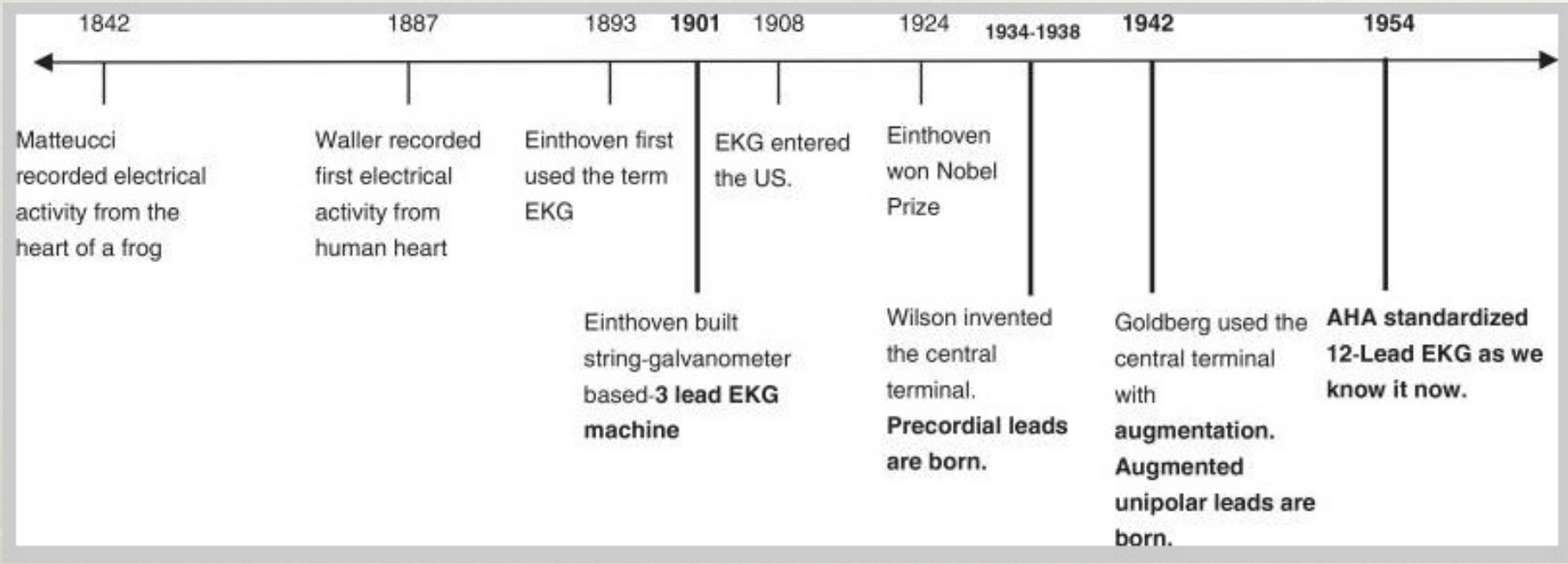
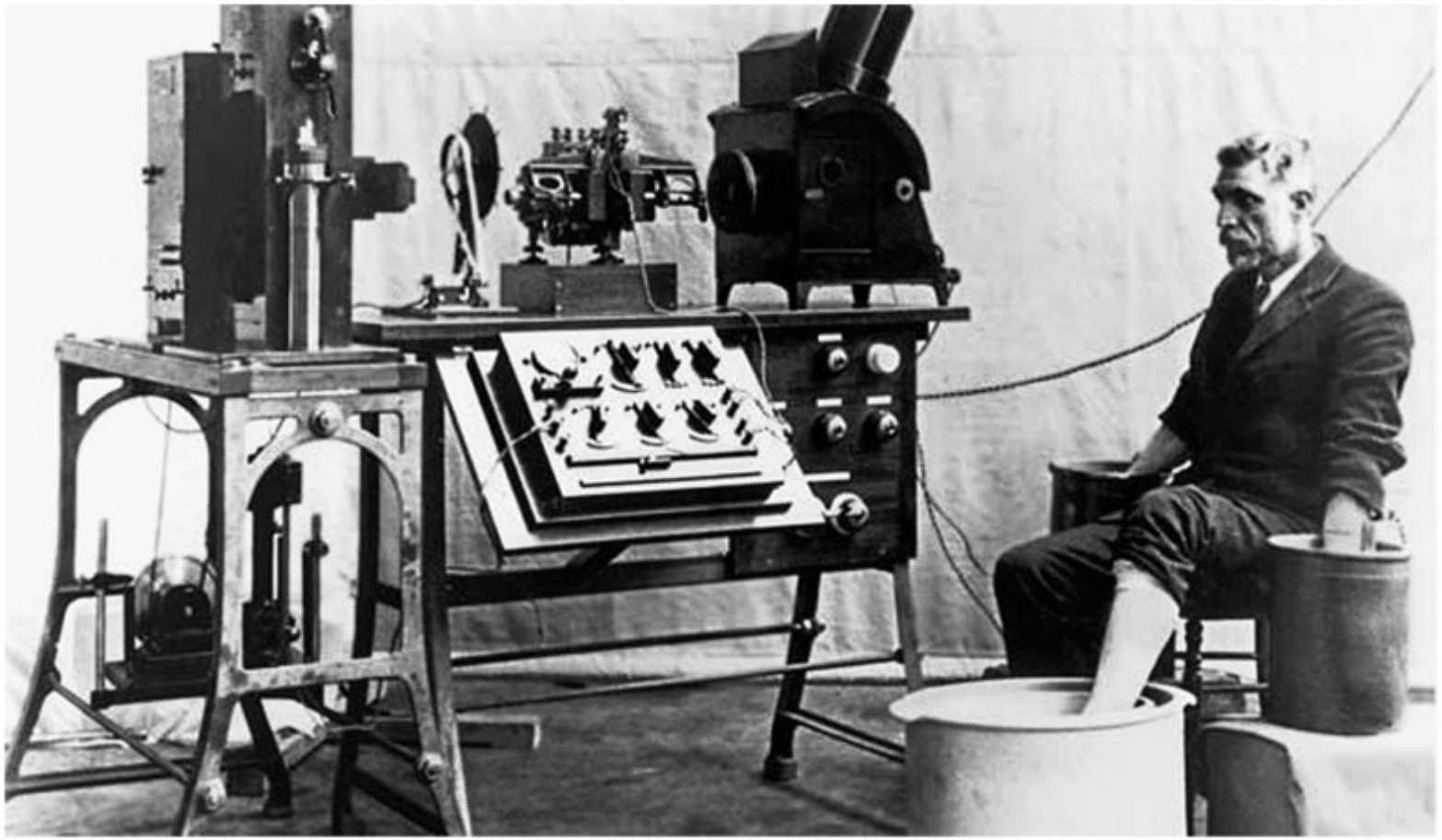
Goals

* History
* Indications
* Pediatric specifics
* Variations
* What to do with an abnormal ECG
* Examples
* Conclusion

History

* Introduced in 1902
* Einthoven – Dutch physiologist
* First ECG machine weighed 600 lbs

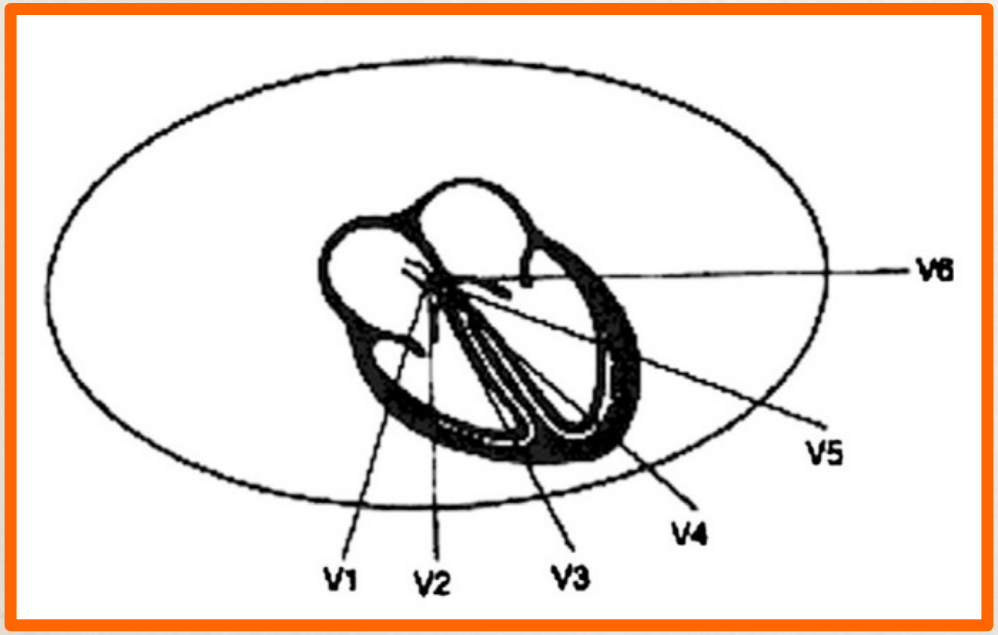




Old string galvanometer electrocardiograph showing the big machine with the patient rinsing his extremities in the cylindrical electrodes filled with electrolyte solution.

History

* First used for arrhythmias – atrial fibrillation
* Myocardial infarction first described in 1910
* ECG used regularly for MI by 1930
* 1938 – precordial leads developed



Pediatric ECG indications

All ages

- Family history
- Drug ingestion
- Evaluate for myocarditis or pericarditis
- Trauma

Infant

- Screen for congenital heart disease
- Evaluate irregular heart rhythm
- Cyanotic episodes

Child

- Symptoms such as syncope, chest pain, palpitations
- Family history

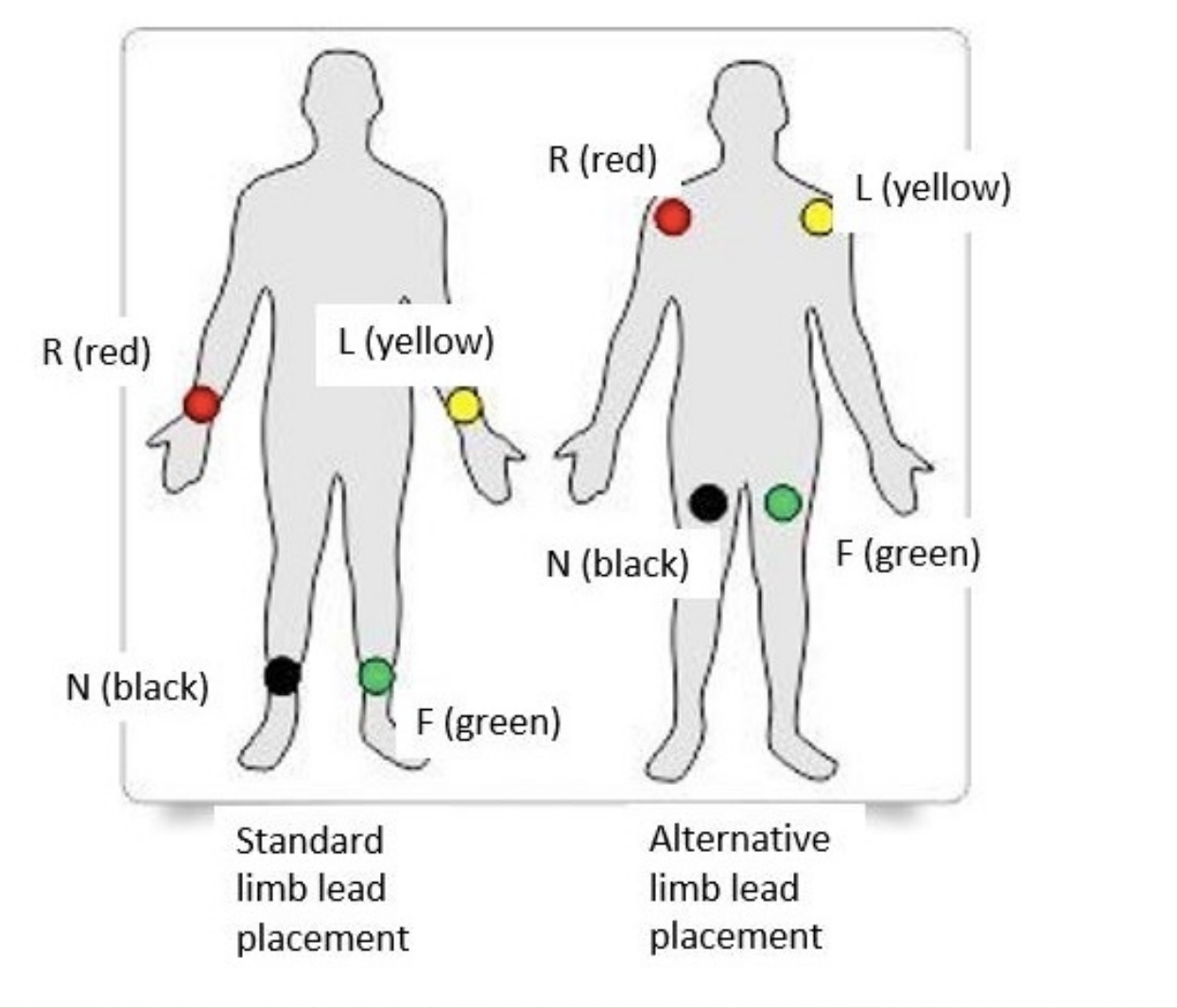
Adolescent

- Symptoms such as syncope, chest pain, palpitations
- Screen for risk of sudden cardiac death

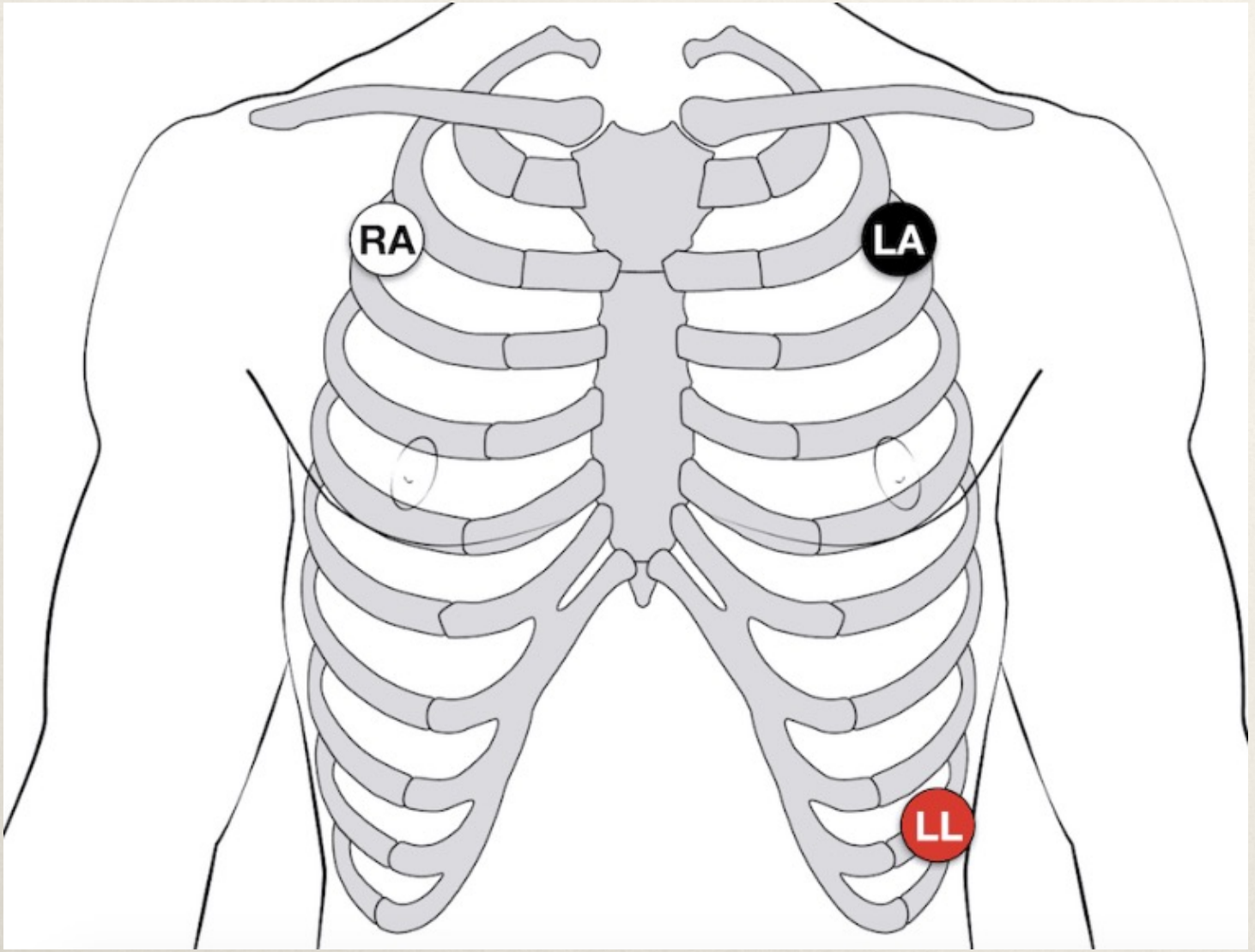
How to place leads

* Limb leads – place on top part of arm or leg
* Precordial leads – consider cutting or having smaller leads for small children
* For hesitant or young children - fun stickers on top of ECG stickers
* Have parent close
* Put stickers on stuffed animal

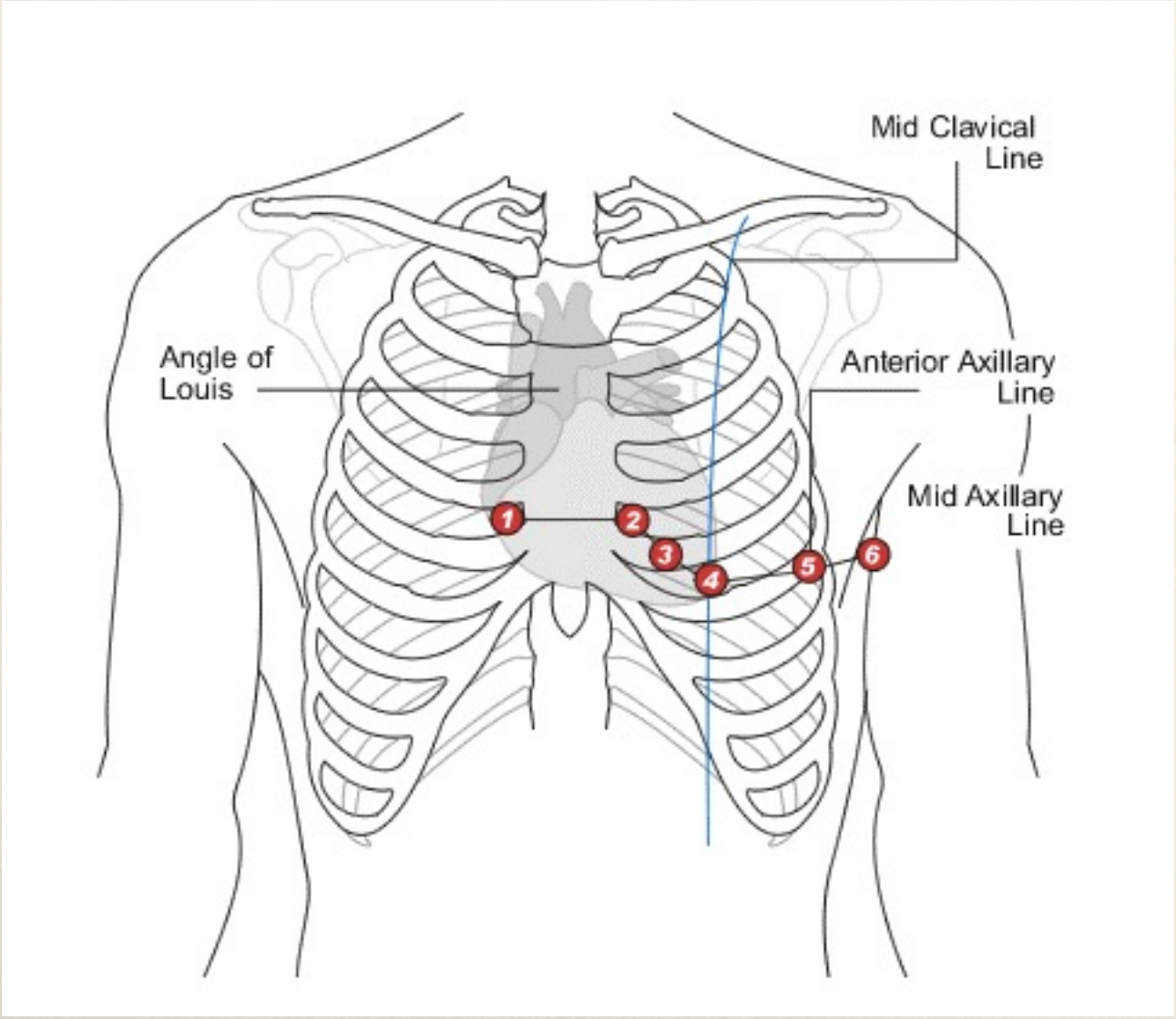
Proximal legs and arms



Rhythm Strip



Precordial leads

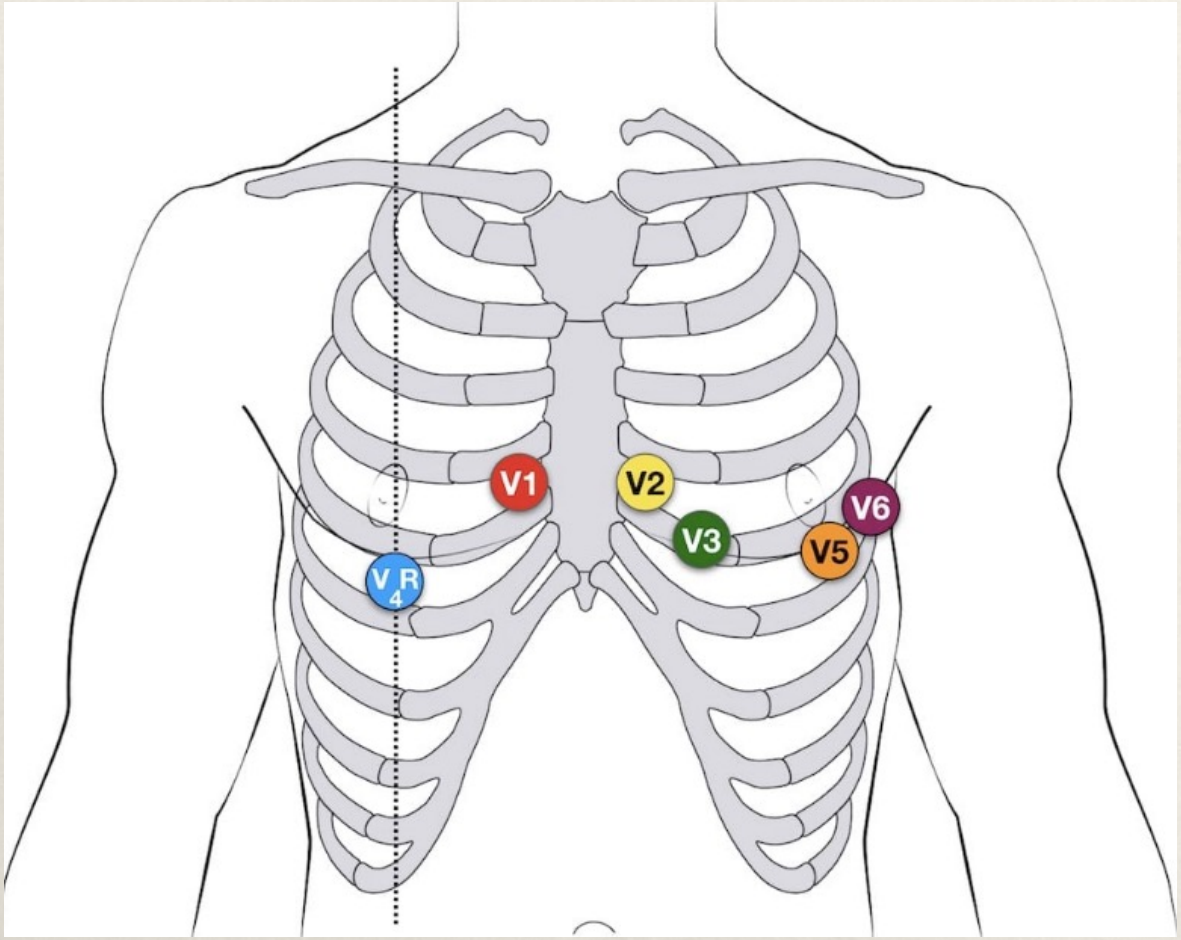


All electrodes

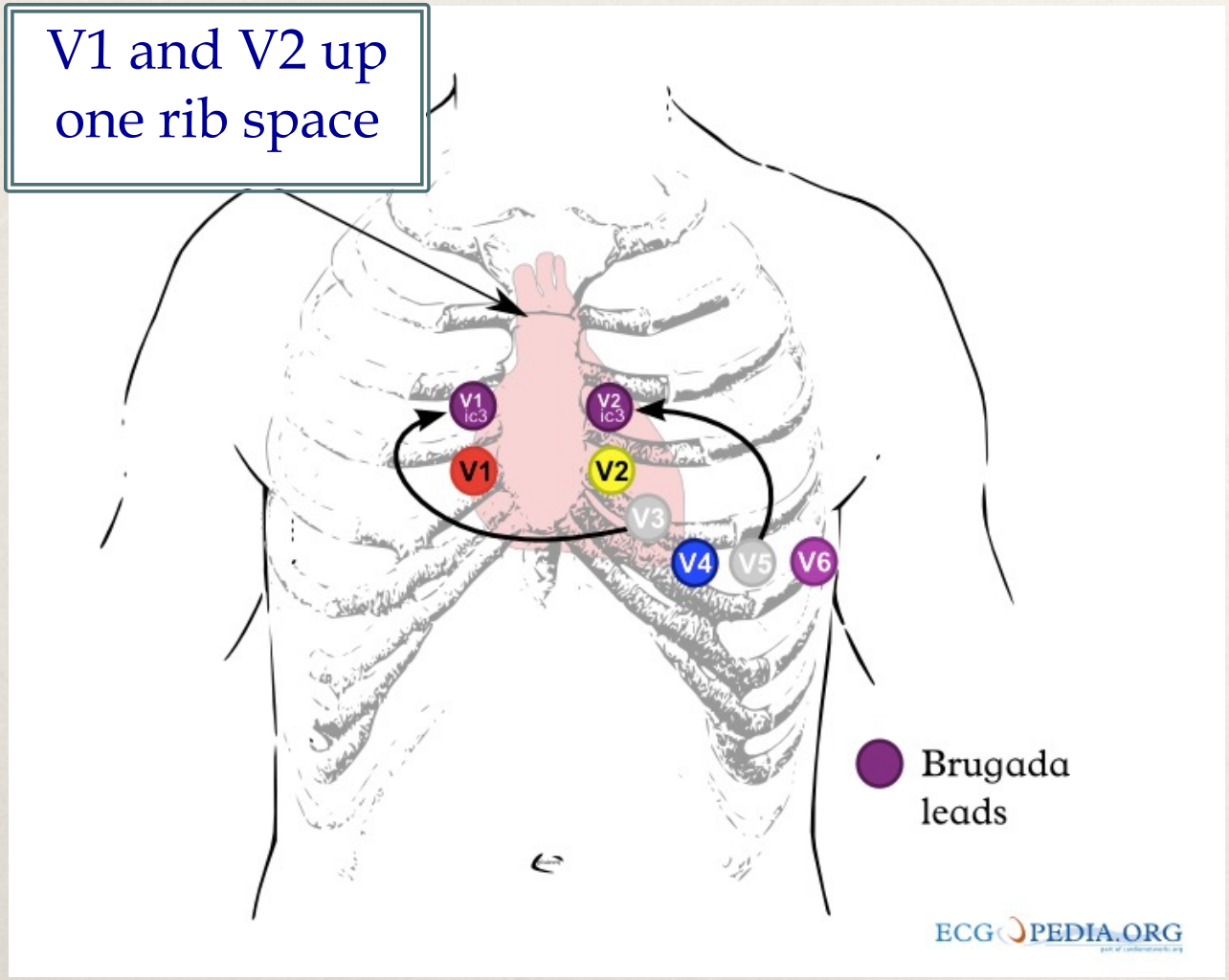
ELECTRODE	PLACEMENT
V1	4th Intercostal space to the right of the sternum
V2	4th Intercostal space to the left of the sternum
V3	Midway between V2 and V4
V4	5th Intercostal space at the midclavicular line
V5	Anterior axillary line at the same level as V4
V6	Midaxillary line at the same level as V4 and V5
N (black)	Above right ankle. (or upper leg, close to torso)
R (red)	Right forearm or right deltoid area
L (yellow)	Left forearm or right deltoid area
F (green)	Above left ankle. (or upper leg, close to torso)

Alternative right sided lead

* V4R – 5th intercostal space, right mid-clavicular line



Alternative for Brugada evaluation

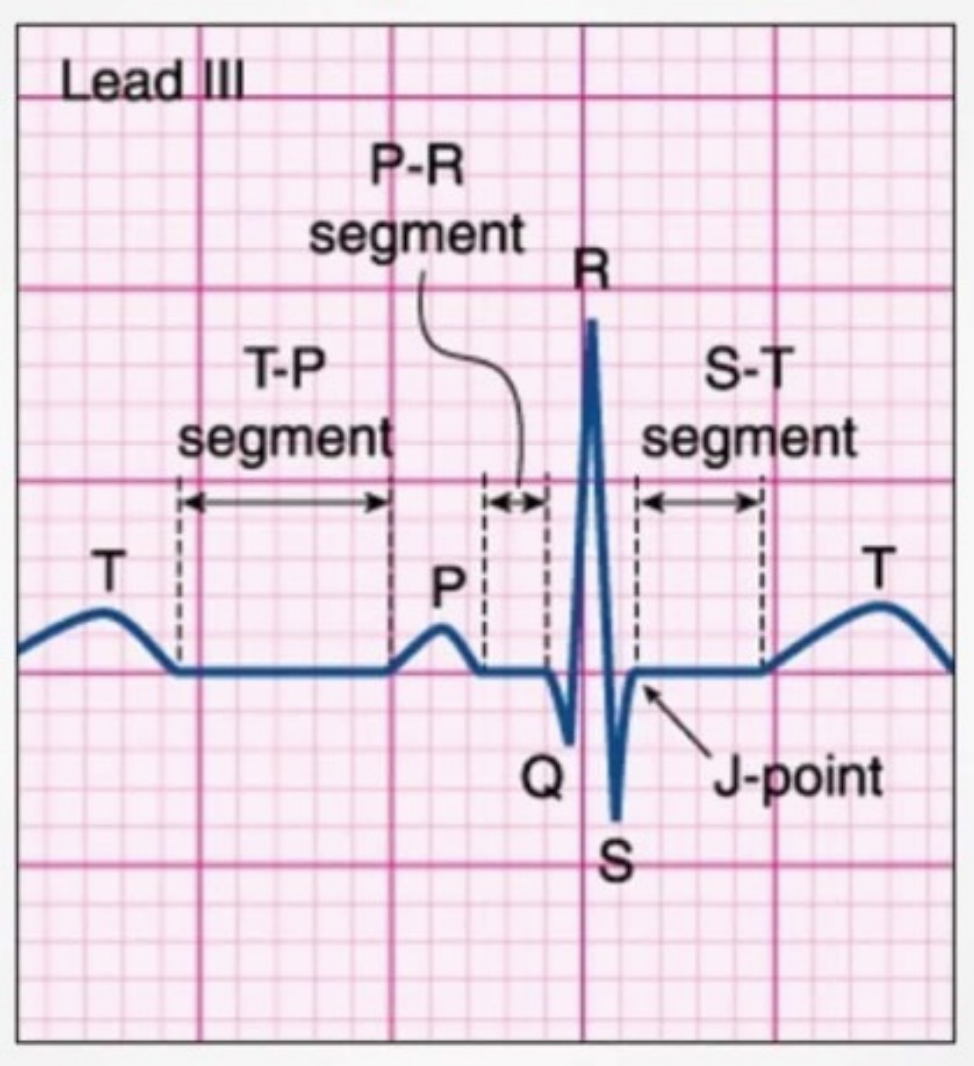


Other variations

* V3R versus V4R
* Only limb leads placed for an active child
* Step test with rhythm strip for PVCs or ectopic rhythm

Evaluation of Pediatric ECG

* Rate
* Rhythm
* Axis
* Intervals
* Voltage
* ST segments
* T waves

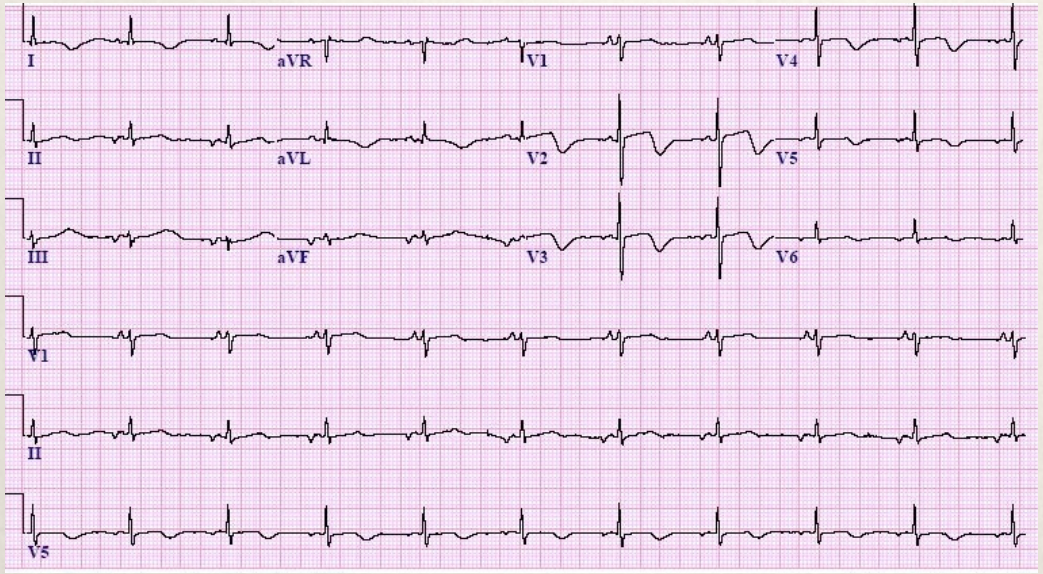


Heart rate

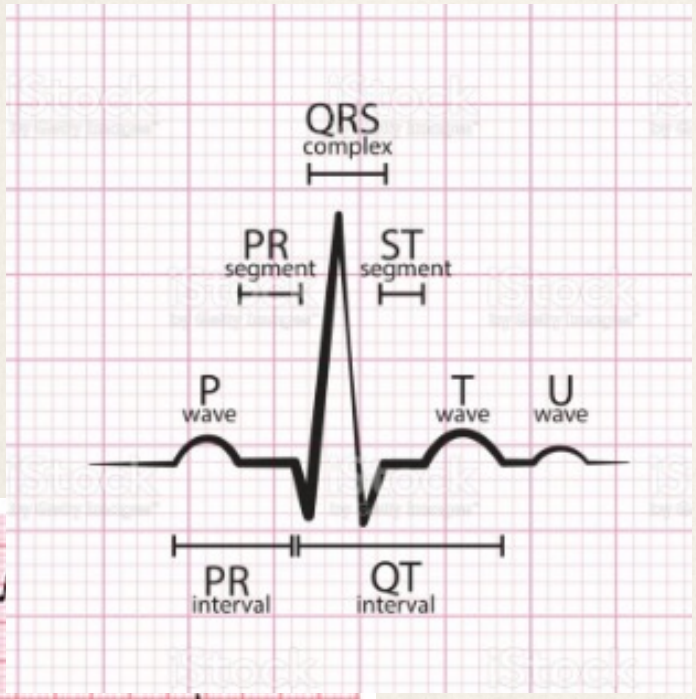
* Newborn: 110 – 150 bpm
* 2 years: 85 – 125 bpm
* 4 years: 75 – 115 bpm
* 6 years: 60 – 100 bpm
* Adolescents : 40 - 100bpm
* Adults: 60 - 100bpm

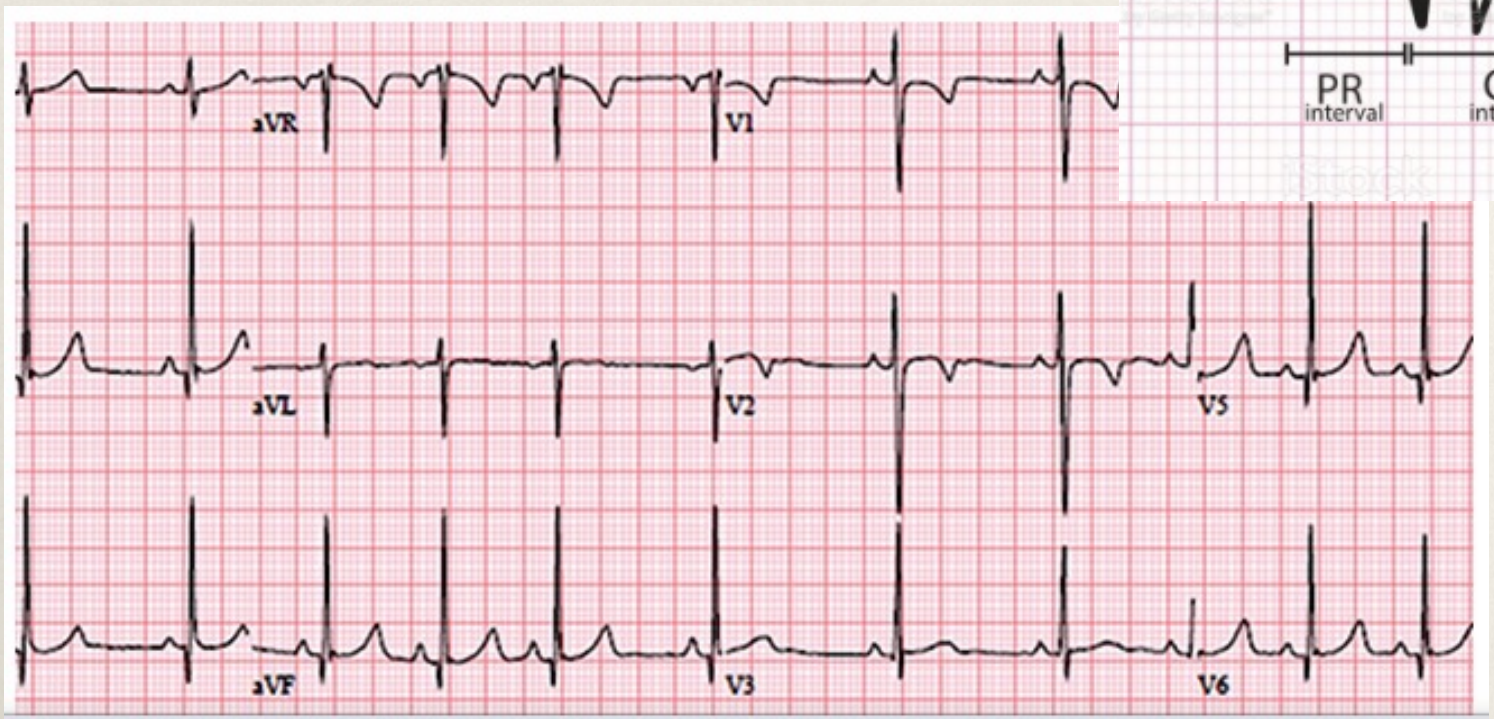
Rhythm

- Sinus rhythm
  - P wave before every QRS complex
  - QRS complex after every P wave
  - P wave positive in lead II and negative in lead aVR
- Ectopic rhythm can be normal for children
- Comment on PACs and PVCs
- Step test may be indicated if patient has ectopic rhythm and symptoms



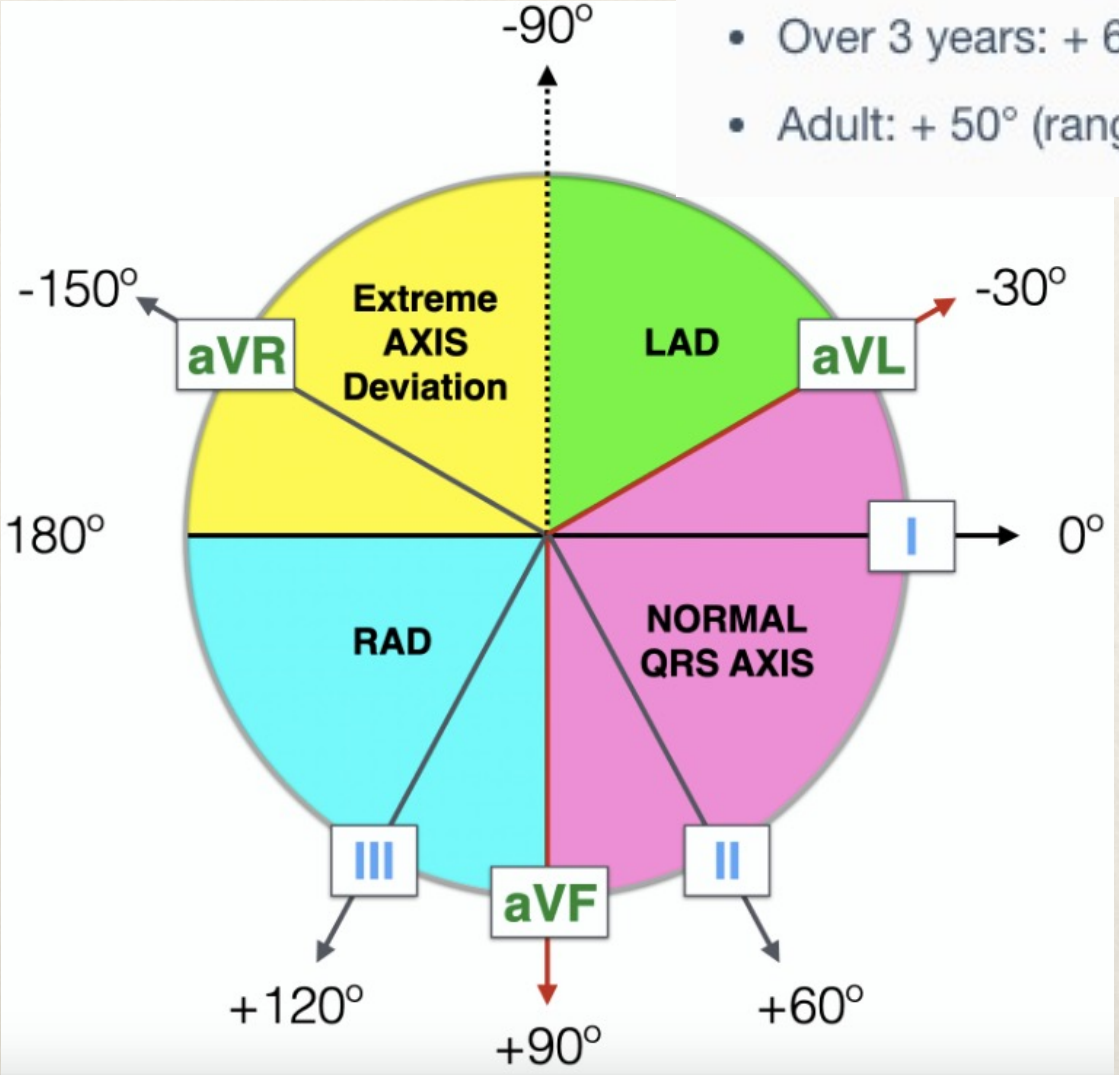
ECG rhythm


QRS
complex
PR
segment
ST
segment
P
wave
T
wave
U
wave
PR
interval
QT
interval

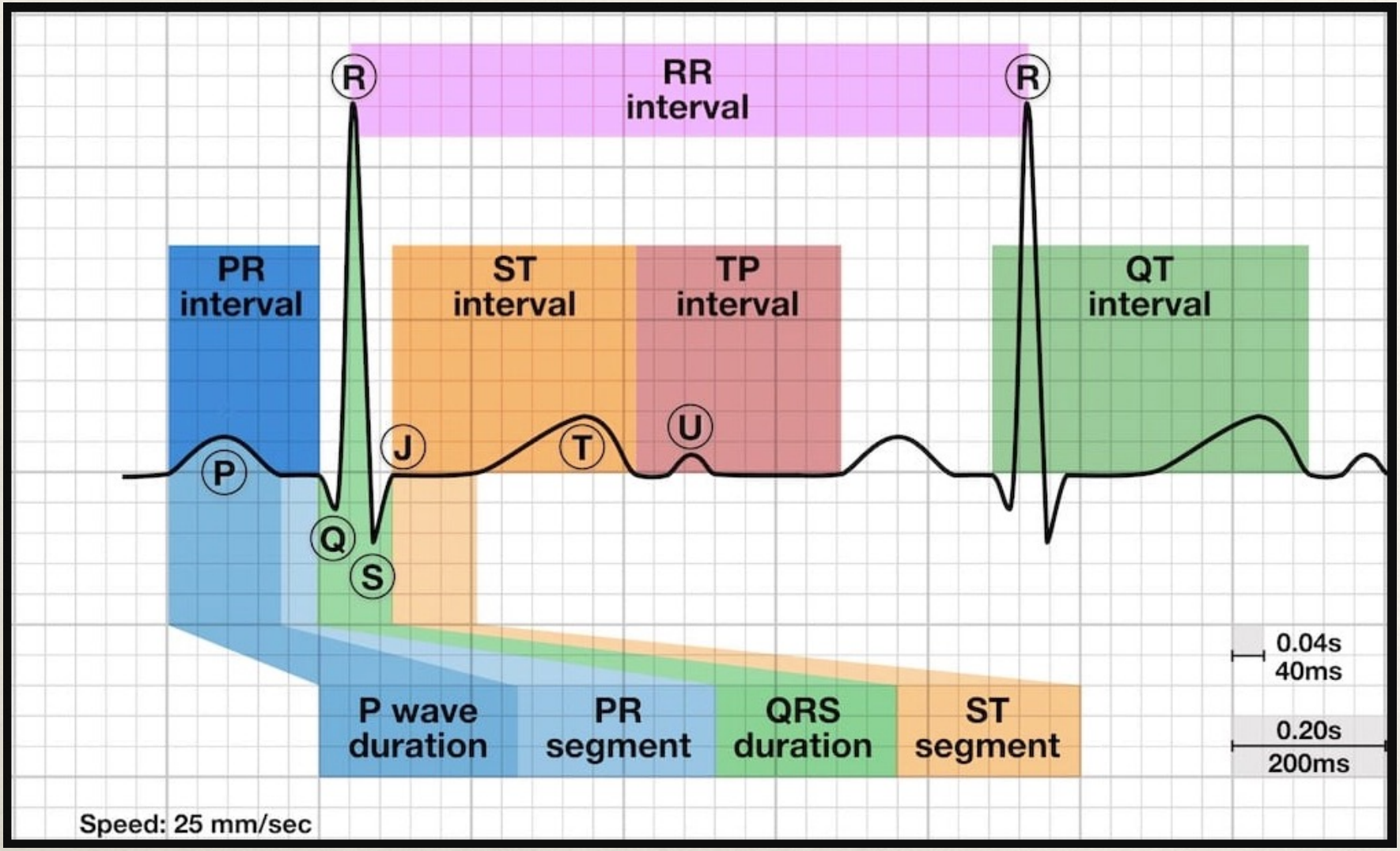

aVR
V1
aVL
V2
V5
aVF
V3
V6

Axis

- 1 week – 1 month: + 110° (range +30° to +180°)
- 1 month – 3 months: + 70° (range +10° to +125°)
- 3 months – 3 years: + 60° (range +10° to +110°)
- Over 3 years: + 60° (range +20° to +120°)
- Adult: + 50° (range -30° to 105°)



Intervals


R
RR interval
R
PR interval
ST interval
TP interval
QT interval
P
J
T
U
Q
S
P wave duration
PR segment
QRS duration
ST segment
0.04s
40ms
0.20s
200ms
Speed: 25 mm/sec

Voltage

Voltage	Lead	0-1mo	1-6mo	6-12mo	1-3yr	3-8yr	8-12yr	12-16yr	Young
R	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 (20)	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)
	V6	6 (21)	10 (20)	13 (20)	12 (24)	14 (24)	14 (24)	14 (22)	10 (21)
S	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)

Q waves

2.7 Q waves

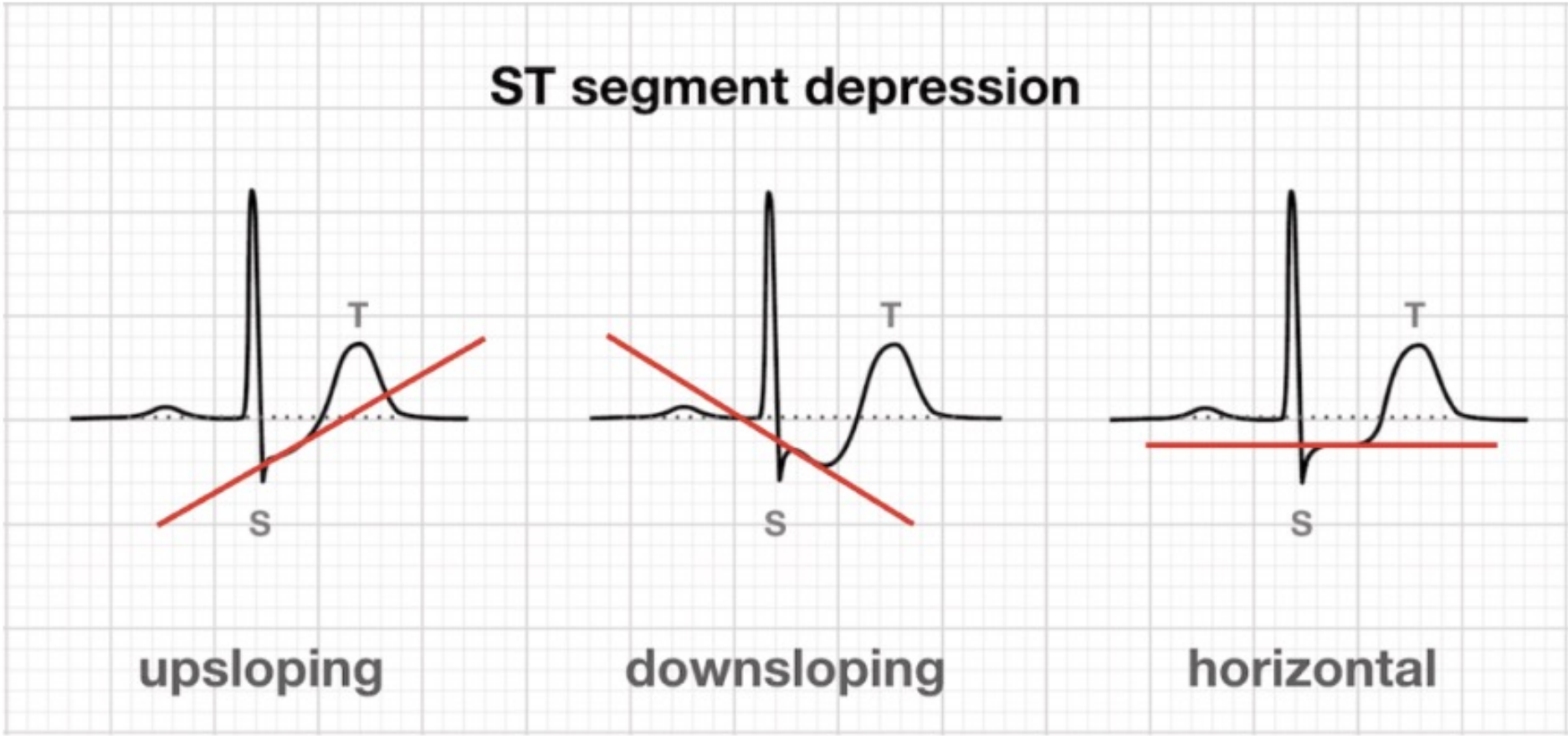
Normal Q waves:

- Narrow (average 0.02 seconds and less than 0.03 seconds)
- Usually less than 5mm deep in left precordial leads and aVF
- May be as deep as 8mm in lead III in children younger than 3 years

Q waves are abnormal if they are:

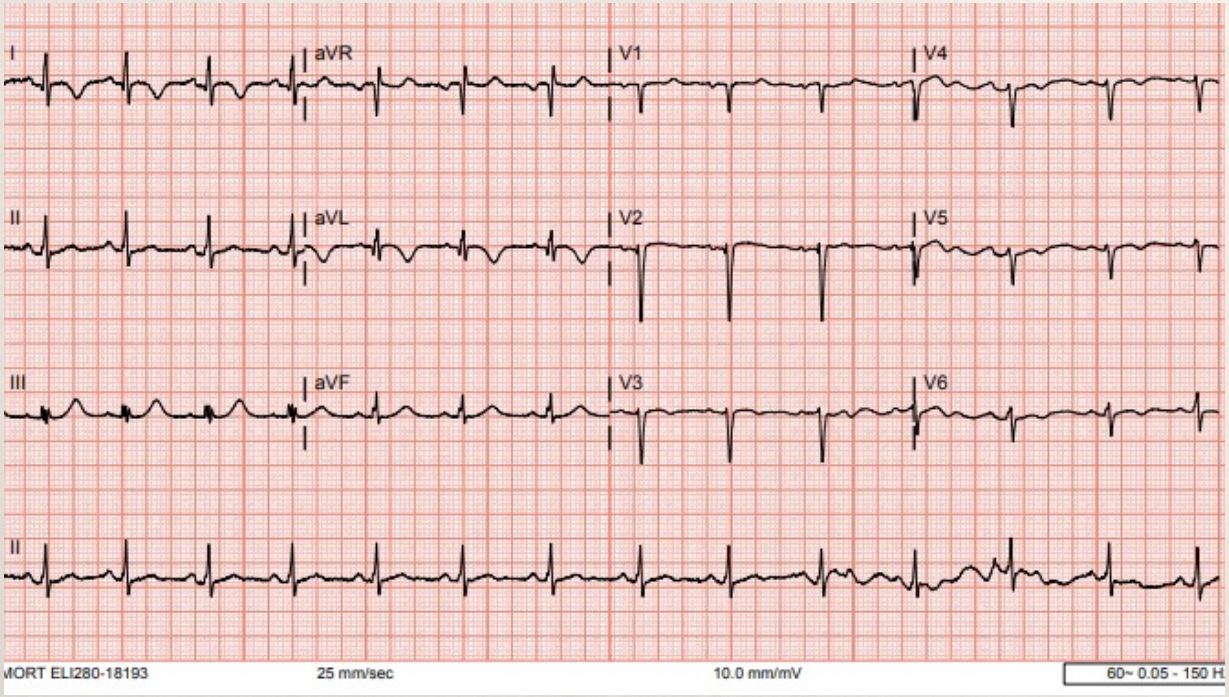
- Present in the right precordial leads ie V1 (eg severe RVH)
- Absent in the left precordial leads (e.g. LBBB)
- Abnormally deep (ventricular hypertrophy) – *look for "dagger" Q waves in leads I, aVL and V5-6, often seen in hypertrophic cardiomyopathy*
- Abnormally deep and wide (myocardial infarction or fibrosis)

ST segments

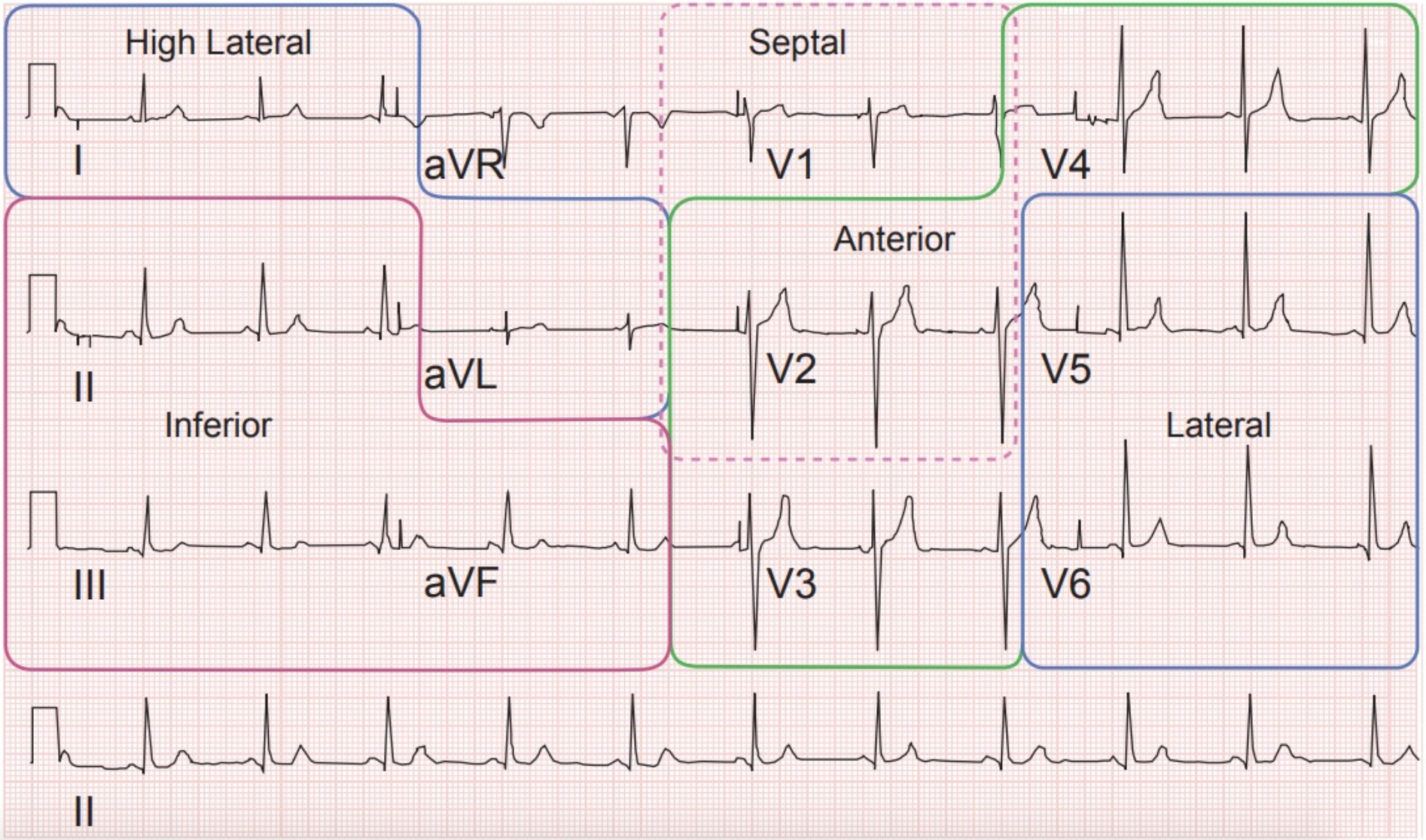

ST segment depression
T
S
T
S
T
S
upsloping
downsloping
horizontal

T waves

* Normal T waves usually have a similar axis to the QRS
* Flat T waves are seen in normal newborns
* Aside from the newborn period, flat and inverted T waves should prompt further evaluation



ECG regions


High Lateral
I
aVR
Septal
V1
V4
II
aVL
Anterior
V2
V5
Inferior
III
aVF
V3
Lateral
V6
II

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CURRENT OPINION

International Recommendations for Electrocardiographic Interpretation in Athletes

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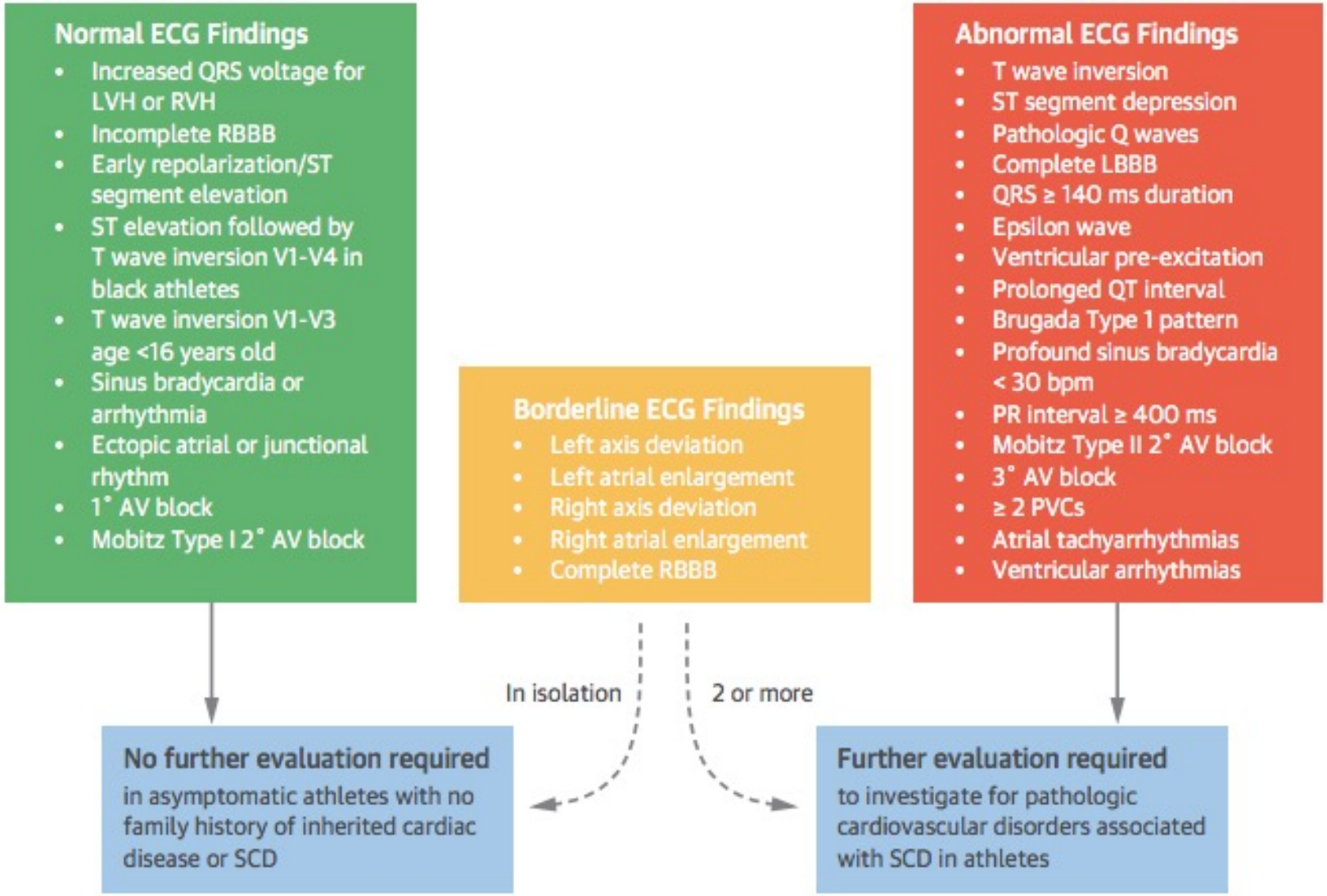
FIGURE 1 International Consensus Standards for Electrocardiographic Interpretation in Athletes



AV = atrioventriular block; LBBB = left bundle branch block; LVH = left ventricular hypertrophy; RBBB = right bundle branch block; RVH = right ventricular hypertrophy; PVC = premature ventricular contraction; SCD = sudden cardiac death.

TABLE 1 Continued

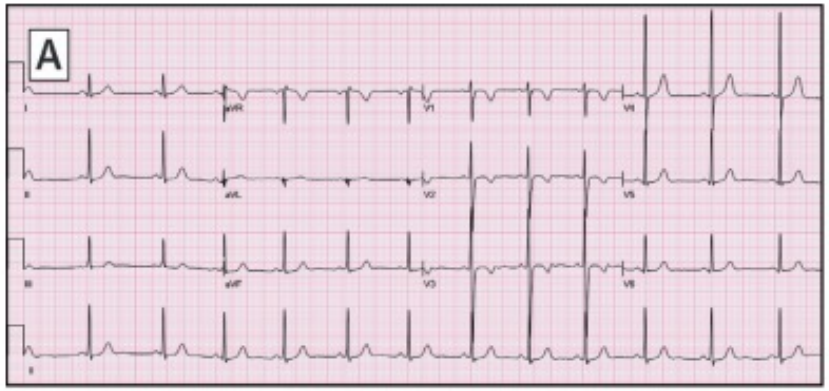
Normal ECG findings in athletes

These training-related ECG alterations are physiologic adaptations to regular exercise, considered normal variants in athletes, and do not require further evaluation in asymptomatic athletes with no significant family history.

Normal ECG finding	Definition
Increased QRS voltage	Isolated QRS voltage criteria for left (SV1 + RV5 or RV6 >3.5 mV) or right ventricular hypertrophy (RV1 + SV5 or SV6 >1.1 mV)
Incomplete RBBB	rSR′ pattern in lead V_1 and a qRS pattern in lead V_6 with QRS duration <120 ms
Early repolarization	J-point elevation, ST-segment elevation, J waves, or terminal QRS slurring in the inferior and/or lateral leads
Black athlete repolarization variant	J-point elevation and convex ('domed') ST-segment elevation followed by T-wave inversion in leads V_1-V_4 in black athletes
Juvenile T-wave pattern	T-wave inversion V_1-V_3 in athletes age <16 yrs
Sinus bradycardia	≥30 beats/min
Sinus arrhythmia	Heart rate variation with respiration: rate increases during inspiration and decreases during expiration
Ectopic atrial rhythm	P waves are a different morphology compared with the sinus P-wave, such as negative P waves in the inferior leads ('low atrial rhythm')
Junctional escape rhythm	QRS rate is faster than the resting P-wave or sinus rate and typically <100 beats/min with narrow QRS complex unless the baseline QRS is conducted with aberrancy
1° AV block	PR interval 200–400 ms
Mobitz Type I (Wenckebach) 2° AV block	PR interval progressively lengthens until there is a non-conducted P-wave with no QRS complex; the first PR interval after the dropped beat is shorter than the last conducted PR interval

*The QT interval corrected for heart rate is ideally measured using Bazett's formula with heart rates between 60 and 90 beats/min; preferably performed manually in lead II or V_5 using the teach-the-tangent method[1] to avoid inclusion of a U-wave (please see text for more details). Consider repeating the ECG after mild aerobic activity for a heart rate <50 beats/min, or repeating the ECG after a longer resting period for a heart rate >100 beats/min, if the QTc value is borderline or abnormal.

AV = atrioventricular block; ECG = electrocardiogram; PVC = premature ventricular contraction; RBBB = right bundle branch block.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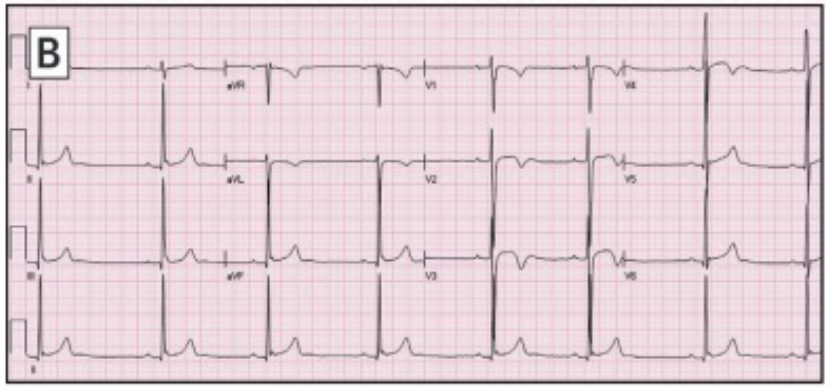
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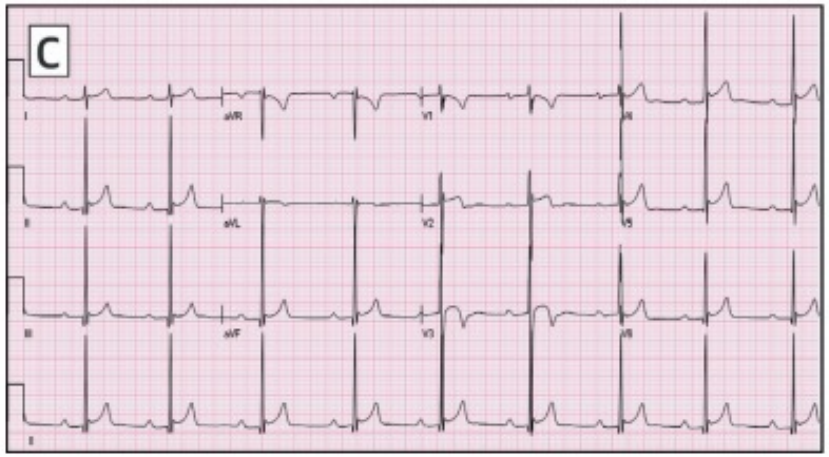
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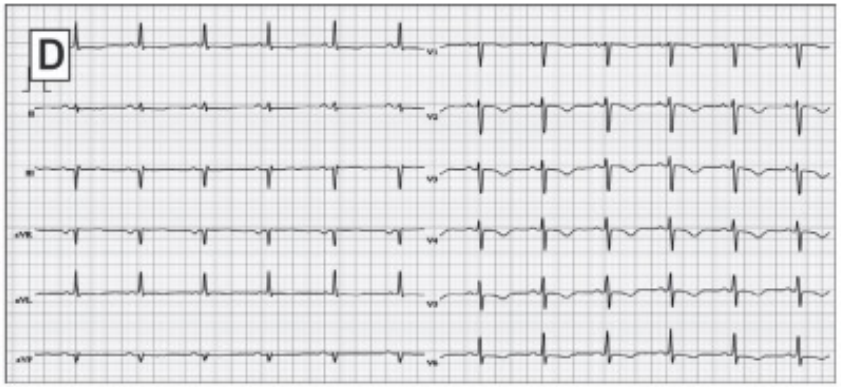
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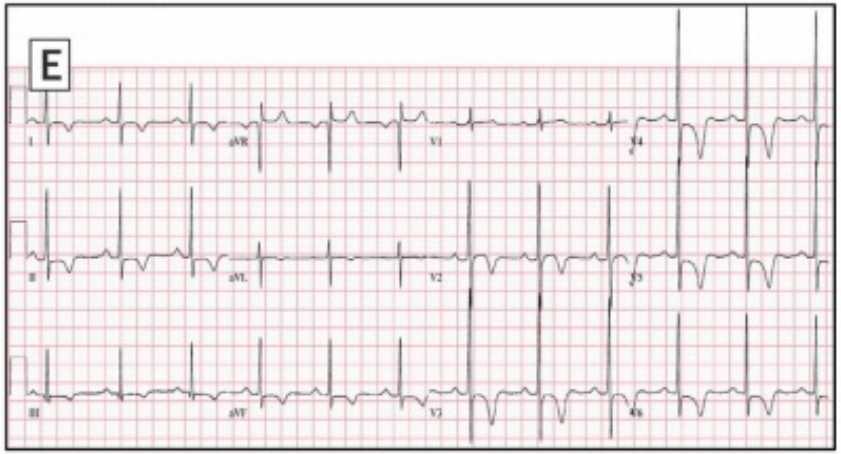

E


F

Other indications

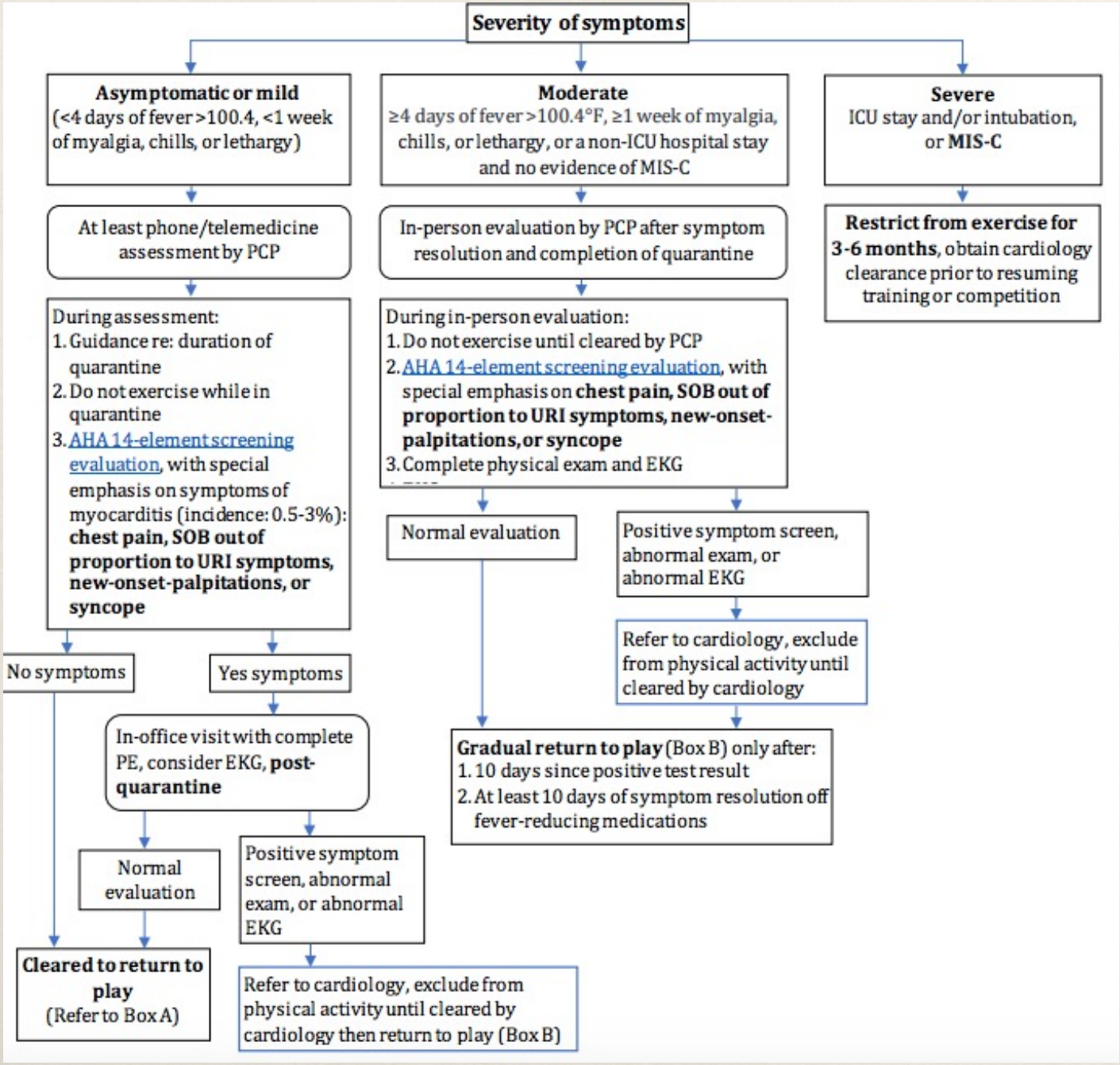
Ingestion	Mechanism of Action	Symptom Onset	Potential Findings	Treatment*
Calcium Channel Blockers	Direct myocardial and vascular calcium channel antagonism	Typical: 2-4 hrs Delayed: 24 hrs	Cardiac depression; Poor perfusion; Hyperglycemia	**Glucagon:** 50 ug/kg IV initial bolus, double and triple subsequent bolus if no effect; Start infusion at response dose per hour
Beta Blockers	Indirect myocardial and vascular calcium channel antagonism Sodium and potassium channel blockade		Cardiac depression + QRS prolongation, QTc prolongation; Poor perfusion; Hypoglycemia	**Glucose-insulin:** 0.5 U/kg regular insulin IV bolus, followed by 0.1–1.0 U/kg/h, titrate to hemodynamic effect; D10 W infusion, titrate to euglycemia **Monitor potassium**
Clonidine & Imidazolines	Decreased release of norepinephrine via alpha-2 and imidazoline receptor agonism	Typical: 30-90 mins Delayed: 4 hrs	Reduced Sympathetic Tone: Bradycardia;; Hypotension; AMS; Miosis; Decreased respiratory drive	**Naloxone** *(Effective only for clonidine)* **Age <5y:** 0.01–0.1 mg/kg IV/IO/IL/ET q3–5 min; Max 2 mg/dose **Age >5y:** 0.4–2.0 mg IV/IO/IL/ET q3–5 min Max dose: 10 mg
Sulfonylureas	Pancreatic beta cell stimulation	Typical: 30 mins to 8 hrs Delayed: 11-45 hrs	Symptomatic hypoglycemia	**Dextrose Boluses + Glucose Checks q30min** **Octreotide**
Tricyclic Antidepressants	Reuptake inhibition of CNS norepinephrine, dopamine, and serotonin Alpha and muscarinic acetylcholine receptor blockade Sodium channel antagonism	Typical: 2-4 hrs Delayed: 24 hrs	QRS prolongation; prominent R-wave in aVR Hypotension; CNS depression	**Sodium Bicarbonate:** Bolus of 1 meq/kg followed by an infusion
Cinchona Alkaloids	Inhibit fast inward sodium channels, mainly myocardial but penetrates nearly all tissues	Typical: 1-2 hrs Delayed: 3 hrs	Prolonged QT, paroxysmal ventricular tachycardia; hypotension; seizures, retinal damage; tinnitus	**Hypertonic Sodium Bicarbonate** **Monitor potassium**
Camphor	Unknown mechanism neurotoxicity Direct mucosal irritation	Typical: 1-2 hrs Delayed: 4 hrs	Seizures; CNS hyperactivity then depression; Elevated LFTs; Mucosal Irritation	**None** *(Supportive only)*
Carbamates & Organophosphates	Acetylcholinesterase inhibition	Typical: 5-60 minutes Delayed: 24 hrs	Most commonly CNS depression Muscarinic & Nicotinic Overstimulation	**Atropine** 0.02 mg/kg every 5 minutes until respiratory secretions dry and bronchoconstriction ceases; Min dose: 0.01 mg **Pralidoxime** Loading dose of 25-50 mg/kg, followed by IV infusion

*Treatments are in addition to supportive measures or standard treatments such as benzodiazepines for seizures, magnesium sulfate for torsades de pointes, respiratory support, fluids/vasopressors for hypotension, etc.

* Ingestions
* ADHD or other Psychiatric medication changes
* Monitoring medications that can prolong QTc interval

Return to sports after COVID-19
overall myocarditis rate 0.5-3%

* Asymptomatic or mild (less than 4 days of fever > 100.4, < 1 week of myalgia, chills and lethargy) – visit with primary care provider by telemedicine or in person
* Moderate symptoms (>4 days of fever >100.4 degrees, > 1 week of myalgias, chills or lethargy, non-ICU hospital stay and no evidence of MIS-C – visit with primary care provider in person
  * Complete physical and ECG
* Severe COVID-19 or MIS-C – restricted for 3-6 months, full cardiology evaluation


Severity of symptoms
Asymptomatic or mild
(<4 days of fever >100.4, <1 week of myalgia, chills, or lethargy)
Moderate
≥4 days of fever >100.4°F, ≥1 week of myalgia, chills, or lethargy, or a non-ICU hospital stay and no evidence of MIS-C
Severe
ICU stay and/or intubation, or MIS-C
At least phone/telemedicine assessment by PCP
In-person evaluation by PCP after symptom resolution and completion of quarantine
Restrict from exercise for 3-6 months, obtain cardiology clearance prior to resuming training or competition
During assessment:
1. Guidance re: duration of quarantine
2. Do not exercise while in quarantine
3. AHA 14-element screening evaluation, with special emphasis on symptoms of myocarditis (incidence: 0.5-3%): chest pain, SOB out of proportion to URI symptoms, new-onset-palpitations, or syncope
During in-person evaluation:
1. Do not exercise until cleared by PCP
2. AHA 14-element screening evaluation, with special emphasis on chest pain, SOB out of proportion to URI symptoms, new-onset-palpitations, or syncope
3. Complete physical exam and EKG
Normal evaluation
Positive symptom screen, abnormal exam, or abnormal EKG
Refer to cardiology, exclude from physical activity until cleared by cardiology
Gradual return to play (Box B) only after:
1. 10 days since positive test result
2. At least 10 days of symptom resolution off fever-reducing medications
No symptoms
Yes symptoms
In-office visit with complete PE, consider EKG, post-quarantine
Normal evaluation
Positive symptom screen, abnormal exam, or abnormal EKG
Cleared to return to play (Refer to Box A)
Refer to cardiology, exclude from physical activity until cleared by cardiology then return to play (Box B)

BOX A: Additional Guidance on Returning to Play

When should children and adolescents return to play?

1) Completed quarantine and minimum amount of symptom free time has passed
2) Can perform all activities of daily living
3) No concerning signs/symptoms

At what pace should children and adolescents return to play?

4) <12yo: progress according to own tolerance
5) 12+: gradual return to physical activity (Box B); should be done over a 7-day minimum and may extend duration for children with moderate symptoms

When should children and adolescents pause return to play?

- If patient develops any chest pain, SOB out of proportion to URI infection, new-onset palpitations, or syncope when returning to exercise, immediately stop and go to PCP for in-person exam

BOX B: Gradual Return to Play

(Adapted from Elliott N, et al, infographic, British Journal of Sports Medicine, 2020; copied from AAP Policy statement)

Stage 1: Day 1 and Day 2 – (2 Days Minimum) – 15 minutes or less: Light activity (walking, jogging, stationary bike), intensity no greater than 70% of maximum heart rate. NO resistance training.

Stage 2: Day 3 – (1 Day Minimum) – 30 minutes or less: Add simple movement activities (eg. running drills) – intensity no greater than 80% of maximum heart rate.

Stage 3: Day 4 – (1 Day Minimum) – 45 minutes or less: Progress to more complex training – intensity no greater than 80% maximum heart rate. May add light resistance training.

Stage 4: Day 5 and Day 6 – 2 Days Minimum) – 60 minutes: Normal training activity – intensity no greater than 80% maximum heart rate.

Stage 5: Day 7 – Return to full activity/participation (ie, contests/competitions).

Conclusion

* Pediatric ECG setup is similar to all patients
* Interpretation is in a stepwise manner
* Normal values and findings vary by age
* For adolescents and young athletes, the international criteria are the best available method of interpretation
* Call with questions