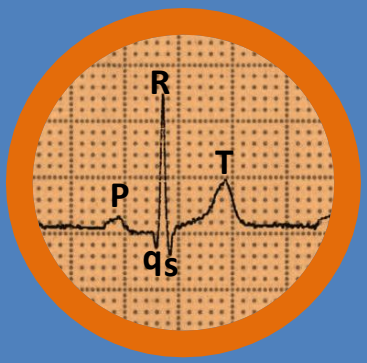

ECG Review : Electrolyte disturbances on ECG

(For Academic Purpose only)

Dr. DURGA PRASAD KHAITAN

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When ECG shows electrolyte disturbances it speaks aloud though its utterances …..

ECG Review : Electrolyte disturbances on ECG

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When ECG shows electrolyte disturbances
It speaks aloud through its utterances …..

Knowledge and skill in the field of electrocardiography have been constantly changing with the new researches and understanding.

With humble words I wish to say that everything of 'Electrolyte disturbances on ECG ' is not covered within this book. Here I am putting some of my written articles related to the topic. It is only a step toward the vast ocean of knowledge. I may be excused for any error or omission.

With thanks and regards


DEDICATED
TO ALL THE
FELLOW COLLEAGUES

Index

HYPERKALEMIA'S FOOTPRINT ON ECG : A VISUAL GUIDE TO THE CLINICIANS

ECG

HYPERKALEMIA'S FOOTPRINT ON ECG : A VISUAL GUIDE FOR CLINICIANS

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OUTLINE

Hyperkalemia's Footprint on ECG : A Visual Guide for Clinicians

A Narrative Review

© **DR. D.P. KHAITAN**
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It is wisdom to envision the footprint of time and to plan the further steps accordingly. One may thus protect oneself from the catastrophic events of adversity , which seem to approach through the rustling wind of threat.

Cracking the code of hyperkalemia on the ECG allows its signs of impending adversity to be recognized earlier. Though it is an alarming puzzle , understanding its electrocardiographic dynamics may pave the way to save the patient's life. ECG changes in hyperkalemia are markers of urgency and severity.

- ☐ **Hyperkalemia slows the race of life , resembling a tortoise's journey—not one of triumph, but of a terminal end.**
- ☐ **It drives a double-edged progression—on one side, the slowing of the conduction pathways; on the other, the decay of myocardial responsiveness. These paths runs in parallel until they collapse into a preterminal warning : the sine wave.**

The ECG is a rapid and invaluable bedside diagnostic tool in hyperkalemia

1. Introduction (Keypoints)

- The ECG is the first whisper of hyperkalemia before the heart cries out – the heart does not wait for lab result. Recognizing such changes in time is not just diagnostic skill – it is a clinical foresight as well..
- The status of hyperkalemia is strengthened in the presence of symptoms such as nausea , vomiting , paraesthesia , muscle weakness , palpitation , unability to standing up ± drowsy status in association with the predisposing entities as enumerated below :
    - Skipped haemodialysis with pre-existing renal disease
    - Acute kidney injury
    - History of diabetes mellitus / hypertension as a predisposing cause of renal insufficiency
    - Drugs
      Potassium-Sparing Diuretics, including Spironolactone ,
      ACE inhibitors , ARBs.
    - Excessive consumptions of potassium rich diet (fruits , leafy vegetables , potatoes , etc.) by a patient with predisposed conditions.
    - History of trauma resulting in 'Rhabdomyolysis'
- If the wave pattern on ECG is suggestive of hyperkalemia , it has a high specificity for its diagnosis and it would be worth to initiate the concerned emergent treatment as per need.

Here to mention that **Venous blood-analysis** provides an immediate result of the patient's potassium level.

- The waves suggestive of hyperkalemia on ECG are more dramatic in its behaviour with faster evolution toward its lethal journey (sine wave , cardiac asystole / ventricular fibrillation). There should be no delay in the institution of its treatment , as needed. **One suggested regimen :**
    - 10 ml of 10% of calcium gluconate mixed with 100 ml D5W or NS to be infused over 5-10 minutes (it may be repeated as per need to achieve QRS < 100 ms or till the appearance of P-wave on ECG)
    - 2 Amps of D50W followed by 10 units rapid acting insulin IV
    - Salbutamol 8 puffs by aerochamber or 20 mg nebulized , but after IV insulin

  Immediately refer the case to the expertise centre for further treatment and haemodialysis , as per need.

2. Electrophysiological Sequence Under Normal Condition

The Cardiac Action Potential is a series of brief changes in voltage across the cardiac cell membrane, brought about by fluxes of ions through ion channels.

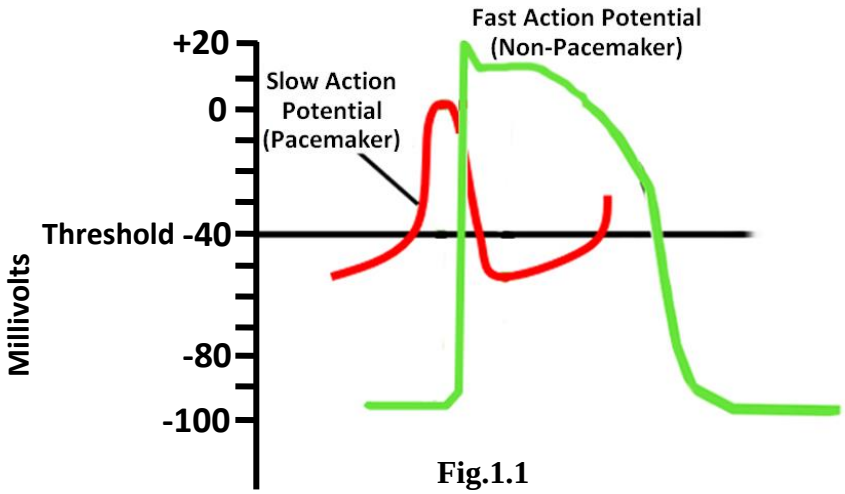


Fig.1.1

There are two sets of action potential :

- **Fast Action Potential** : This potential is seen in contractile cells (atria and ventricles) that are backed up by rapid depolarization due to the opening of fast $\mathbf{Na^+}$channels. Since HIS bundle - purkinje system is connected to the ventricular myocytes , it also shares the fast action potential to allow the impulses to pass rapidly through it.

- **Slow Action Potential** : The SA and AV nodes , being rich in slow $\mathbf{Ca^{2+}}$ channels cause different ion channel kinetics. The initial potential of this nodal system is less negative compared to the RMP of the contractile units of myocytes. This lesser negativity allows the action potential to be automatically activated in a slowly rising semi-curve manner (SA node activation automatically → to AV node with transient delay – 0.10 sec therein to facilitate the atrial empty due to the ventricle.

3. Sequential electrophysiological steps with hyperkalemia

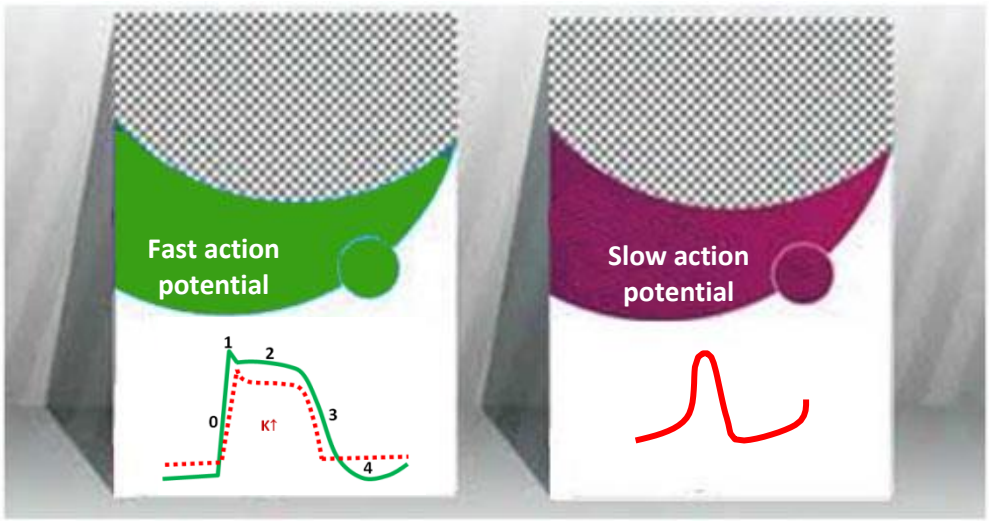


Fig.1.2

Fast Action Potential	Slow Action Potential
• In hyperkalemia → resting potential is less negative , with Na+ channels partly inactivated → the overall effect is smaller upstroke, shortened plateau, faster repolarization • Speeding up repolarization phase 2 and 3 → tall , peaked T-wave with shorter ST segment and QT interval.	• SA and AV nodes are less affected initially They use slow Ca^{++} channel , which are less sensitive to early K^{+} rise but they may be affected later , initially protected by their self automaticity • The overall effect is a flattened phase 4 slope , slowing automaticity

Sequential steps are :

❒ **T-Wave Changes & QT Shortening**

Extra potassium outside cells speeds up repolarization phase 2 and 3. This causes tall, peaked T-waves and shorter ST segment and QT interval

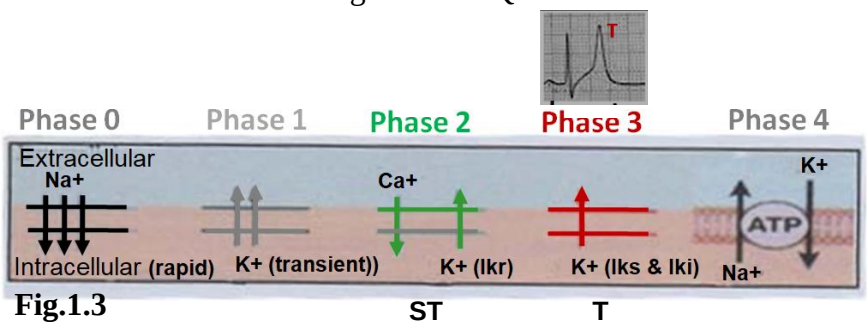
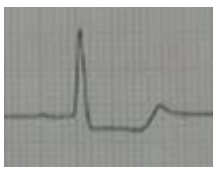


Fig.1.3

❒ **Slowed Atrial Conduction**

Hyperkalemia makes atrial cells less negative, affecting fast Na+ channels first . Atrial myocytes depolarize earlier, leading to slower and weaker conduction , ultimtately sweeping to atrial paralysis (flattened or low-amplitude P-wave with prolonged PR interval).



Flattened P-wave→Atrial standstill

Fig.1.4

❒ **Internodal Tracts Stay Functional Longer**

They do have Ca^{2+} dependent depolarization and so resist early effects of hyperkalemia.

❒ **SA & AV Nodes Are Less Affected Initially**

They use slow Ca++ channels, which are less sensitive to early K+ rise but they may be affected later , initially protected by their self automaticity.

❒ **Blockade**

Bundle branch block , AV block

❒ **Ventricular Conduction**

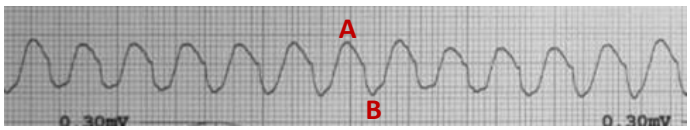
His–Purkinje and ventricles use fast Na+ channels

✓As extracellular potassium rises, it lays its heaviest hand on the most distal segments—be it the Purkinje arborization or the terminal ventricular myocytes.

This descending suppression paints a different electrophysiological spectrum , as illustrated below :

Secondary pacemaker capability of Purkinje fibres is suppressed → infranodal escape pacemaker is unreliable due to its downregulated conduction (either of bundle branches) → associated diffuse intraventricular conduction delay → sine wave → asystole

Fig.1.5



Classical sine wave is displayed here as up (**A** – widened ventricular depolarization phase) and down (**B** – widened ventricular repolarization phase) oscillation

This classification enables the clinicians to have correlation in between quantum of hyperkalemia and ensuing ECG changes

Early (K^+ ~5.5–6.0 mmol/L)	Slight slowing of SA node; possible mild PR prolongation Tall, peaked T waves (due to faster repolarization)
Mild-Moderate (K^+ ~6.0–6.5 mmol/L)	Flattening of P wave, progressive PR prolongation T waves more peaked; beginning QRS widening
Moderate-Severe (K^+ ~6.5–7.5 mmol/L)	Loss of P wave; junctional or atrial standstill begins Widened QRS; decreased contractility
Severe (K^+ >7.5–8.5 mmol/L)	Bundle branch blocks, AV block, ventricular escape Further QRS widening, T wave fusion begins
Pre-terminal (>8.5 mmol/L)	Complete conduction system collapse QRS and T merge → Sine wave pattern
Terminal (>9.0–10 mmol/L)	Electrical silence (asystole)

4. Overlapping ECG patterns in hyperkalemia : A pertinant consideration

Hyperkalemia often presents with unpredictable and overlapping ECG changes. The proposed concept of overlapping ECG changes in hyperkalemia offers a more realistic and clinically appliciable tool for bedside diagnosis. By moving beyond the rigid sequential model , clinicians can better recognize early warning signs , act promptly and potentially prevent cardiac arrest.

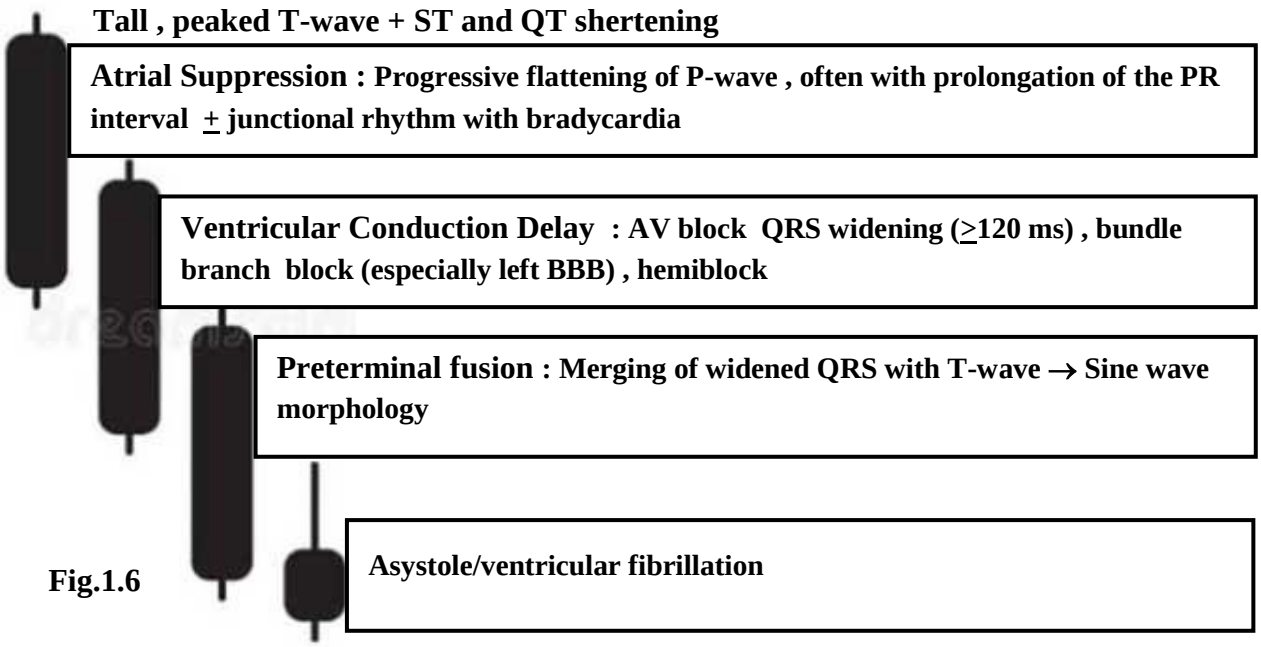


Fig.1.6

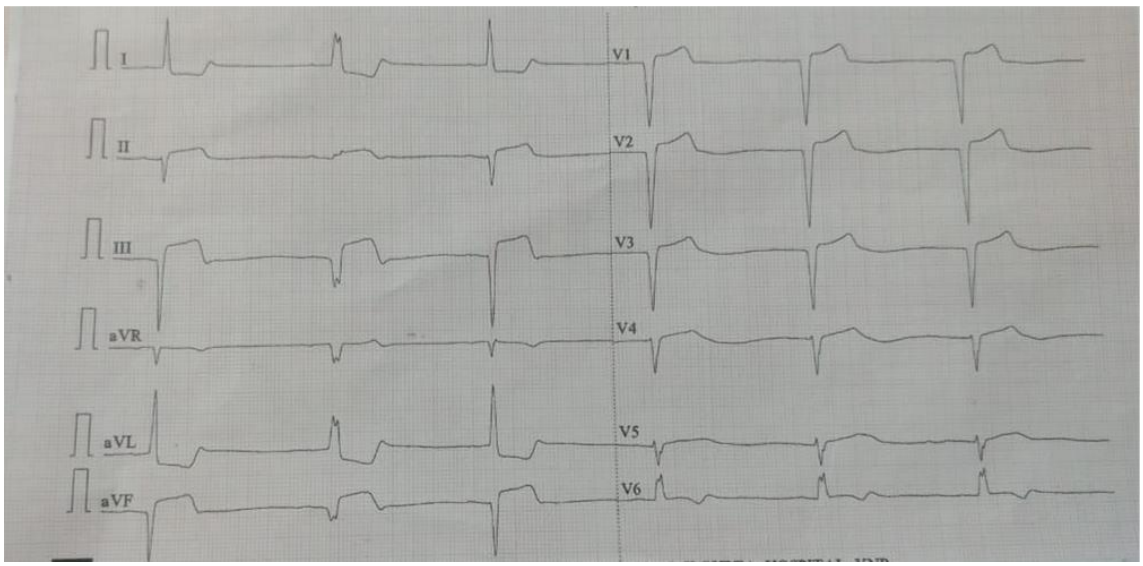
With the above sketch , the different stages of hyperkalemia have been illustrated. They may not be limited to stagewise , rather there exists a possibility of overlapping such changes with each other. There may be individual variability in response to hyperkalemia how does it responds to cardiac myocytes and its conductive tissues. The following factors might be responsible for such overlapping :

- As potassium rises , atrial and ventricular changes appear on ECG at different rates , and so they may have overlapping pattern.
- Variable expression of ion channels
  - Individuals have genetic and physiological differences in the density and kinetics of ion channels (e.g., Na^+, K^+, Ca^{2+} channels).
  - These variations cause different thresholds for how the atria, ventricles, and nodes respond to rising K^+.
- Differences in Autonomic Tone and Medications
  Vagal tone, beta-blockers, calcium channel blockers, or digoxin can all modulate how electrical signals propagate through different cardiac tissues.
  This can influence which ECG changes appear first or overlap.
- Underlying Cardiac or Renal Disease
  Conditions like left ventricular hypertrophy, ischemia, or renal failure may alter myocardial contractibility or ± the mode of conduction.

- Rate and Duration of Hyperkalemia
  Acute hyperkalemia leads to more pronounced and synchronized changes.
  In chronic hyperkalemia, the heart may partially adapt, causing some ECG changes to appear blunted or scattered across time and not in a textbook order.

5. An interesting Case study

71 years male presented with one day h/o Diarrhoea , drowsy incoherent state in association .
BP Pulse unrecordable , Non-Diabetic and Non-hypertensive
Serum Na 121 , K 5.86 all in mE/L , 20 ml urine in last 24 hrs , cardiac echo done 2 days back normal



Source : Global Heart Rhythm Forum dated 10th May 2025 , presented by **Dr. R.K Gupta** , Senior Consultant Physician , Yamunanagar , Haryana

ECG Findings	Interpretition
i. Flat P-wave → prolonged PR interval (0.22 sec) → Junctional escape rhythm (with bradycardia) → LBBB pattern (no tall T anywhere on ECG) **NB** : Zoom the ECG tracings to its maximum to view flat P-wave with prolonged PR interval	• A flat or absent P wave does not always signify SA node failure—it often reflects atrial conduction block, while the SA node silently endures (with PR>) • A nodal pattern emerging after flat P waves with bradycardia should rightly be termed a "junctional escape rhythm" • LBBB in association suggests advanced conduction system involvement ± Intermittent LBBB pattern points to somewhat fluctuating level of hyperkalemia
ii. Q-wave with ST elevation in inferior leads (II, III , aVF) with reciprocal ST depression in leads I and aVL	Discordant STE especially in context with lead III with > 1 mm STE > 25% of the depth of the preceding wave (at the LBBB site) – with the presence of Q and ST elevation in other inferior leads suggests inferior STEMI (modified Smith-Sgarbossa criteria)

The stepwise detailing of the entire clinical scenario :

✓ Please read through the investigation reports as laid down in the previous page with red outlines

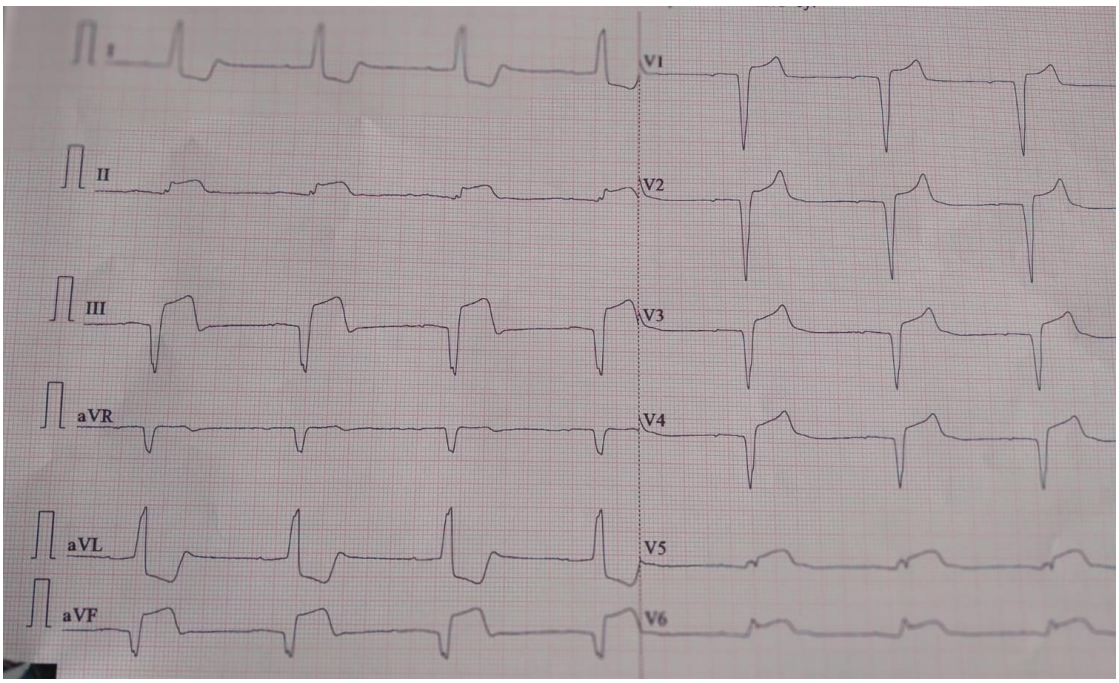
Step 1 : Most possibly the patient had passed into hypovolemia related Acute kidney injury (AKI)

Step 2 : Possibly further progressed to the stage of Hyperkalemia -renal induced

Step 3 : ECG findings suggestive of hyperkalemia , as elaborated in the previous page.

Step 4 : Evidence of Acute STEMI (inferior) , the details discussed in the previous page.

ECG of the same patient recorded after 1 hour : the findings are more or less the same except there is also evolution to anterolateral STEMI (V5 V6) in addition



Discussion :

This case is indeed stirring and educationally rich—a dramatic yet tragically oriented cascade that deserves thoughtful exploration – diarrhoea of one day standing in this old patient → hypovolemia-induced AKI → secondary hyperkalemia → electrocardiographic manifestations of acute STEMI , as discussed above. Further to say , the causative factors involved here with the absence of tall T-wave inspite of this cascade of hyperkalemia would be worth to be discussed here :

- Myocardial tissue by acute MI was most possibly so suppressed that ventricular repolarization (T-wave) no longer appears exaggerated.
- The existing LBBB pattern on ECG might had masked typical tall T-wave changes
- The history by itself suggests the rapid evolution of renal induced secondary hyperkalemia which might have overwhelmed the myocardium before repolarization changes to manifest.

- T-wave may be deceptively normal in hyperkalemia
  In approximately 20–25% of hyperkalemia cases, the T wave may remain normal in shape and amplitude throughout, even with moderate to severe elevations of serum potassium. This variant presentation is often termed **"electrocardiographic silence"** of hyperkalemia.

This would be worthwhile to discuss here some pertinent issues concerned with this case :

- ❒ Here there is involvement of left bundle branch block (LBBB) as a marker of conduction delay. Hyperkalemia causes generalized conduction slowing, but the anatomical complexity, higher sodium-channel dependence, and greater functional demand of the left bundle make it more likely to show this block earlier and more obviously than the right bundle.
- ❒ It is also known fact that acute MI may also cause LBBB pattern on ECG.
  Patients presenting with acute myocardial infarction (MI) and a left bundle branch block (LBBB), the presence of hyperkalemia (elevated potassium levels) can complicate the diagnosis. It is crucial to recognize and treat hyperkalemia promptly to prevent adverse cardiac events with improved outcomes.
- ❒ The association of Hyperkalemia with acute myocardial infarction exposes the patient to increased mortality by further deteriorating the renal function.

6. Take Home Message

- ☐ The ECG is a rapid and invaluable bedside diagnostic tool in hyperkalemia
- ☐ The status of hyperkalemia is strengthened in the presence of symptoms such as nausea , vomiting , paraesthesia , muscle weakness , palpitation , unability to standing up ± drowsy status in association with the background of hyperkalemia predisposing conditions.
- ☐ The waves suggestive of hyperkalemia on ECG are more dramatic in its behaviour with faster evolution toward its lethal journey (sine wave , cardiac asystole / ventricular fibrillation). There should be no delay in the institution of its treatment , as needed
- ☐ Hyperkalemia narrates a tortoise's journey—not one of triumph, but of a terminal slowing. It begins quietly, flattening the P wave, prolonging the PR, widening the QRS. At each step, the conduction tissues tire, the myocardium dulls, and what was once a brisk sprint of depolarization becomes a heavy, labored march. Eventually, the tortoise halts—not from exhaustion, but from electrical silence with a preterminal warning as the 'sinus wave'.
- ☐ The proposed concept of overlapping ECG changes in hyperkalemia offers a more realistic and clinically appliciable tool for bedside diagnosis. By moving beyond the rigid sequential model , clinicians can better recognize early warning signs , act promptly and potentially prevent cardiac arrest (for details see page 5-6)

☐ Some pertinent consideration :

- In approximately 20–25% of hyperkalemia cases, the T wave may remain normal in shape and amplitude throughout, even with moderate to severe elevations of serum potassium. This variant presentation is often termed **"electrocardiographic silence"** of hyperkalemia
- There may be involvement with left bundle branch block (LBBB) , more common compared to RBBB as a marker of conduction delay. Hyperkalemia causes generalized conduction slowing, but the anatomical complexity, higher sodium-channel dependence, and greater functional demand of the left bundle make it more likely to show this block earlier and more obviously than the right bundle.
- The association of Hyperkalemia with acute myocardial infarction exposes the patient to increased mortality.

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11. Referred to ChatGPT whenever needed

FROM MATHEMATICS TO MEDICINE : THE SINE WAVE IN HYPERKALEMIA

ECG

FROM MATHEMATICS TO MEDICINE : THE SINE WAVE IN HYPERKALEMIA

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OUTLINE

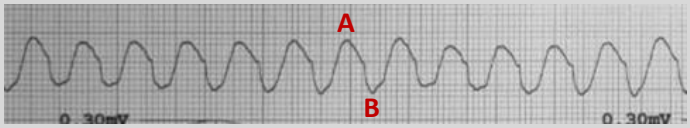
Introduction

The sine wave , a symbol of continuity in math , becomes a warning of discontinuity in life during hyperkalemia – it should be diagnosed promptly with its emergent treatment to prevent the lethal consequences

Electrophysiology

A worsening of cardiac conduction system leading to somewhat exaggerated widening of the QRS complex which ends up in its fusion with the ensuing widened T-wave (**sine wave pattern**).

The classical sine wave is without the co-existing P-wave.



Classical sine wave as up (**A** – widened ventricular depolarization phase) and down (**B** – widened ventricular repolarization phase) oscillation

Take Home Message

References

From Mathematics to Medicine : The Sine Wave in Hyperkalemia

A Narrative Review

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The Sine Wave in mathematics represents a repetitive up and down oscillations with the same shape , frequency , and amplitude on either side – repeating itself over time as if a continuous graph. In other words the sine wave is a graph having a smooth curve oscillation between positive and negative values.
Sine wave on ECG in hyperkalemia is having a sinusoidal pattern , very much mimicking as that of sine wave in mathematics , and when seen , it points towards the warning of imminent death.

- ☐ **As the serum potassium level increases to a critical level, there is worsening of cardiac conduction system causing a merger of the resultant widened QRS complex with that of widened T-wave – an unified run with equally expressed up and down troughs of QRS and T waves respectively**
- ☐ **With downgoing cardiac conduction system there is every possibility of collapsing of such sine wave to a straight line of cardiac asystole.**

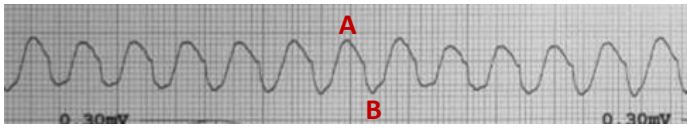
A sine-wave pattern on ECG is having a high specificity for detecting hyperkalemia. By its timely diagnosis and prompt management the further steps of this gloomy journey may be reverted back to normal.

1. Introduction (Keypoints)

- Sine wave pattern on ECG in hyperkalemia though rarely encountered in practice , it is a clinically significant and dreadful condition – it should be diagnosed promptly to prevent its lethal consequences.
- ECG is a simple tool to suspect hyperkalemia even before the potassium estimation by the laboratory is available. There are some pointers of hyperkalemia on ECG , such as symmetrical T-wave tenting , PR interval prolongation with reduced P-wave amplitude or even its absence , prolongation of the QRS ——

  The dreaded scenario of hyperkalemia on ECG is the appearance of sine wave.
- A classical sine wave in hyperkalemia denotes an unified run of up and down oscillations with equal spacing and amplitude ; this oscillation is considered due to the worsening of cardiac conduction during ventricular depolarization and ventricular repolarization , as illustrated by the following ECG tracing :

Fig. 1.1



Classical sine wave is displayed here as up (**A** – widened ventricular depolarization phase) and down (**B** – widened ventricular repolarization phase) oscillation

The sine wave of hyperkalemia can be compared to that of sine wave in mathematics :

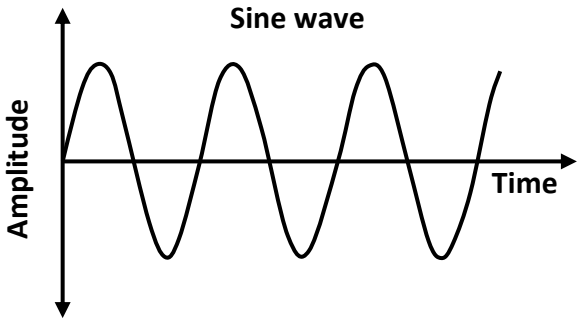


Fig. 1.2

The sine wave in mathematics is up and down curve that oscillates up and down with equal spacing and amplitude – a graph of repetitive oscillations.

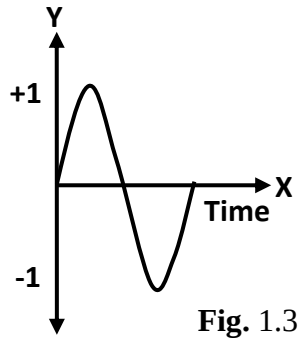


Fig. 1.3

A concept of Sine

Why is it called sine wave ?

The sine wave is a mathematical sinusoid curve that describes a smooth repetitive oscillation graph. Here the up turn is the same as that of down turn in its spacing and amplitude. This visual representation is known as sine graph , as illustrated with the side sketch.

- **If the sine wave pattern is detected on ECG , it is having a high specificity for the diagnosis of severe hyperkalemia**. Under such circumstances even with non-availability of serum potassium estimation in the emergency department , initiation of emergent treatment should be instituted.
  (It would be worthwhile to mention here that **Venous blood gas analysis** provides an immediate result of the patient's potassium level).
- The status of hyperkalemia is further strengthened in the presence of symptoms such as nausea , vomiting , paraesthesia , muscle weakness , palpitation , unability to standing up ± drowsy status with any of the followings :
  (commonly encountered conditions are enumerated here)
  - Skipped haemodialysis with pre-existing renal disease
  - Acute kidney injury
  - History of diabetes mellitus / hypertension as a predisposing cause of renal insufficiency
  - Drugs
    Potassium-Sparing Diuretics, including Spironolactone
    ACE inhibitors (or ARBs)
  - Excessive consumptions of potassium rich diet (fruits , leafy vegetables , potatoes , etc.) by a patient with predisposed conditions.
  - History of trauma resulting in 'Rhabdomyolysis'

For details of causative factors in hyperkalemia
Ref : Davidson's Principles and Practice of Medicine (International 24th Edition)
P 629 , Table 19.16 Causes of hyperkalemia

- This is to be mentioned here that the sine waves are more dramatic in its appearance on ECG with faster evolution towards the lethal journey (cardiac asystole / ventricular fibrillation). There should be no delay in the institution of its treatment , as needed.

  One suggested regimen :
  - 10 ml of 10% of calcium gluconate mixed with 100 ml D5W or NS to be infused over 5-10 minutes (it may be repeated as per need to achieve QRS < 100 ms or till the appearance of P-wave on ECG)
  - 2 Amps of D50W followed by 10 units rapid acting insulin IV
  - Salbutamol 8 puffs by aerochamber or 20 mg nebulized , but after IV insulin

  Immediately refer the case to the expertise centre for further treatment and haemodialysis , as per need.

2. Electrophysiology

In hyperkalemia there is usually a stepwise progression of changes on ECG.

As the serum potassium level increases to a critical level , there is a worsening of cardiac conduction system leading to somewhat exaggerated widening of the QRS complex which ends up in its fusion with the ensuing widened and inverted T-wave. Such fusion of the QRS complex with the corresponding T-wave is referred to as **sine wave pattern**.

For proper understanding let us review stepwise progression of ECG changes in hyperkalemia :

Accelerating response

The potassium current responsible for potassium efflux during repolarization is much sensitive to increased extracellular potassium level. Function of I_{Ki} (rapid evolving potassium current) increases with hyperkalemia causing enhanced potassium conduction during phase 2 and 3 of the action potential. This leads to faster and shorter repolarization , being revealed on surface ECG as the symmetrical tented T wave with shortening of ST segment , peaked up as shortened QT interval.

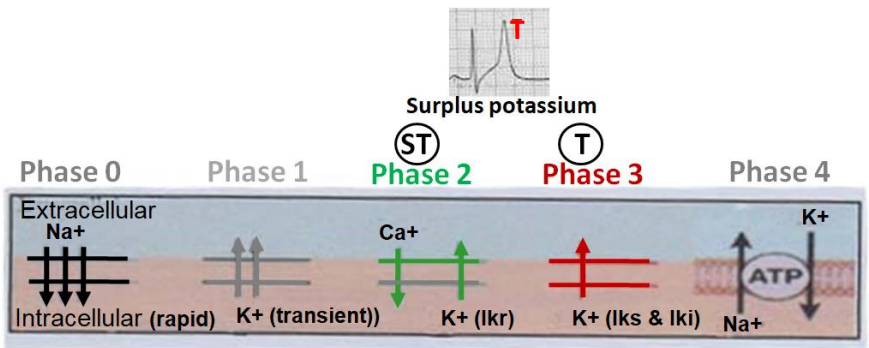


Fig. 1.4

Deaccelerating response

Hyperkalemia leads to conduction abnormality with impaired myocardial conduction :

A stepwise journey :

- **Atrial paralysis :** Atrial myocytes are more sensitive to hyperkalemia than the SA node , ventricular tissues or the Bundle of His. Even with further increment of serum potassium level , **sinus node continues to propagate its electrical activity to the ventricles even in the absence of atrial depolarization , such conduction is called as sino-ventricular rhythm.**

  Theoretically the existence of such sinus node activity passing to the ventricular system in the absence of P wave can be confirmed from the induced respiratory sinus arrhythmia – inspiration increases and expiration decreases the ventricular rate.

- **QRS widening**

  The conduction velocity through the ventricle is determined by upstroke phase 0 of the ventricular action potential that is governed by rapid influx of sodium ion. The influx rate is related to the relationship between the resting membrane potential = - 90 mV and threshold potential (-60 mV) after which a spontaneous action potential occurs.

  With ongoing hyperkalemia , the resting membrane potential is less negative with its closer relationship to the normal threshold potential. That's why , the influx of sodium ions is retarded with the subsequent decrement in the conduction velocity – causing a widening of the QRS complex.

  Closer is the value of resting membrane potential to the threshold potential , the less rapid is the influx of sodium ions with the slower conduction velocity , as illustrated below as red dash line (in hyperkalemia).

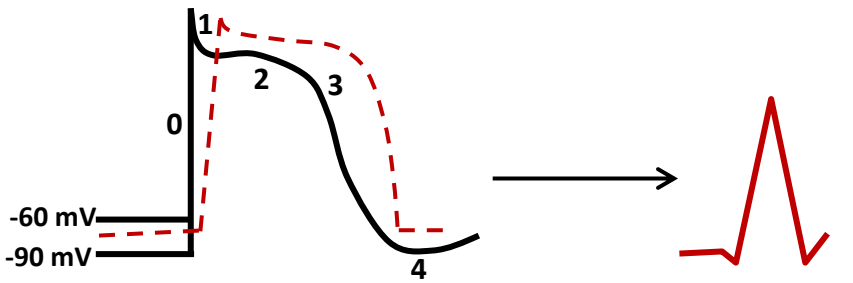


Fig. 1.5

-90 mV = more negative resting membrane potential

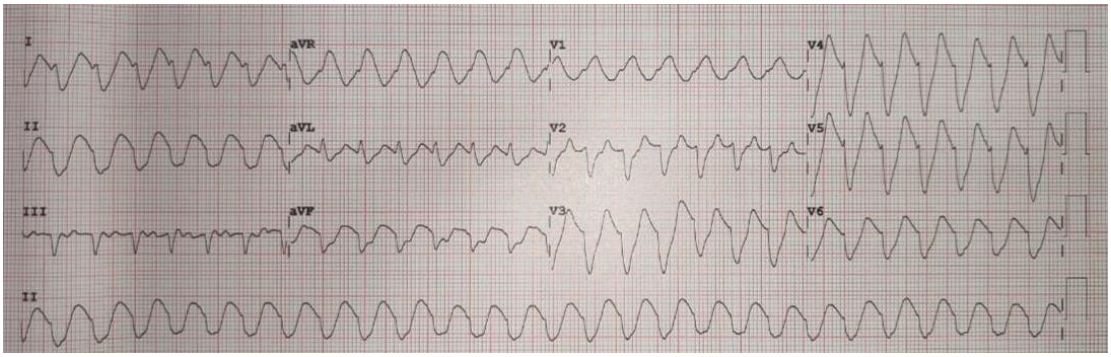
Somewhat less negative resting membrane potential (with ongoing hyperkalemia)

-60 mV = Normal threshold membrane potential

✓ More is the distance in between resting membrane potential (induced by hyperkalemia) and normal threshold membrane potential , the less rapid is the influx of sodium ion with the slower conduction velocity resulting in QRS widening.

- **Merging together of widened QRS complex with that of the widened T-wave = Classical sine wave (with the absence of P-wave)**

This phenomenon of sine wave is well illustrated by the ECG , as put below :
(History : Middle aged Diabetic female presenting with weakness , giddiness , nausea and vomiting)



Source : CME INDIA on 12.08.2023 by Dr. A.N. Rai , Former Prof. & Head Medicine and Principal ANMMCH , Gaya, Bihar ; Chairman AIMS, Gaya

Findings on ECG :

- Ventricular rate 94 bpm (the merged QRS and T wave should be counted as single beat)
- Rhythm lead II shows a run of up and down oscillations , almost with equal pacing and amplitude **— sine wave** (fusion of widened QRS with widened T)
- Lead V1 is showing much widening of the QRS complex almost equivalent to 0.28 sec simulating with right bundle branch block pattern.

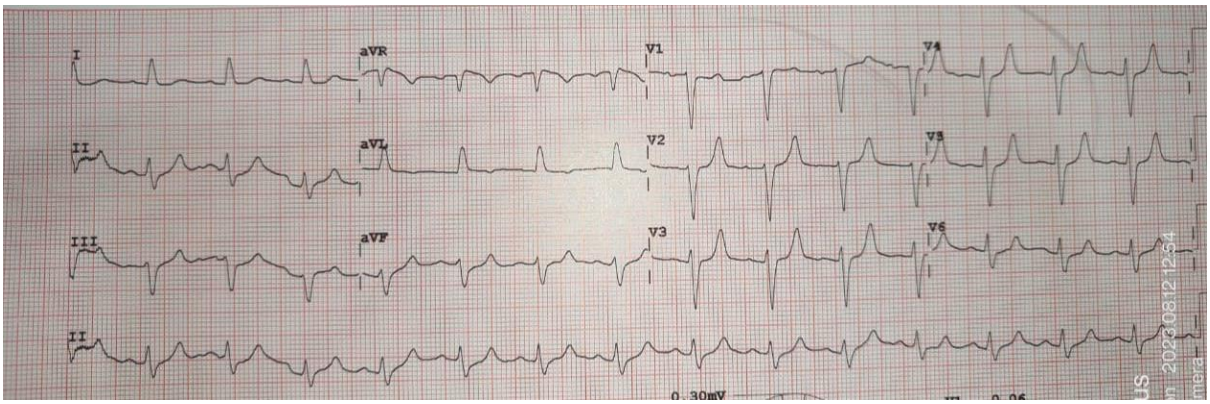
Comments :

- In this case the presence of sine waves on ECG is highly suggestive of severe hyperkalemia , consistent with the laboratory findings : serum potassium 7.6 mmol/L (and serum creatinine 4.80 mg/dL).
- With ongoing hyperkalemia , the resting membrane potential is less negative with its closer relationship to the normal threshold potential. That's why , the influx of sodium ions is retarded with the subsequent decrement in the conduction velocity – causing a widening of the QRS complex.
- Widened T-wave is also due to the worsening of cardiac conduction system.

D/D :

The presence of sine wave with so much ventricular rate (94 bpm) might impart a pseudo impression of ventricular tachycardia but it should be kept in mind that ventricular tachycardia is not having so superwide QRS as in this case. The so fast ventricular rate encountered in this case is most possibly due to the much closer merging of QRS complex wtih T wave (If anyone administer Amiodarone or apply direct current cardioversion to the patient by thinking this to be VT , it would bring further deterioration in cardiac conduction with immediate cardiac asystole).

See the following ECG after correcting hyperkalemia – this returned back to normal



3. Take Home Message

- ☐ The presence of sine wave on ECG is having a high specificity of severe hyperkalemia
- ☐ Sine wave in hyperkalemia denotes an unified run of up and down oscillations with equal spacing and amplitude ; this oscillation is considered due to the worsening cardiac conduction during ventricular depolarization and ventricular repolarization.
- ☐ Even with non-availability of serum potassium estimation in the emergency department , initiation of emergent treatment should be instituted to save the life of the patient.
- ☐ This can be said that the sine wave , a symbol of continuity in math, becomes a warning of discontinuity in life during hyperkalemia.

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UNVEILING THE BRASH SYNDROME ON ECG

ECG

UNVEILING THE BRASH SYNDROME ON ECG

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MD (MEDICINE) FCGP(IND) FIAMS(MEDICINE) FICP FICCMD FIACM

OUTLINE

Introduction

- **BRASH syndrome** is an acronym having multifaceted expression : Bradycardia, Renal Failure , AV blockade, Shock and Hyperkalemia

'Clinical Red Flags' to be kept in mind while diagnosing the case of BRASH syndrome

- Bradycardia out of proportion to hyperkalemia
- Mild to moderate hyperkalemia (5.5–6.5 mmol/L) causing severe bradycardia
- Recent illness, volume depletion, or medication changes
- On AV nodal blockers (beta-blockers, CCBs, digoxin)
- Subtle hyperkalemic ECG changes

ECG changes

Bradyarrhythmias dominate the picture

ECG does not typically show the stereotyped electrocardiographic changes observed in patients with hyperkalemia in association with BRASH Syndrome

Discussion

An interesting case study

Take Home Message

References

Unveiling the BRASH syndrome on ECG

A Narrative Review

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If any biochemical signal goes up wrongly , the body has mechanisms to let it down just to maintain homeostasis – the dynamic process of self-regulation that keeps the body's internal environment within the physiological norm , even when external conditions are fluctuating. This is known as the controlling negative feedback loop , if OK the body tells , 'All is well'. BRASH syndrome is a confluence of events resulting from the failure of this negative mechanism , if left untreated it can result in death.

- **BRASH syndrome is defined as a summation of Bradycardia , Renal failure , AV node blocker , Shock , and Hyperkalemia.**
- **Here , potassium isn't the sole villain — it's a co-conspirator in this deadly feedback loop. The concomitant use of AV blocker in the presence of downregulated renal perfusion results in profound bradycardia , which may eventually lead to shock.**

BRASH syndrome reminds us that ECG is the reflection of such a feedback mechanism failure – a cry for its early recognition and correction by the clinicians.

1. Introduction (Keypoints)

- **BRASH syndrome** is an acronym having multifaceted expression :
  Bradycardia, **R**enal Failure, **A**V blockade, **S**hock, and **H**yperkalaemia.
- This is a rare clinical syndrome attributed to :
  - The concomitant use of AV blocker in the presence of downregulated renal perfusion results in profound bradycardia.
  - Here profound bradycardia is out of proportion to the degree of hyperkalemia

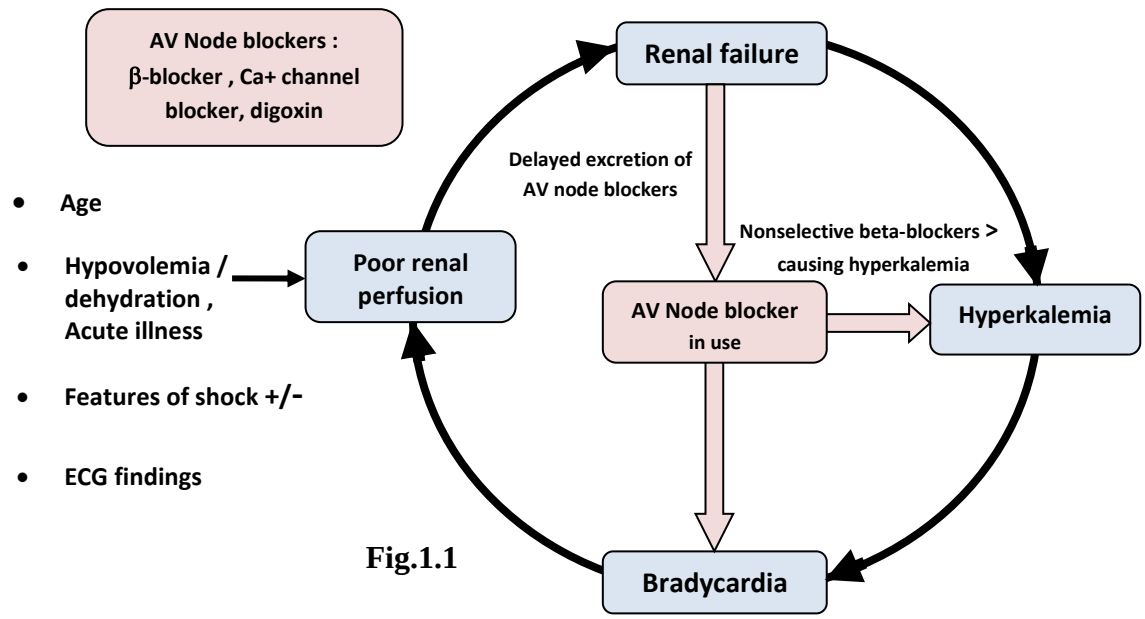


Fig.1.1

'Study Model' for BRASH Syndrome

- In BRASH Syndrome, potassium isn't the sole villain — it's a co-conspirator in a deadly feedback loop.

  - Hypovolemia / dehydration in the presence of concurrent use of AV blocker → renal failure with delayed excretion of AV node blocker → profound bradycardia
  - Low cardiac output due to profound bradycardia + systemic vasodilatation , aggravated by hyperkalemia and AV nodal blockers → shock
  - The degree of hyperkalemia is not so profound as that of bradycardia

  Here , the BRASH syndrome is characterized by profound bradycardia out of proportion to the degree of hyperkalemia. If this remains untreated , it can progress to shock ± multi-organ failure. Here **Potassium Level is often mild to moderate (e.g., 5.5–6.5 mmol/L), but causes severe bradycardia due to synergy impact in between all the factors involved with BRASH syndrome**.

"Many case reports have documented profound bradycardia associated with even mild hyperkalemia, likely due to the synergistic effect of the concomitant atrioventricular nodal blockade, which is the hallmark of BRASH syndrome"

Ref :
BRASH Syndrome
Kristi Lizyness; Olga Dewald.
Last Update: February 15, 2025.
https://www.ncbi.nlm.nih.gov/books/NBK570643/

- Little is known about epidemiology but cases are typically in the elderly.
  - BRASH Syndrome is often initiated by hypovolemia / dehydration resulting from any reason such as acute gastroenteritis. This hypovolaemia causes poor renal perfusion, leading to an acute kidney injury that further prevents the normal excretion of AV blocking drugs and potassium.
  - Other precipitants are medications described in case reports include that promote hyperkalemia or renal injury (e.g. ACEi, ARB, digitalis , beta blockers).

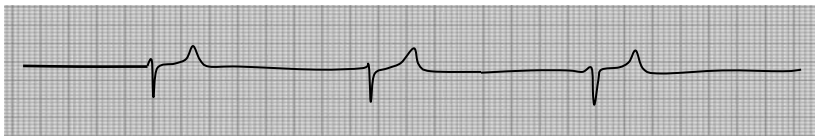
2. 'Clinical Red Flags' to be kept in mind while diagnosing the case of BRASH syndrome

- Bradycardia out of proportion to hyperkalemia
- Mild to moderate hyperkalemia (5.5-6.5 mmol/L) causing severe bradycardia
- Recent illness, volume depletion, or medication changes
- On AV nodal blockers (beta-blockers, CCBs, digoxin)
- Subtle hyperkalemic ECG changes

NB : Venous blood analysis provides an immediate result of the patient's potassium level

3. ECG changes

- ECG does not typically show the stereotyped electrocardiographic changes observed in patients with hyperkalemia in association with BRASH syndrome. The stepwise progression of ECG changes is absent here .
- Bradyarrhythmias dominate the picture (this is out of the proportion to the degree of hyperkalemia), so clinicians may miss the link to K+ unless they actively consider it. Sometimes subtle changes like tall-T might be peeped through the ECG tracings..

Fig.1.2 

4. Discussion

❒ In BRASH syndrome , AV nodal blockers may trigger this episode making further worsening of bradycardia and renal perfusion – this syndrome usually not precipitated unless patient is on AV nodal agent.

Since their development in the 1960s, atrioventricular nodal-blocking medications, such as β-blockers and calcium channel blockers, have been used to treat conditions such as coronary artery disease, hypertension, and tachyarrhythmias, including atrial fibrillation.

The incidence of BRASH syndrome is more with non-selective β-blockers because it affects both β1 and β2 receptors.

> β1 receptors on Heart → Decreases heart rate and AV conduction (bradycardia)
>
> β2 receptors on Kidneys (juxtaglomerular) → Reduces renin release → less aldosterone → impaired potassium excretion

Whenever there is a 'must' need of the use of β-blocker , one should use selective β1-blockers (e.g., Metoprolol). These selective β-blockers primarily affect the heart (β1) with less effect on potassium handling. Hence , less likely trigger the full BRASH cycle.

❒ Though common in elderly with CKD, younger patients can also develop BRASH, especially during dehydration or acute illness.

❒ Shock Is Often Misattributed

Hypotension in BRASH may be wrongly treated as pure hypovolemia or sepsis.

In reality, it stems from low cardiac output due to bradycardia + systemic vasodilation, aggravated by hyperkalemia and AV nodal blockers.

❒ Preventing the evolution of BRASH Syndrome—a synergistic interplay of Bradycardia, Renal failure, AV nodal blockade, Shock, and Hyperkalemia—all the five associates require a proactive multifaceted approach.

✓ **Even after initial stablization , patients remain vulnerable to recurrence if underlying risks (AV blockers , renal function) are not addressed long-term.**

❒ Commonly Missed Aspects in Practice

- Underestimating mild hyperkalemia
- Ineffectiveness of atropine in bradycardia due to AV node suppression
- Failure to stop AV nodal blockers in time
- Delayed recognition due to overlapping features with isolated AKI or drug toxicity
- Misattribution of hypotension to hypovolemia alone

❒ Early Detection and Intervention

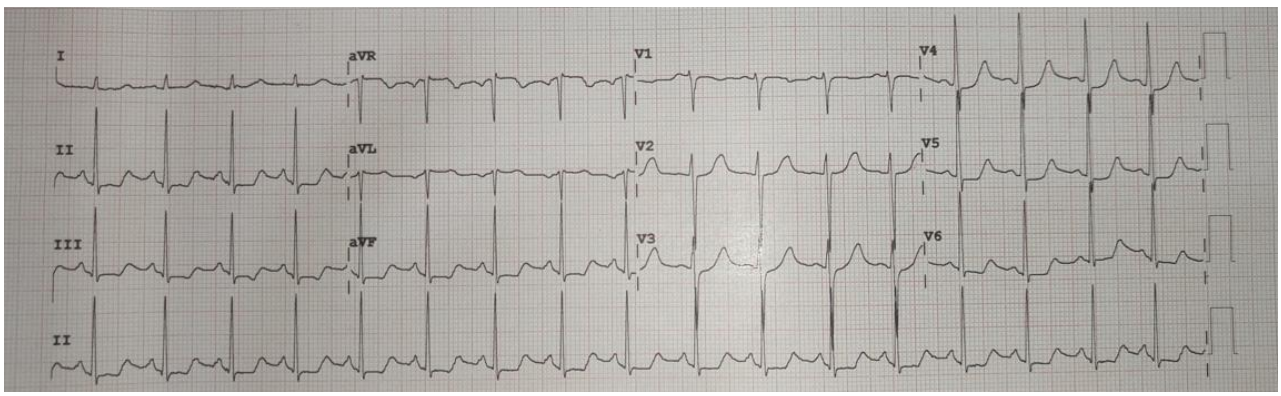
Regular Check-ups: Schedule periodic evaluations for at-risk patients to detect early signs of BRASH components.
Prompt Response: Address minor elevations in potassium or slight declines in renal function promptly to prevent escalation

For the purpose , further to say that it needs a clear cut understanding how AV blockers precipitate the BRASH syndrome :

- Hypovolemia / dehydration in the presence of concurrent use of AV blocker → renal failure with delayed excretion of AV node blocker → profound bradycardia
- Low cardiac output due to profound bradycardia + systemic vasodilatation , aggravated by hyperkalemia and AV nodal blockers → shock
- The degree of hyperkalemia is not so profound as that of bradycardia

5. An interesting case study

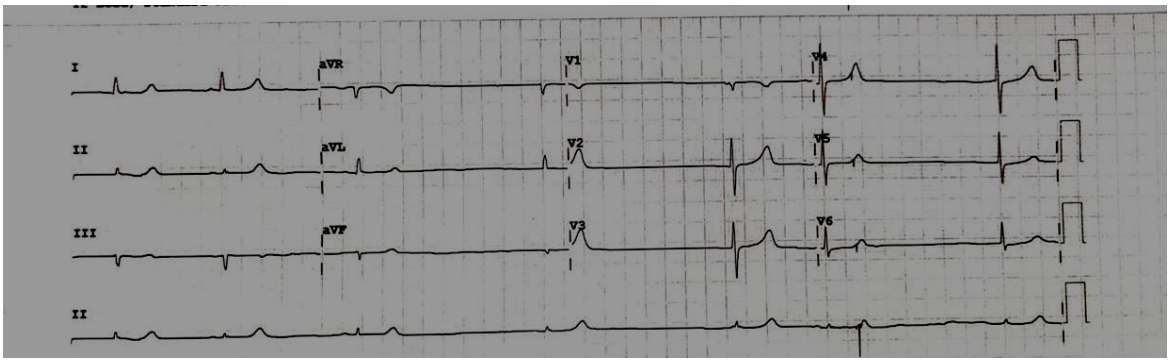
A Middle aged Diabetic female with CKD had PCNL for large Renal stones 3 days ago She was on Insulin and SGLT2 Inhibitor for control of Diabetes and Amodep AT for Hypertension . SGLT2 was stopped 3 days prior to surgery. 3 hours before the operation preoperative Blood came down 130 mg/dL and remained 140 to 180 mg/dL on post operative period , hemoglobin 8.0 gm/dl ECG given below :



ECG finding : Mild sinus tachycardia with systolic overload strain pattern (ST depression in inferior + anterolateral chest leads) in the background history of hypertension (echo showed concentric LVH with EF 55%) .

✓✓Her condition suddenly deteriorated on 3rd postoperative day with fall of BP 90 mg systolic and severe Bradycardia with pulse rate 50/ minutes. Her Blood Chemistry and ECG are shown below.

Electrolyte :		**Reference Value**	
Serum Sodium	135.80 mmol/L	135.00 - 155.00	mmol/L
Serum Potassium	**5.15** mmol/L	3.50 - 5.00	mmol/L
Serum Chloride	100.00 mmol/L	96.00 - 106.00	mmol/L



✓✓**Source :** CME INDIA dated 13th July , 2024 , posted by **Prof. Dr. A.N. Rai** , Former Prof. & Head Medicine and Prinicipal ANMMCH , Gaya Bihar ; Chairman AIMS, Gaya (Both ECGs)

ECG finding :

- Profound Bradyarrhythmia mostly with junctional rhythm
- Tall , tented T , most obvious over V2-V4
- Low voltage on frontal plane (possibly due to associated shock)

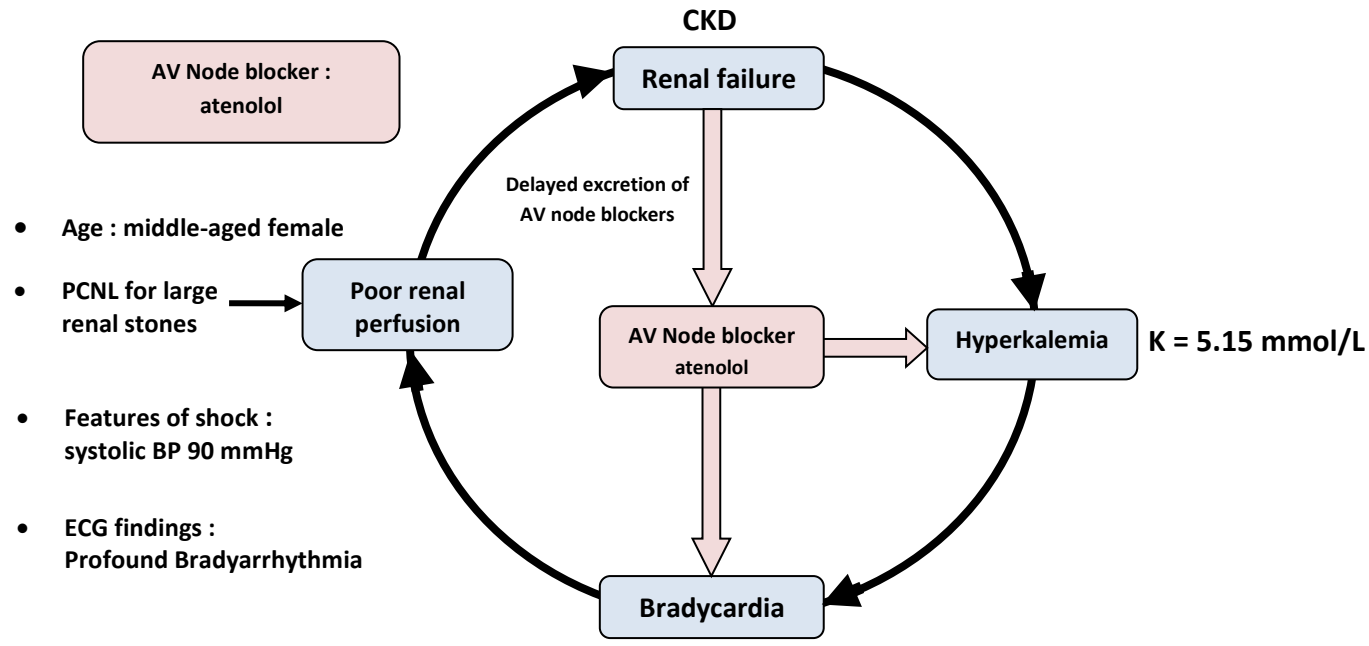


Fig.1.3 **Marked bradyarrhythmia**

'Study Model' for BRASH Syndrome

Discussion :

Presence of all the elements conjointly '**B**radycardia, **R**enal Failure, **A**V blockade, **S**hock , and **H**yperkalaemia'. is a definite pointer to BRASH syndrome

5. Take Home Message

- **BRASH syndrome** is an acronym having multifaceted expression :
  Bradycardia, **R**enal Failure, **A**V blockade, **S**hock, and **H**yperkalaemia.

- Further to say that it needs a clear cut understanding how AV blockers precipitate the BRASH syndrome (this usually not precipitated unless the patient is on AV nodal agent)
  - Hypoveolemia / dehydration in the presence of concurrent use of AV blocker → renal failure with delayed excretion of AV node blocker → profound bradycardia
  - Low cardiac output due to profound bradycardia + systemic vasodilatation , aggravated by hyperkalemia and AV nodal blockers → shock
  - The degree of hyperkalemia is not so profound as that of bradycardia

- ECG Changes
  Bradyarrhythmias dominate the picture (this is out of the proportion to the degree of hyperkalemia), so clinicians may miss the link to K+ unless they actively consider it. Sometimes subtle changes like tall-T might be peeped through the ECG tracings.

- Commonly Missed Aspects in Practice
  - Underestimating mild hyperkalemia
  - Ineffectiveness of atropine in bradycardia due to AV node suppression
  - Failure to stop AV nodal blockers in time
  - Delayed recognition due to overlapping features with isolated AKI or drug toxicity
  - Misattribution of hypotension to hypovolemia alone

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WHEN THE ECG DICTATES THE POTAASSIUM DROP

ECG

WHEN THE ECG DICTATES THE POTASSIUM DROP

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OUTLINE

When the ECG Dictates the Potassium Drop

A Narrative Review

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Homeostasis is a self-regulating process by which an organism tends to maintain its biostability while adjusting the conditions that are best adept for its survival. We are programmed to maintain homeostasis – whenever a part of the system is out of the balance , the rest of the members of the system will try to bring it back to normalcy. The same is true when the body faces the potassium drop in hypokalemia.

- ☐ **Potassium is shifted from intracellular to extracellular space as a homeostatic step to buffer the drop in serum K^+. This is a short-term compensatory action but depletes intracellular stores.**
- ☐ **When extracellular K^+ drops, despite attempts to buffer it, ECG changes appear due to altered cardiac electrophysiology.**

In hypokalemia the story of ECG changes depends upon how the heart's internal ionic milieu affects electrophysiological dynamics through alterations in cardiac action potential.

1. Introduction (Keypoints)

- In hypokalemia, understanding potassium dynamics is crucial—its extracellular deficiency disrupts the cardiac action potential in a sequential manner and the ECG serves as a sensitive and early detector of such electrophysiological changes.
- **An internal regulation against such extracellular K loss in hypokalemia**
  Potassium is the principal intracellular cation, and its extracellular loss can profoundly affect the cardiac health , that's why , the whole homeostatic mechanism is directed to minimize such potassium deficit.

  - Na^+/K^+ ATPase activity increases to retain intracellular K^+
  - Kidneys reduce K^+ excretion, regulated by aldosterone and distal nephron K^+ channels

  But simultaneously potassium is also shifted from intracellular to extracellular space to buffer the drop in serum K^+. Despite attempts to buffer K^+ , there still exists an altered cardiac electrophysiology to be reflected as ECG changes.
- Normally, RMP in cardiac cells is about -90 mV, maintained largely by the K^+ gradient. In hypokalemia, extracellular K^+ drops → membrane is leaky and so becomes hyperpolarized (more negative RMP). This increases the threshold for depolarization, and accordingly , there is a diminution in its conduction velocity → somewhat delayed depolarization.

- This retardation in conduction velocity is also extended along the entire length of repolarization which gets reflected on ECG as signals of reverse propagation : firstly as the decreased T-wave amplitude , with the corresponding increase in U-wave amplitude (a progressive inverse relationship in between T and U wave morphology) , all these lead to a fusion of T with U resulting in pseudo prolongation of QT (QU) interval. The next immediate signature is ST segment depression.
- When a patient comes with either of the following symptoms associated with co-existing predisposing conditions , the case is suspected to be one of hypokalemia.
  - Muscular weakness/cramps
  - Fatigue , constipation
  - Tingling/numbness
  - At times palpitations
- Predisposing conditions :
  - Potassium loss through vomiting and diarrhea
  - Low dietary intake
  - Increased excretion of potassium with diuretic use (especially loop diuretics), hyperalderosteronism, renal tubular acidosis, diabetic ketoacidosis, glucocorticoids use.
  - Conditions causing intracellular shift of potassium such as hypokalemia periodic paralysis , insulin effect , alkalosis.

2. Normal cardiac electrophysiology : A prerequisite to understanding hypokalemia

The cardiac life flows through the smooth functioning of its 'Action Potential'. There are certain specific pores over the cardiac membrane through which ionic inflow and outflow occur - these are known as 'cardiac channels'.

Broadly speaking there are two directions with the flow of the current , namely inward current and outward current , as illustrated below :

- ☐ The rapid inward flow of Na^+ during **Phase 0** , governed by negative resting potential at about -90 mV
- ☐ A brief outward flow of K^+ during **Phase 1**
- ☐ The inflow of Ca^{2+} with simultaneous outflow of K^+ during **Phase 2** (Plateau Phase)
- ☐ Cessation of Ca^{2+} inflow followed by outflow of K^+ during **Phase 3**

And at the end there is restoration of resting phase (**Phase 4**) brought about mostly by Na^+-K^+ ATPase pump.

The entire concept is illustrated by the following sketch :

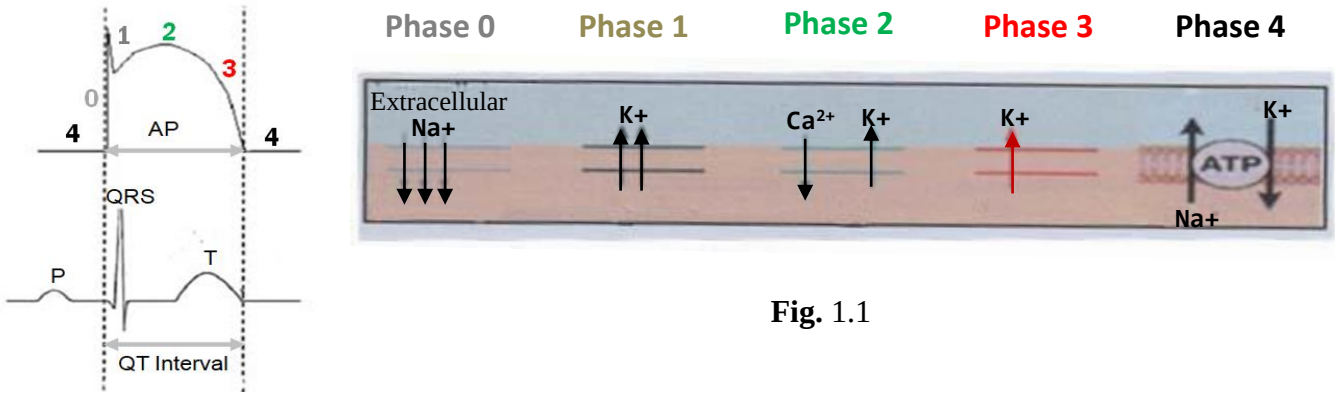
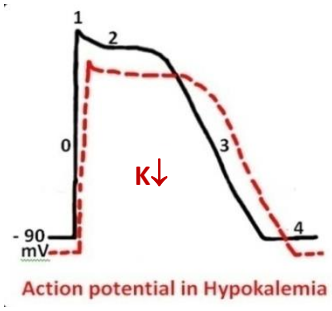


Fig. 1.1

3. ECG Changes corresponding to alterations in cardiac action potential

❒ **Hypokalemia** is defined as a serum potassium level of less than 3.5 mmol/L. ECG changes typically do not appear until the hypokalemia is moderate (2.5–3.0 mmol/L). The gap between the lower limit of normal potassium levels and the delayed onset of hypokalaemic manifestations is attributed to the body's homeostatic mechanisms, which buffer the drop in serum potassium.

❒ **Low extracellular potassium in hypokalemia makes the resting cardiac membrane (RMP) more negative :**



- In hypokalemia, extracellular K^+ drops → the resting cardiac membrane becomes hyperpolarized (more negative RMP)
- This increases the threshold for depolarization, potentially tends to slow its conduction (slow Na^+ inward flow)

Fig. 1.2

❒ "**Reversed Repolarization in Hypokalemia"**
Firstly the decreased T-wave amplitude , with the corresponding increase in U-wave amplitude (a progressive inverse relationship in between T and U wave morphology) , all these lead to a fusion of T with U resulting in pseudo prolongation of QT (QU) interval. The next immediate signature is ST segment depression.

✓ ECG changes begins at the terminal phase of the repolarization , progresses backwards in sequence : ↓

↓ T-wave amplitude	• The phase 3 of the ventricular action potential is mediated by delayed rectifier potassium current (IKr and IKs) . • In hypokalemia , reduced extracellular K^+ lowers the driving force for K^+ to get out of the cell , slowing repolarization. • This delay alters the T-wave morphology – appearing as with diminished T-wave amplitude
↑ U-wave amplitude	• With a further drop in K^+ there is a progressive inverse relationship in between T and U waves. Normally buried U-wave becomes unmasked as T wave amplitude drops (most evident in leads V2-V4). • U wave reflects delayed repolarization of the His-Purkinje system or mid-myocardial M cells. • This inverse relationship of T and U wave amplitude brings them closure , so they get merged together leading to Pseudo QT prolongation (QU) .

Illustration of inverse relationship in between the T and U waves :

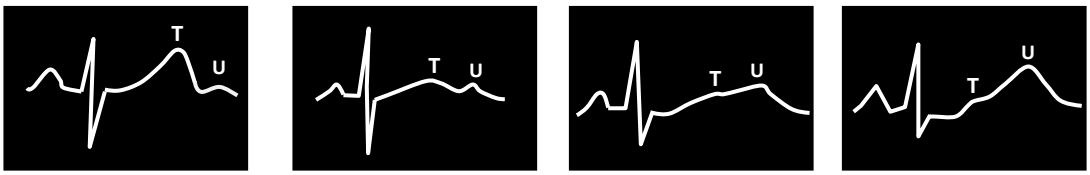


Fig. 1.3

- The ECGs may show a characteristic "dip (T) and rise (U) pattern" reflecting these waveform perturbations.

↓ ST segment depression

- Reduced outward current during hypokalemia → increased calcium influx through calcium channels.
- The overall current flow is away from the exploring electrode in the direction of increased calcium influx → ST segment depression.
- These events also lead to a bit lengthening of ST segment adding further to QT prolongation.

NB : When the P pulmonale pattern is accompained by typical ECG findings of hypokalemia , it might be pseudo due to hypokalemia. Perhaps the cause of increase in P wave is partly due to the overlap of P wave and U wave.

4. Arrhythmogenicity in hypokalemia

Hypokalemia can slow impulse propagation leading to enhanced myocardial dispersion , which predisposes to reentrant arrhythmias.

Impact on ventricular myocytes

- ☐ QT /QU leads to increased ventricular dispersion with heterogeneous conduction
- ☐ Enhanced risk of ventricular tachyarrhythmias
  - Frequent PVCs → bigeminy, non-sustained or sustained VT
  - Torsades de Pointes (if QT/QU is prolonged enough)

Impact on atrial myocytes

- ☐ Electrical heterogeneity leading to dispersion of refractoriness, a key substrate for reentry circuits , e.g. , atrial fibrillation and atrial flutter.
- ☐ It can also trigger isolated atrial beats as well

Hypokalemia doesn't initiate arrhythmias by itself— rather it primes the heart to be more sensitive to triggers (e.g., ischemia, drugs like digoxin). This would be worth to mention here that Hypokalemia enhances digitalis binding to the Na^+/K^+-ATPase.

5. Clinical correlates of hypokalemic changes

K level **Normal K+ : 3.5-5.0 mmol/L**	**ECG changes**	**Symptoms**
Mild hypokalemia K^+ = 3.0-3.5 mmol/L	May be normal ± mild flattening of T-waves	Mild fatigue , weakness
Moderate hypokalemia K^+ = 2.5-3.0 mmol/L	T flattening , U wave changes , ST depression	Muscles cramps , weakness , constipation
Severe hypokalemia K^+ < 2.5 mmol/L	Prominent U waves , prolonged QU / QT with arrhythmias including torsades	Muscular paralysis , even including respiratory depression (even rhabdomyolysis may occur)

6. Some pertinent facts to be kept in mind

- Hypomagnesaemia is often associated with hypokalemia, which may increase the risk of malignant ventricular arrhythmias
- And therefore , check both potassium and magnesium levels especially in any patient with severe hypokalemia.
- Replace potassium to ≥ 4.0 mmol/L and magnesium to within normal limit to stabilise the myocardium and protect against arrhythmias – this is standard practice in most CCUs and ICUs.
- Hypokalemia should be corrected promptly, especially in patients with:

  Heart failure
  Digitalis therapy
  Structural heart disease
  Prior AF

  These are more prone to develop malignant arrhythmias

- Early ECG changes (T wave flattening) are a warning; late changes (U waves, QT prolongation, arrhythmias) can be life-threatening.

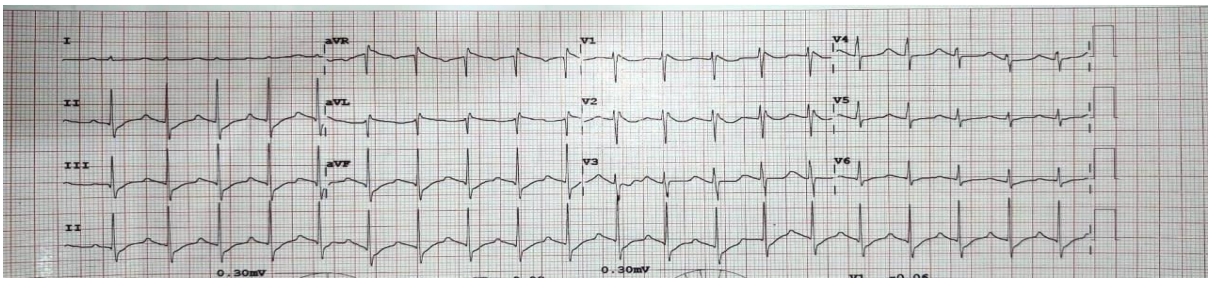
Surawocz et al. criteria for hypokalemia

- ☐ U wave amplitude of > 1 mm
- ☐ U wave amplitude > T wave amplitude in the same lead
- ☐ ST segment depression of ≥ 0.5 mm
  - Typical of hypokalemia : if three of the above features were present in two leads
  - Compatible with hypokalemia : if two of the above features or one related to the U wave were present

- Sometimes in hypokalemia there may be diminished insulin release from the β cells of the pancreas.

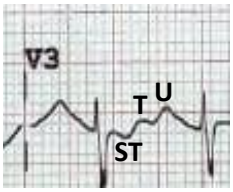
7. An interesting case study

A young patient presented with Quadriparesis and respiratory arrest.
His ECG posted as below :



Source : **Dr. Mritunjay Kumar Singh**, Senior Nephrologist and consultant Physician at AIMS, Gaya

ECG Findings :



Magnified view through lead V3

- QU (QT) prolongation > 50% of the corresponding RR interval
- Inverse relation in between T and U wave – "dip (T) and rise (U) pattern" is a very characteristic feature of hypokalemia
- Accompanied with slight depression of ST segment

NB : These ECG changes are best seen in this case over lead V3 but not uniformally through all the beats in the same lead. The non-uniform appearance of hypokalemic ECG changes within the same lead is typically due to dynamic repolarization variability caused by hypokalemia itself , may be compounded by autonomic fluctuations , U wave interference or possibly respiratory-related electrical shifts (here to note that this patient was also having respiratory arrest).

Investigations :

Serum Potassium				
14/03/2021	**15/03/2021**	**16/03/2021**	**17/03/2021**	**18/03/2021**
1.48 mmol/L	1.81 mmol/L	2.52 mmol/L	3.50 mmol/L	4.10 mmol/L

Serum magnesium on 15/03/2021 = 1.63 mg/dL (Normal value = 1.70-2.20 mg/dL)

Discussion :

- Prolonged QTc interval is due to the combined effect of hypokalemia and hypomagnesemia. The patient recovered fully from this catastrophe.

8. Take Home Message

☐ In hypokalemia, understanding potassium dynamics is crucial—its extracellular deficiency disrupts the cardiac action potential in a sequential manner and the ECG serves as a sensitive and early detector of such electrophysiological changes.

☐ **An internal regulation against such extracellular K loss in hypokalemia**
Potassium is the principal intracellular cation, and its extracellular loss can profoundly affect the cardiac health , that's why , the whole homeostatic mechanism is directed to minimize such potassium deficit.

- Na^+/K^+ ATPase activity increases to retain intracellular K^+
- Kidneys reduce K^+ excretion, regulated by aldosterone and distal nephron K^+ channels

☐ But simultaneously potassium is also shifted from intracellular to extracellular space to buffer the drop in serum K^+. Despite attempts to buffer K^+ , there still exists an altered cardiac electrophysiology to be reflected as ECG changes.

☐ Normally, RMP in cardiac cells is about -90 mV, maintained largely by the K^+ gradient. In hypokalemia, extracellular K^+ drops → membrane becomes hyperpolarized (more negative RMP).

Features	Effect of Hypokalemia
Intracellular K^+	Mobilized to buffer serum levels
RMP	Becomes more negative (hyperpolarized)
Action Potential	Delayed repolarization
ECG Changes	Flattened T waves, prominent U waves, prolonged QT, ST depression
Risk	Ventricular arrhythmias

☐ "**Reversed Repolarization in Hypokalemia"**
Firstly as the decreased T-wave amplitude , with the corresponding increase in U-wave amplitude (a progressive inverse relationship in between T and U wave morphology) , all these lead to a fusion of T with U resulting in pseudo prolongation of QT (QU) interval. The next immediate signature is ST segment depression.

☐ Hypokalemia may be associated with hypomagnesimia. This increases the risk of malignant ventricular arrhythmias.

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THE U WAVE WARNS, THE SINE WAVE ALARMS : ECG REFLECTION OF POTASSIUM EXTREMES

ECG

THE U WAVE WARNS, THE SINE WAVE ALARMS : ECG REFLECTIONS OF POTASSIUM EXTREMES

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OUTLINE

The U Wave Warns , the Sine Wave Alarms : ECG Reflections of Potassium Extremes

A Narrative Review

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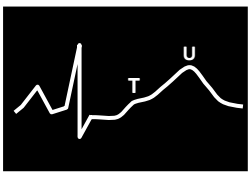
"Warning" is more about serving a prior information to a dreadful situation , if neglected it may lead to a catastrophic event but not so immediately, on the other hand **"Alarming"** suggests a more dreadful situation just to happen if a proper action is not taken immediately. Inspite of warning nothing much happens at once until the status quo becomes more roaring , while alarming sounds much towards an immediate happening.
Both hypokelamia and hyperkalemia have a deep-dive which may threaten the life.

- ☐ **The U wave , the warning signature of hypokalemia is a subtle signal of ventricular arrhythmias due to delayed repolarization.**
- ☐ **The Sine wave is a pre-terminal alarming of hyperkalemia, not only just of conduction delay, but of electrical collapse in the myocardium.**

It is truly to say that both these conditions, though opposite in direction —each capable of destabilizing the heart through two distinct but equally lethal pathways.

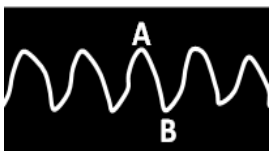
1. Introduction (Keypoints)

- Potassium is the most abundant intracellular cation, playing a pivotal role in maintaining biocellular integrity – the disturbed homeostasis with hypo-hyperkalemia may initiate life threatening sequences. Alterations in serum potassium, even within narrow limits, can lead to profound electrical disturbances that herald potentially fatal arrhythmia , though they do so via distinct electrophysiological mechanisms.
  - U-wave reflects delayed repolarization with pro-arrhythmic impact.

Fig. 1.1 

TU summation is associated with increased ventricular dispersion and a higher risk of ventricular arrhythmias , like Torsades de Pointes.

  - Sine-wave reflects a dreadful summation of ventricular depolarization and ventricular repolarization which tends to collapse to asystole.

Fig. 1.2 

Classical Sine wave is displayed here as up (**A** – widened ventricular depolarization phase) and down (**B** – widened ventricular repolarization phase) oscillation in continuity.

- Electrocardiography (ECG) serves as a vital real-time mirror of these ionic imbalances. Among its most revealing reflections are two hallmark waveforms: the U wave of hypokalemia and the Sine wave of hyperkalemia.

- This article seeks to scout out these waveforms not merely as isolated curiosities, but as critical evaluation of underlying pathophysiology. Through an analytic comparison of their genesis, ECG manifestation and clinical significance, the main purpose is to recognize the potassium instability—whether deficient or excessive—is not merely a electrocardiographic abnormality, but rather a dynamic and potentially lethal force within the cardiac conduction system.

2. Electrophysiological Insight with the Purkinje-Myocyte Junction

- The Purkinje fibers deliver the incoming impulses from HIS-bundle purkinje system to the underlying mesh of myocardial tissue , with a very fast conduction velocity of 2-4 meters/s.
- Purkinje-myocardial junction (PMJ) is having gap junction end-plates connecting purkinje fibres to ventricular myocytes.
- Purkinje cells with large diameter dump its charges into the mesh-network of ventricular myocytes and in doing so its action potential duration covers more width compared to those of myocytes , as if the myocytes are underneath the protective umbrella of purkinje fibers.

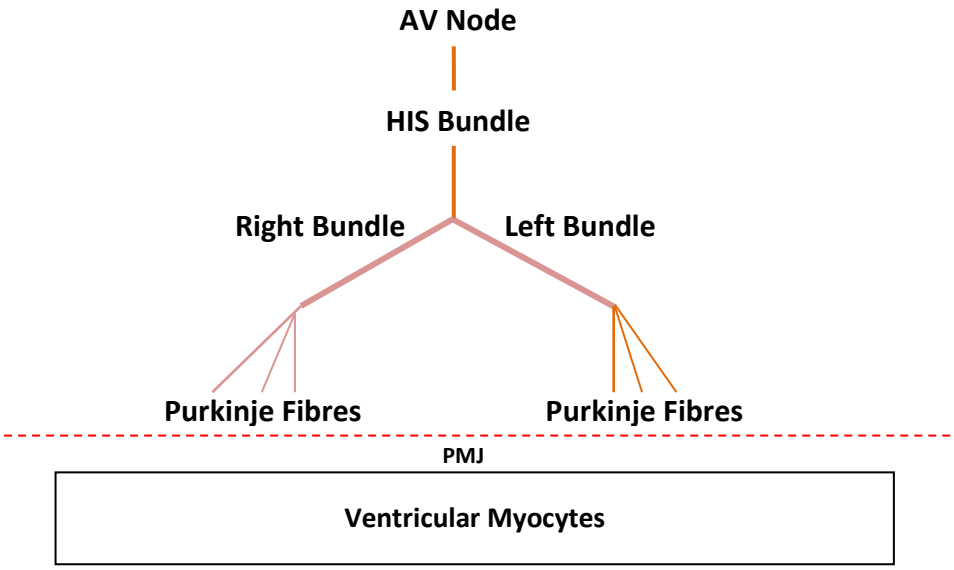
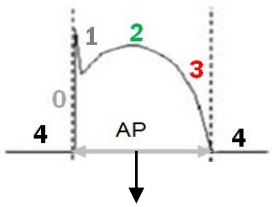


Fig. 1.3



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Purkinje Action Potential	Ventricular Action Potential
• Long APD (action potential duration) • Latent automaticity	• Shorter APD (Epi < Endo < M) • Flow toward epicardium shapes T wave

❒ Because PFs remain depolarized longer, they can electrotonically flatten the repolarization of adjacent myocytes, smoothing transmural gradients under normal conditions.

The entire concept of depolarization (0) and repolarization (1 + 2+ 3) is illustrated by the following sketch :

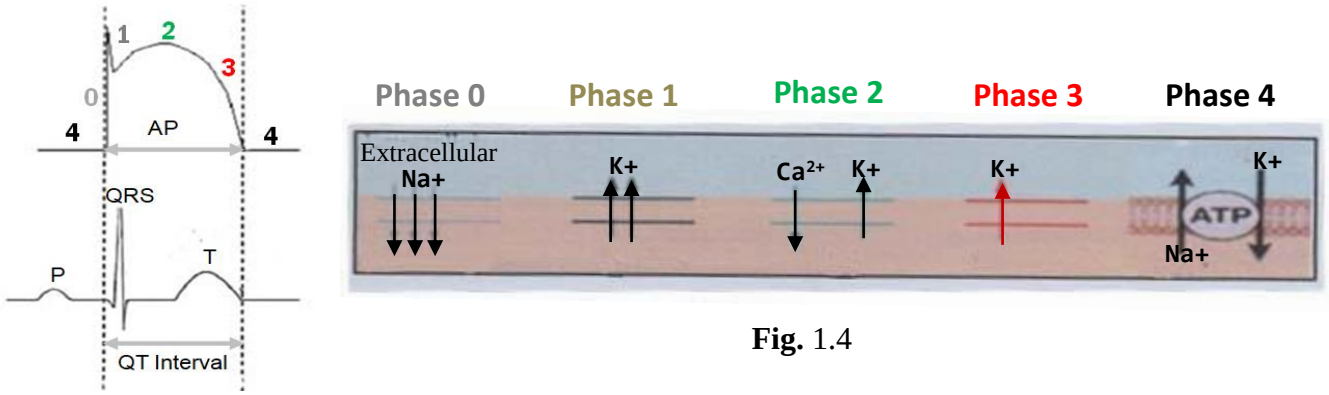


Fig. 1.4

- ☐ The rapid inward flow of Na^+ during **Phase 0** , governed by negative resting potential at about -90 mV
- ☐ A brief outward flow of K^+ during **Phase 1**
- ☐ The inflow of Ca^{2+} with simultaneous outflow of K^+ during **Phase 2** (Plateau Phase)
- ☐ Cessation of Ca^{2+} inflow followed by outflow of K^+ during **Phase 3**

And at the end there is restoration of resting phase (**Phase 4**) brought about mostly by Na^+-K^+ ATPase pump.

❒ Long PF APD vs. shorter epicardial APD → transmural voltage gradient that inscribes the normal T wave during phase 3 via the outflow of K^+ ions.

3. The U-wave , a warning signature of hypokalemia → Ventricular arrhythmias

ECG changes begin at the terminal phase of the repolarization :

- In hypokalemia , reduced extracellular K^+ lowers the driving force for K^+ to get out of the cell and so slowing repolarization.
- This delay alters the T-wave morphology – appearing as with diminished T-wave amplitude
- With a further drop in K^+ concentration there is a progressive inverse relationship in between T and U waves. Normally buried U-wave becomes unmasked as T wave amplitude drops (most evident in leads V2-V4).
- U wave reflects delayed repolarization of the His-Purkinje system or mid-Myocardial cells ($K^+ \leq 2.5$ mmol/L).
- This inverse relationship of T and U wave amplitude brings them closure , so they get merged together leading to Pseudo QT prolongation (QU).
  → Ventricular dispersion → Ventricular arrhythmias

The Purkinje system often initiates ventricular arrhythmia while the working myocardium sustains re-entry once dispersion exists.

4. The Sine wave is a pre-terminal alarming of hyperkalemia

The following pertinent points are to be considered in this context :

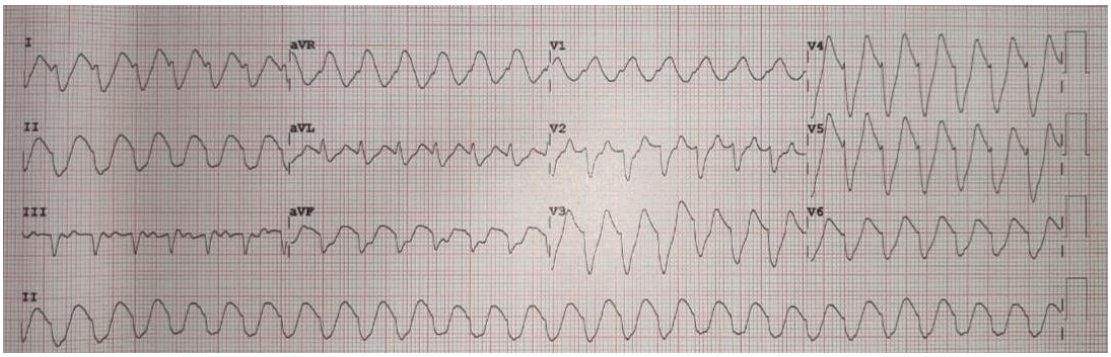
- Normally compared with proximal conduction system , the purkinje system is having higher K+ conductance (higher conduction velocity) with latent automaticity.
- In hyperkalemia , the secondary pacemaker capability of purkinje fibres is suppressed and become unreliable once the proximal bundle branch conduction is non-functioning.
- At the pre-terminal point of hyperkalemia (≥7.5-8.5 mmol/L) there is complete cessation of bundle branch functioning , therefore , no direct impulses are capable of reaching to the purkinje system , which under circumstances assumes its own automaticity , but it does not sustain much.
- Towards the end the ventricular myocytes initiate its own rhythm which is atypical non-lasting complex which leads to merging of widened QRS complex with that of widened T wave → Sine wave. The Sine wave is up and down oscillating rhythm with almost equal spacing and amplitude in between.
- This is a preterminal unstable rhythm which tends to collapse to cardiac standstill as asystole. This incidence can be compared to the almost broken branch of a tree which may collapse to the ground just with the wind of air.

5. An interesting case study : Sine wave of hyperkalemia

Classical sine wave (with the absence of P-wave)

This phenomenon of sine wave is well illustrated by the ECG , as put below :

History : Middle aged Diabetic female presenting with weakness , giddiness , nausea and vomiting



Source : CME INDIA on 12.08.2023 by **Dr.A.N. Rai** , Former Prof. & Head Medicine and Principal ANMMCH , Gaya, Bihar ; Chairman AIMS, Gaya

Findings on ECG :

- Ventricular rate 94 bpm (the merged QRS and T wave should be counted as a single beat)
- Rhythm lead II shows a run of up and down oscillations , almost with equal pacing and amplitude **—sine wave** (fusion of widened QRS with widened T)
- Lead V1 is showing much widening of the QRS complex almost equivalent to 0.28 sec simulating with right bundle branch block pattern.

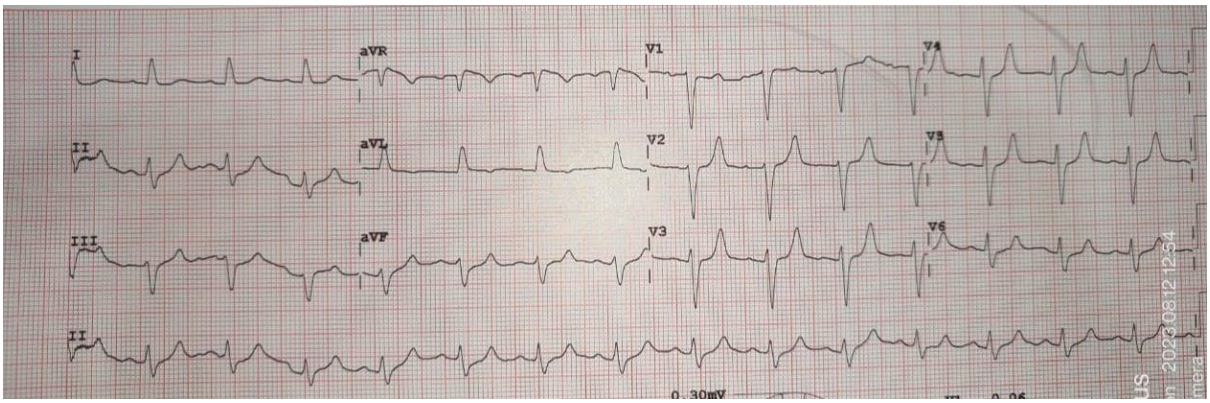
Comments :

- In this case the presence of sine waves on ECG is highly suggestive of severe hyperkalemia , consistent with the laboratory findings : serum potassium 7.6 mmol/L (and serum creatinine 4.80 mg/dL).
- At the preterminal state of hyperkalemia , the secondary pacemaker capability of purkinje fibres is supressed and becomes unreliable , which together with its propagation failure leads to Sine wave with subsequent landing to frank asystole.
- If the sine wave pattern is detected on ECG , it is having a high specificity for the diagnosis of severe hyperkalemia. Under such circumstances even with non-availability of serum potassium estimation in the emergency department , initiation of emergent treatment should be instituted.
  (It would be worthwhile to mention here that **Venous blood gas analysis** provides an immediate result of the patient's potassium level).

D/D :

The presence of sine wave due to the much closer merging of QRS complex with T wave might impart a pseudo impression of ventricular tachycardia but it should be kept in mind that ventricular tachycardia is not having so superwide QRS as in this case. In ventricular tachycardia QRS complexes have a distinct morphology , not merging with T-wave. The presence of sine wave is consistent with the laboratory report of serum potassium suggestive of hyperkalemia (If anyone administer Amiodarone or apply direct current cardioversion to the patient by thinking this to be VT , it would bring further deterioration in cardiac conduction with immediate cardiac asystole).

See the following ECG after correcting hyperkalemia – this returned back to normal



6. Take Home Message

- ☐ The Purkinje–myocyte system is not just a high-speed "wire". It is a dynamic modulator of repolarization, finely tuned by ion-channel expression, particularly dependent upon extracellular potassium concentration. Altered perturbation either by hypo-hyperkalemia can transform this safety system into the nidus of lethal arrhythmia.

- In hypokalemia U wave reflects delayed repolarization of HIS-Purkinje system or mid-myocardial cells. It warns clinicians of a correctable catashrophe before it becomes lethal.
- In hyperkalemia towards its terminal state , the secondary pacemaker capability of purkinje fibres is rather suppressed and become unreliable , which together with its propagation failure can lead to fatal Sine wave with subsequent landing to frank asystole. The Sine wave does not warn – it marks a terminal conduction instability , with the mortality window of minutes if untreated.
- Purkinje-Myocyte interface is the crucial site in ventricular instability from U-wave to Sine wave , the signature of hypo-hyperkalemia respectively.
  - The U wave , the warning signature of hypokalemia is a subtle signal of ventricular arrhythmias due to delayed repolarization.
  - The Sine wave is a pre-terminal alarming of hyperkalemia, not only just of conduction delay, but of electrical collapse in the myocardium.

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HYPOKALEMIA : THE MASTER PLAYER OF ARRHYTHMIC DISSONANCE

ECG

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OUTLINE

Hypokalemia : The Master Player of Arrhythmic Dissonance

A Narrative Review

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The heart is electrophysiologically well protected but there may be certain points of break-in – the utterances in stupidity by chance, romping through the ripples of unwanted electricity what the cardiologists term arrhythmia. Arrhythmias are often triggered during a "vulnerable period" in the cardiac cycle.

To diagnose arrhythmia is to unravel the disturbed ionic choreographic pattern. Without its understanding , it remains a futile attempt towards its diagnosis.

- ☐ **Afterdepolarization is the soul essential in this arrhythmic disonance : delopolarizing electrical sparks that occur following the initial phase 0 depolarization of the cardiac action potential.**
- ☐ **Two types of afterdepolarization sparks**
  Early afterdepolarization (EAD) : involving 2/3 phase of repolarization (QT prolonation with heterogenetiy) → Torsades de pointes
  Delayed afterdepolarization (DAD) : involving phase 4 of repolarization with no heterogeneity → usually monomorphic VT

In hypokalemia dissonant ionic choreography destabilises myocardial synchrony , unraveling its electrophysiological journey.

1. Introduction

- Every heart carries a rhythm pattern of its own — sometimes harmonious, sometimes non harmonious. Such occurrence is a universal human experience – in electrolyte imbalance the heart may assume the ripples of unwanted electricity to be reflected as arrhythmia. Among such situations , potassium deficiency may become a master of arrhythmic dissonance.
- To understand the concept of arrhythmia in hypokalemia it becomes essential to have the glimpse of corresponding ECG changes.

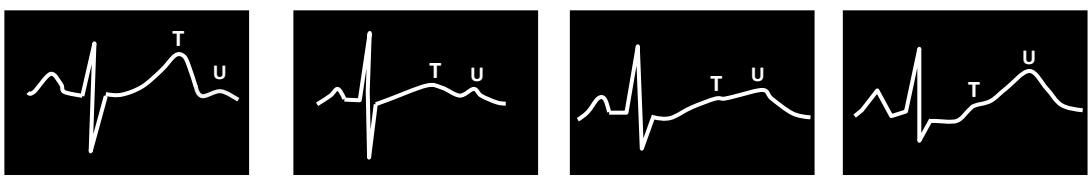

Fig. 1.1

By understanding the sequential pattern of ECG changes in hypokalemia , it becomes evident that repolarization is prolonged through cumulative effect of ST-segment depression and T-U fusion. This prolongation is manifested as an extended QT(U)

interval creating a substrate for ventricular arrhythmias , if combined with ventricular heterogeneity , it heralds the malignant shadow of torsades de pointes.

- This review article aims at unraveling the electrophysiological basis of hypokalemia from benign irregular beats to life-devastating ventricular arrhythmias. The purpose here remains clear : to understand arrhytmia in the light of changing dynamic ionic choreography.

2. Electrophysiology of arrhythmia in hypokalemia (A bird's eye view)

In hypokalemia, the understanding of potassium dynamics is crucial—its extracellular deficiency retards all the phases of cardiac action potential.

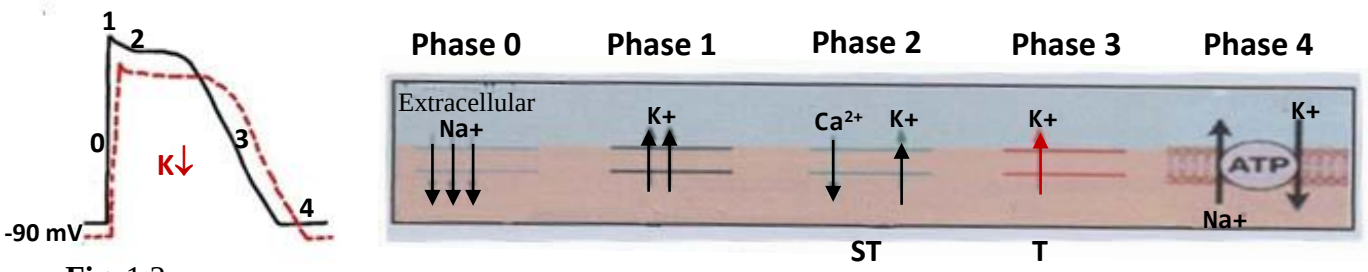

Fig. 1.2

- **Phase 0** : Normally the rapid inward flow of Na^+ during Phase 0 is governed by negative resting potential at about -90 mV

  In hypokalemia

  - Extracellular K^+ drop→ the resting cardiac membrane becomes hyperpolarized (more negative RMP)
  - This increases the threshold for depolarization, potentially it tends to retard its conduction (slow Na^+ inward flow)

- **Phase 1** : Short lived K+ outflow imparts practically no alteration.

- **Phase 2** : Normally the inflow of Ca^{2+} with simultaneous outflow of K^+ occurs during this Plateau phase :
  In hypokalemia there is some retardation in conduction velocity along this phase.

- **Phase 3** : Normally the cessation of Ca^{2+} inflow followed by outflow of K^+
  The conduction velocity is retarded much during this phase (potassium dependent outflow phase). All the layers of myocardium – epicardium , endocardium and mid-myocardium are not repolarized synchronously and smoothly , mid-myocardium with purkinje fibers repolarizing at the end→ repolarization heterogeneity with extended ventricular dispersion → QT prolongation →substrate for torsades de pointes (EAD induced)

- **Phase 4** : Normally there is restoration of repolarized phase to resting polarized phase , brought about mainly by Na^+-K^+ ATPase pump
  Diastolic instability with higher heart rates during this phase may allow 'delayed afterdepolarization' (DAD) to be operated , even in the absence of QT prolongation.

3. EADs and DADs : Dissonant ionic choreography

A. Early Afterdepolarizations (EADs) occur during the repolarization phase 2/3 of the cardiac action potential - the ↑ potential duration with slower heart rates favours EADs.

Explain : Normally at the beginning of the action potential (phase 0) , Na^+ channels open massively → with rapid inward flow of Na^+ , then almost all these channels are inactivated quickly , so Na^+ entry stops. But a small fraction of Na^+ channels are not inactivated fully or reopen briefly during the phase 2-3. This creates a persistent inward Na^+ current **(Late Na^+ current)** , much smaller than the phase 0 spike but somewhat long-lasting.

Late Na^+ current is a key player in trigger mechanism acting upon the reopened L-type Ca^{2+} channels – here the sufficient time is available for the reopening of these channels in the background of prolonged QT interval.

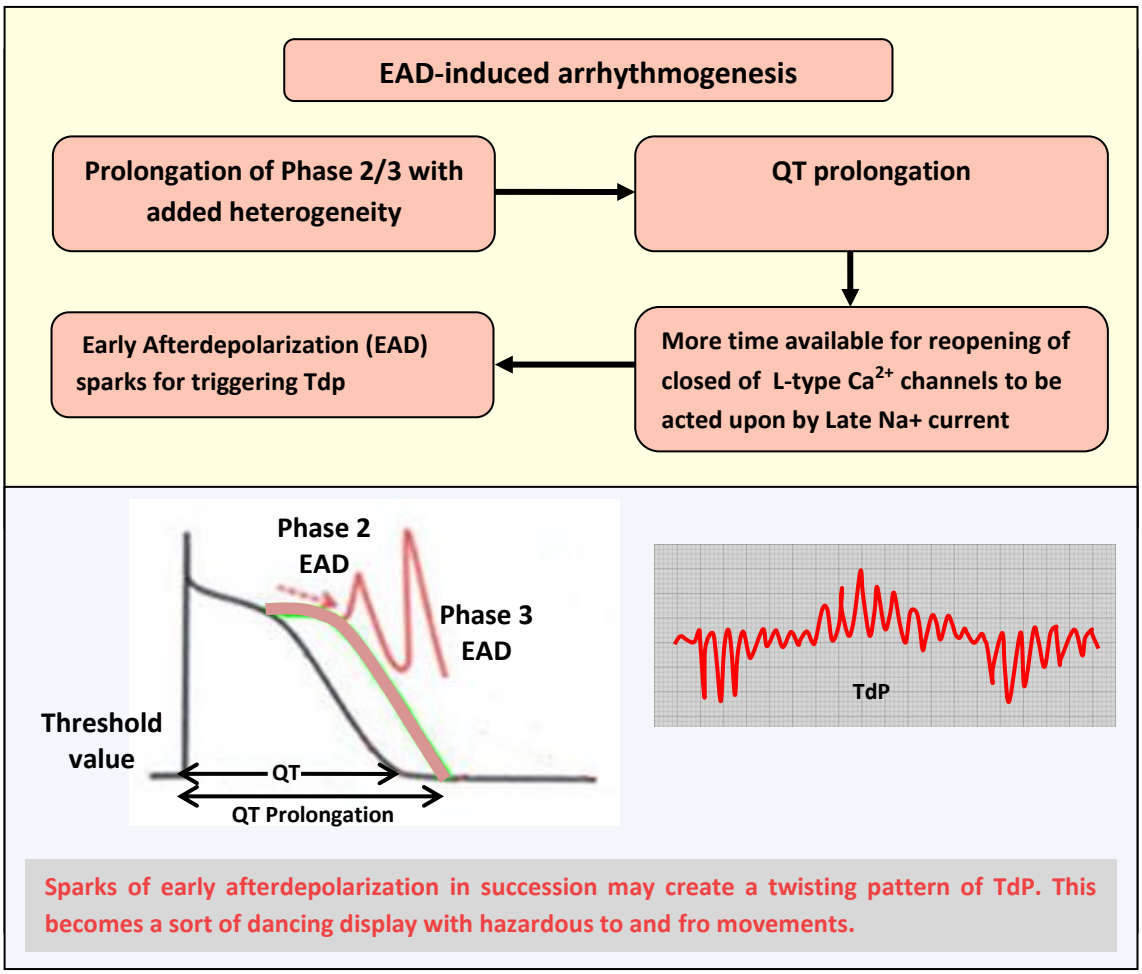

Fig. 1.3

Ionic mechanism of EAD : Certain electrophysiological pearls

- ☐ **Platform** : Prolonged QT mainly due to delayed Phase 3 repolarization with ventricular heterogeneity
- ☐ **Trigger :**
  - Reopening of closed L-type Ca^{2+} channels
  - Acted upon by Late Na^+ current

Why a twisting pattern in TdP ?

All the layers of myocardium – epicardium , endocardium and mid-myocardium are not repolarized synchronously and simultaneously due to the heterogeneity of phase 3 repolarization , as discussed before. This is true to say that there is no synchronous repolarization of these three layers throughout the myocardium , but rather they do repolarize in a haphazard way – depending upon such a situation therein , a non-harmonious and heterogenous situation is created to have a twisting pattern of TdP.

B. Delayed Afterdepolarizations (DADs) occur during the repolarization phase 4 of the cardiac action potential without the pattern of heterogeneity , higher heart rates related events due to rapid pacing allow self perpetuating cascade of DADs sparks as triggering for MVT.

Explain (Na^+ current–transient inward current) :

This seems worthwhile to mention here that an electrical current is always needed to ignite the Ca^{2+} ions to trigger the events of whether EADs or DADs – the sequence of events may differ in both the situations . This Iti current is activated by sudden increase in the concentration of intracellular calcium ions.

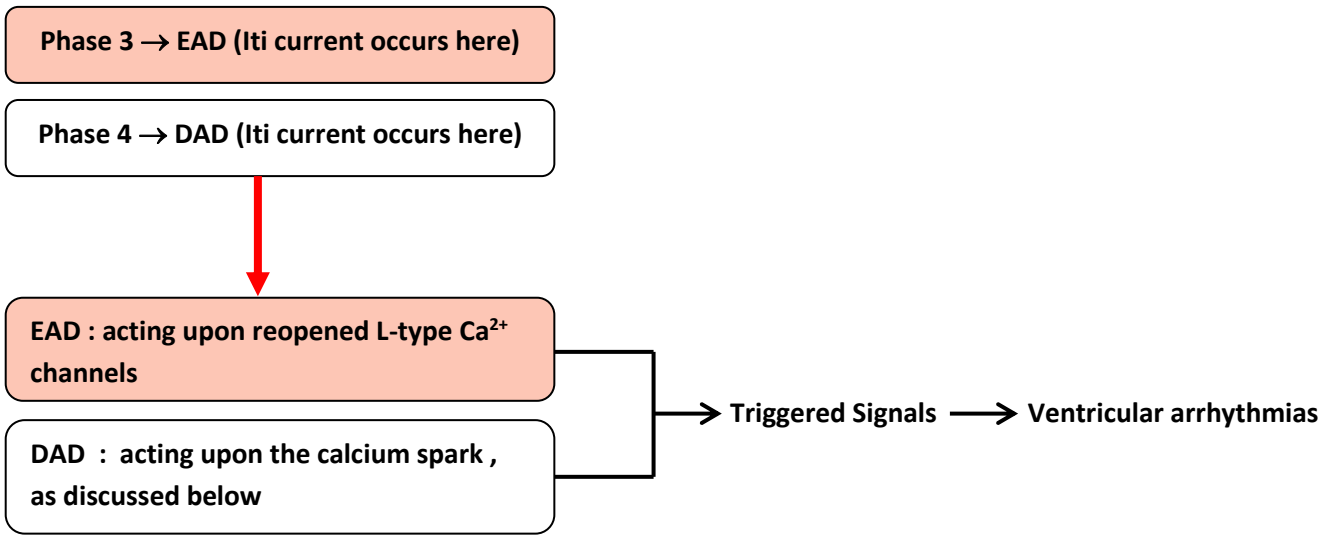

Fig. 1.4

Sequence of events during DAD

- Initially hypokalemia reduces the function of Na^+-K^+ ATPase pump, resulting in intracellular Na^+ accumulation.
- This reduces the driving force for the Na-Ca exchanger (acting as a reverse gear), leading to calcium overload inside myocytes (See fig. 1.5)
- And when Ca^{2+} is extruded via Na-Ca exchanger (this time acting as a forward gear) , it exchanges for Na+ entry , producing a transient inward current (Iti)
- This inward current is the seed for delayed afterdepolarizations.
- DADs predispose to triggered monomorphic VT or fibrillation.

Diagrammatic representation of events during DAD :

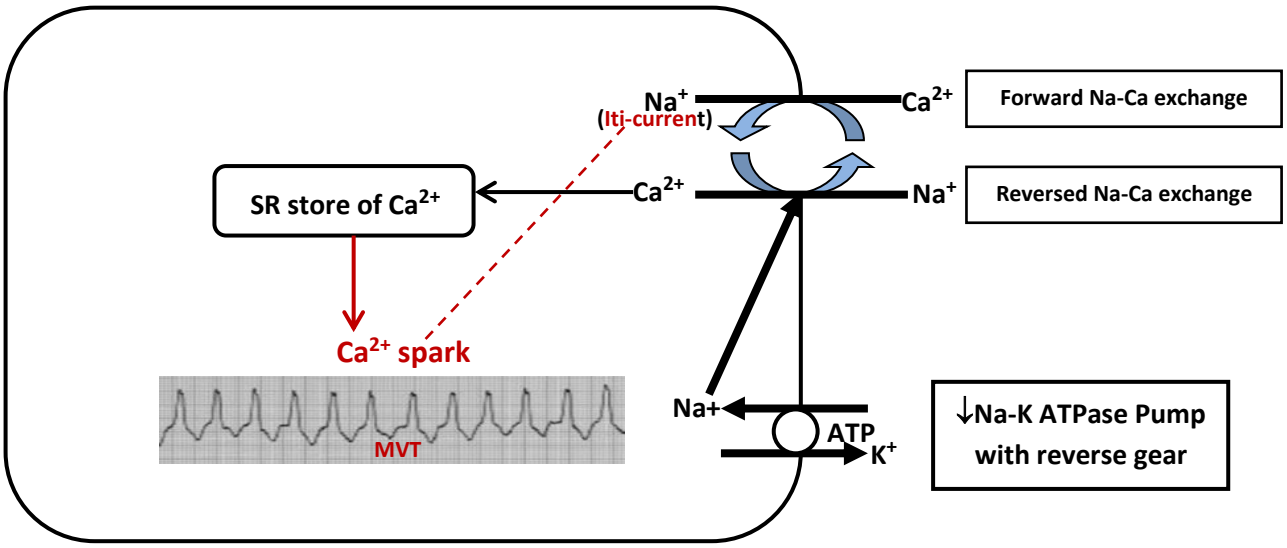

Fig. 1.5

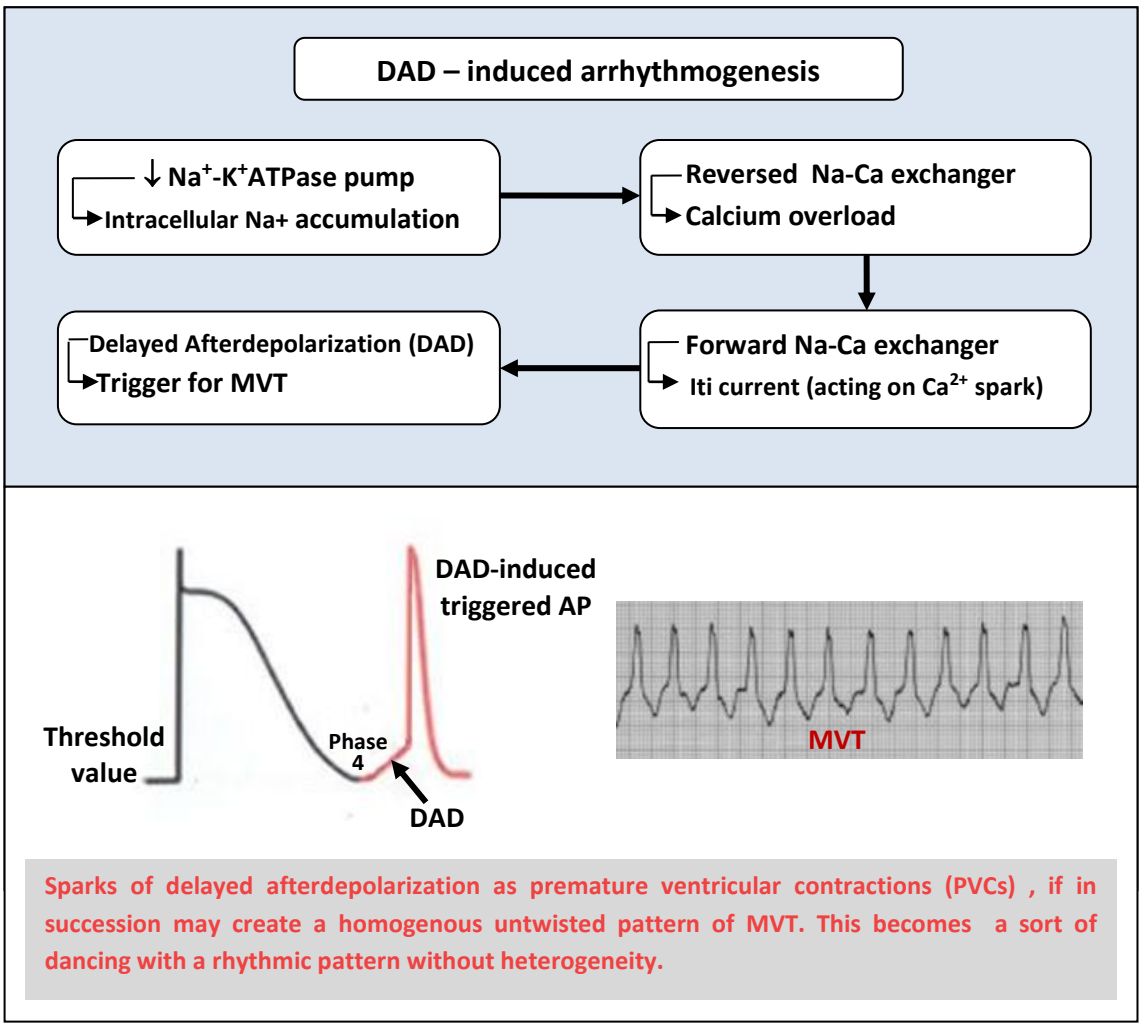

Fig. 1.6

Ionic mechanism of DAD : Certain electrophysiological pearls

- ☐ **Platform** : Na^+-K^+ ATPase impairment with subsequent steps as discussed above.
- ☐ **Trigger :**
  - Iti (transient inward current) acting on Ca^{2+} spark leading to 'Delayed Afterdepolarization'→ Monomorphic VT

4. Arrthythmias associated with EADs/DADs in brief

Here is a brief account of arrhytmias associated with EAD and DAD in hypokalemia

☐ **EAD-related arrhythmias**

- Torsades de pointes (TdP)
- Polymorphic VT
- Triggered VF (when TdP degenerates)

NB : TdP needs a globally prolonged QT with diffuse vertical dispersion , whereas polymorphic VT may set in with the background of regional repolarization heterogeneity.
Atrial myocytes with a short action potential do not create the nidus here for atrial arrhythmias.

☐ **DAD-related arrhythmias**

- Monomorphic VT
- Ventricular bigeminy / Couplets / triplets
- Ventricular fibrillation
- Impact over atrial myocytes (with larger action potential)
  - DADs act as a key substrate for reentry circuits , e.g. , atrial fibrillation and atrial flutter
  - It can also trigger isolated atrial beats as well

5. Some pertinent facts to be kept in mind

- Hypomagnesaemia is often associated with hypokalemia, which may increase the risk of malignant ventricular arrhythmias
  And therefore , it is advisable to check both potassium and magnesium levels especially in any patient with severe hypokalemia.
- Replace potassium to ≥ 4.0 mmol/L and magnesium to within normal limit to stabilise the myocardium and protect against arrhythmias – this is standard practice in most CCUs and ICUs.
- Hypokalemia should be corrected promptly, especially in patients with:

Heart failure Digitalis therapy Structural heart disease Prior AF	These are more prone to develop malignant arrhythmias

- **Early ECG changes (T wave flattening) are a warning; late changes (U waves, QT prolongation, arrhythmias) can be life-threatening.**
  Normally all the layers of myocardium – epicardium , endocardium and mid-myocardium are repolarized simultaneously with a disciplined harmony giving rise to a single wave – the 'T'. U-wave represents delayed repolarization of the purkinje system and can be seen in healthy individuals , especially with bradycardia (slow heart rate) – this U-wave follows the T-wave. With the increasing gravity of hypokalemia , there is a progressive inverse relationship in between T and U waves.

Normally buried U wave becomes unmasked as T-wave amplitude drops. More severe is the degree of hypokalemia , there is more decreased amplitude of T-wave with increased amplitude of corresponding U-wave – this indicates the associated prolongation of repolarization phase 3 with heterogeneity.

6. Take Home Message

- ☐ Potassium deficiency is said to be a master of arrhythmic dissonance , associated with two patterns of afterdepolarization :
  - **Early afterdepolarization (EAD)** : involving 2/3 phase of repolarization (QT prolonation with heterogenetiy) → Torsades de pointes
  - **Delayed afterdepolarization (DAD)** : involving phase 4 of repolarization with no heterogeneity → usually monomorphic VT

- ☐ The sequence of events may differ in both the types as enumerated above but the end result remains the same – the interaction between the calcium flow with Iti current (transient inward current) leading to a cascade of arrhythmia.
  This electrical current is always needed to ignite the Ca^{2+} ions to trigger events of whether EADs or DADs. This current comes into play when sudden increase in the concentration of intracellular calcium ions occurs.

- ☐ **EAD-induced arrhythmogenesis**
  Prolongation of Phase 2/3 with added heterogeneity → QT prolongation → More time available for reopening of closed of L-type Ca^{2+} channels to be acted upon by Late Na^{+} current (equivalent to Iti current) → Early Afterdepolarization (EAD) sparks for triggering Tdp.
  Tdp needs a globally prolonged QT with diffuse vertical dispersion , whereas polymorphic VT may set in with the background of regional repolarization heterogeneity.

- ☐ **DAD-induced arrhythmogenesis**
  Simplified Statement :
  In hypokalemia, impairment of the Na^{+}–K^{+} ATPase during phase 4 causes intracellular Na^{+} accumulation. With such ionic insult, the Na^{+}–Ca^{2+} exchanger is forced into a 'two-way gear': first allowing excess Ca^{2+} entry (with Na^{+} exit) and then reversing to extrude Ca^{2+} (with Na^{+} re-entry). This oscillatory pendulum-like run, though compensatory, destabilizes the myocyte and so creates the triggering events of delayed afterdepolarizations (DADs).
  Isolated ventricular bigemini , couplets or even triplets may occur. There may also be impact of this non-harmonious electrical activity over atrial myocytes giving rise to different atrial arrhythmias.

- ☐ Always to look at a running display of hypokalemia changes on ECG. Early ECG changes (T-wave flattening) are a warning ; late changes (U-waves , QT prolonation , arrhytmias) can be life-threatening.

- Hypomagnesaemia is often associated with hypokalemia , which may increase the risk of malignant ventricular arrhythmia. Therefore , it is considered reasonable to replace potassium to ≥ 4.0 mmol/L and magnesium to be in normal limits to stabilize the myocardium and this protects against arrhythmias – this is standard practice in most CCUs and ICUs .
- The conditions such as heart failure , digitalis therapy , structural heart disease , the history of prior AF predispose the individuals more to develop malignant arrythmias . That's why , hypokalemia should be corrected promptly with such group of patients.

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ECG CHANGES IN HYPERCALCEMIA REFLECTS ITS IMPACT ON CARDIAC ACTION POTENIAL

ECG

ECG CHANGES IN HYPERCALCEMIA REFLECT ITS IMPACT ON CARDIAC ACTION POTENTIAL

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OUTLINE

ECG Changes in Hypeprcalcemia reflect its impact on cardiac action potential

A Narrative Review

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Homeostasis, in general, is the main fundamental driving force for all living organisms to exist. The maintenance of stable internal environment is mainly based on the ionic balancing , a crucial demand for optimal functioning and survival of life. Maintaining the right balance at the ionic level is very much essential for all cellular processes , including the induction of cardiac action potential.

Calcium is not just a structural element of bone , but also the important orchestral player of cardiac action potential – concerned with contraction , conduction and maintenance of cardiac rhythm.

- ☐ **Calcium influx with potassium efflux during the plateau phase of the cardiac action potential maintains the ST segment on ECG and ensures coordinated myocardial contraction.**
- ☐ **Hypercalcemia inducts more calcium influx during the plateau phase resulting in ST/QT shortening as the primary event and the subsequent potassium efflux in other repolarization phases is the adaptive attempt by the myocardial membrane to reclaim its electrophysiological stability.**

Understanding these two mechanisms is essential for interpreting the ECG changes associated with hypercalcemia

1. Introduction (Keypoints)

- Ionic alterations during the cardiac action potential are well-recognized consequences of hypercalcemia. By profoundly influencing cardiac electrical activity, hypercalcemia produces characteristic changes on the ECG. As a non-invasive, rapid, and highly informative tool, the ECG plays a crucial role in detecting these abnormalities, thereby enhancing diagnostic accuracy and contributing to improved patient outcomes.
- To appreciate the ECG changes in hypercalcemia one may equate plateau phase (phase 2) of the cardiac action potential as a sliding box. Excessive extracellular calcium ions shut the sliding box earlier by causing quicker inactivation of L-type calcium channels , abbreviating the plateau (ST-segment) , the result is a shortened QT interval.
- Recognition of such earlier electrical changes in hypercalcemia is of paramount clinical significance. Such patients may be asymptomatic or present themselves with vague complaints. To keep in mind that subtle ECG alterations may be the earliest indicators of hypercalcemia. In addition , the hypercalcemia can coexist with underlying cardiac disease, potentiating the onset of arrhythmia with adverse outcomes.

- Normal serum calcium range : 8.5-10.5 mg/dL (2.1-2.6 mmol/L)
  Ionized calcium is more physiologically relevant than total calcium in acute ECG changes. About 40-50% of total serum calcium is bound to albumin. Only the free (ionized calcium) is biologically active , directly interacting on the ionic channels. Arterial blood gas analyzer can provide ionized calcium measurement quickly and instantly.
  (Normal range = 1.1-1.32 mmol/L)
- **This article reviews the characteristic ECG changes in hypercalcemia , correlating these with cardiac action potential. This makes the subject more understandable.**

2. Impact of hypercalcemia on cardiac action potential

The phases of normal cardiac action potential are illustrated by the following sketch :

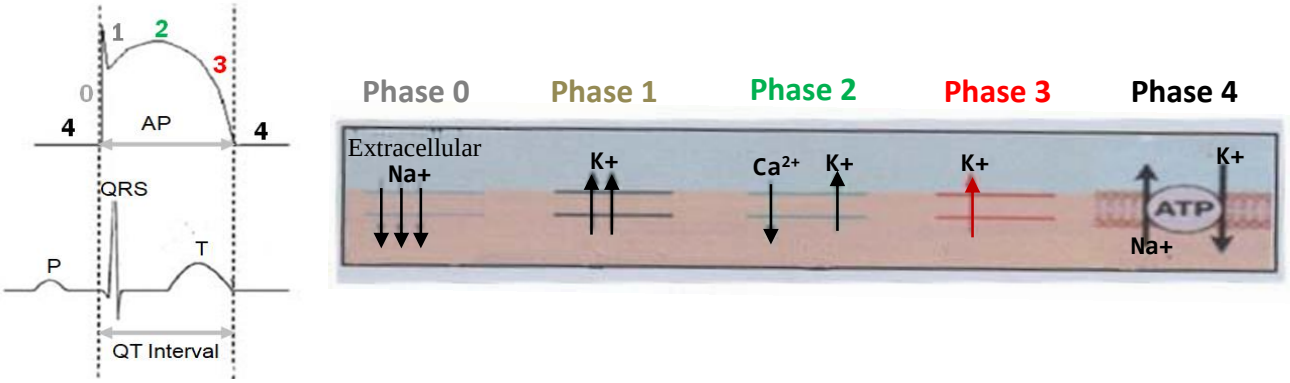


Fig. 1.1

- ☐ The rapid inward flow of Na^+ during **Phase 0** , governed by negative resting potential at about -90 mV
- ☐ A brief outward flow of K^+ during **Phase 1**
- ☐ The inflow of Ca^{2+} with simultaneous outflow of K^+ during **Phase 2** (Plateau Phase)
- ☐ Cessation of Ca^{2+} inflow followed by outflow of K^+ during **Phase 3**

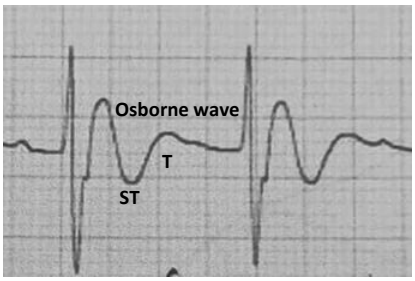
And at the end there is restoration of resting phase (**Phase 4**) brought about mostly by Na^+-K^+ ATPase pump.

It is worth mentioning at the outset that in hypercalcemia elevated calcium serum level accelerates the closure of the L-type calcium channels, effectively shortening the plateau phase (phase 2) of the cardiac action potential. Due to the adapted repolarization kinetics there is more potassium efflux during phase 3 resulting in changes in T-wave configuration. But in more profound cases there is more exaggerated J-point , witnessed as J-wave (Osborne wave) at the junction in between QRS and abbreviated ST segment (illustrated with fig.1.2 on the next page)

The following considerations are important when analyzing cardiac action potentials in relation to hypercalcemia :

- The shortening of Phase 2 is due to increased extracellular calcium which leads to an abrupt closure of the plateau. However, this shortened duration does not permit full K^+ efflux, which is a crucial step for proper repolarization. That's why , a shortened ST segment (phase 2) is lacking the graceful plateau of action potential.
- In response to further increased extracellular calcium concentration phase 3 may be prolonged , allowing extended time for potassium to exit out of the myocardial cells. This may manifest as a broad-based delayed terminal T-wave or biphasic T-wave due to heterogeneity in epicardium vs endocardium. At times the abrupt efflux of potassium may lead to tall , narrow and somewhat peaked T-wave , with very much abbreviated ST segment.
- In profound hypercalcemia , calcium exerts its impact not only by shortening the plateau (phase 2) , but rather also advocating premature potassium efflux even during Phase 1 – a phenomenon occasionally manifested on the ECG as Osborne-like wave.
- Phase 4 is also exposed earlier facilitating the emergence of delayed afterdepolarizations (DADs) — abnormal depolarizations occurring after full repolarization, often driven by calcium overload within the sarcoplasmic reticulum. These DADs, if they reach threshold, can trigger premature ventricular contractions or full-blown ventricular tachyarrhythmias.

Thus, the ECG changes in hypercalcaemia, while seem to be benign, have a proarrhythmic potential in iteself. The QT shortening with early onset of Phase 4 prepares a substrate primed for delayed triggered activity, particularly in the ventricles — a phenomenon that creates the need for heightened vigilance in hypercalcaemic states, even when overt symptoms are not present.



- Abbreviated ST segment
- Superimposed Osborne wave (at the junction between QRS and abbreviated ST segment)
- Widening of T-wave

Fig. 1.2 **ECG changes in profound hypercalcemia**

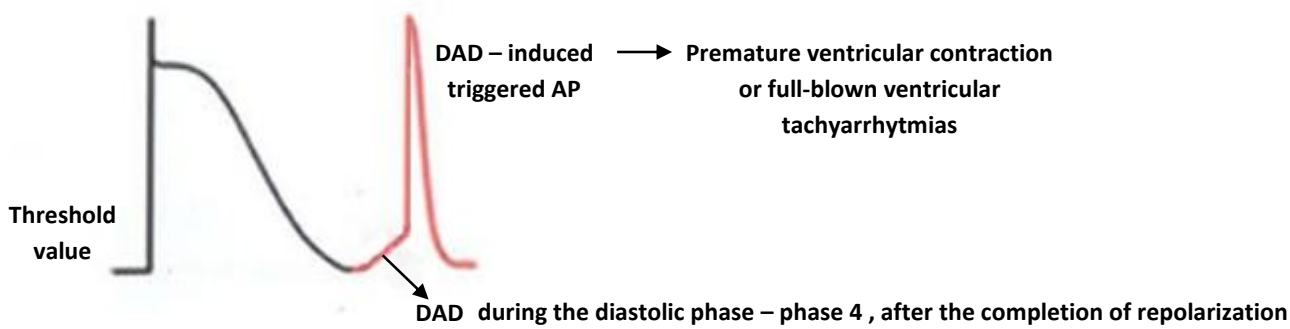


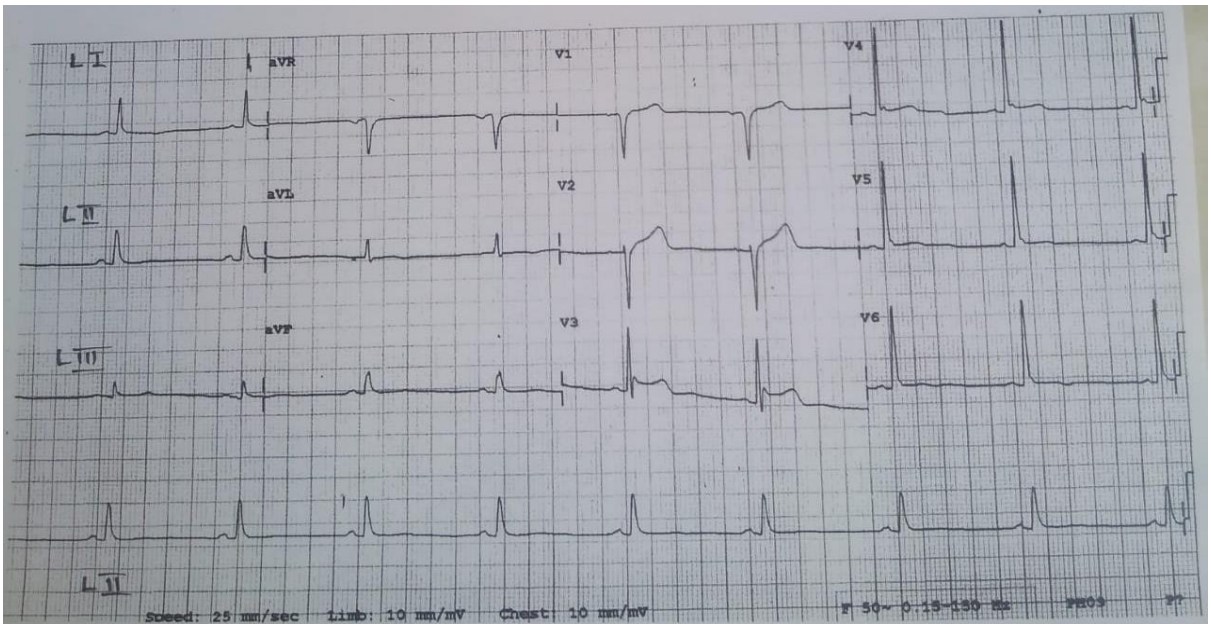
Fig. 1.3 **Induction of Delayed afterdepolarization (DAD)**

3. The concerend ECG changes (summary)

- **Abbreviation of ST segment → Short QT interval (first hallmark)**
- **T-wave changes→ widened or narrow tall T or at times biphasic T (reflect altered repolarization)**
- **Osbrone (J) wave at J point – marker of severe hypercalcaemia and arrhythmic risk**
- **DAD-induced triggered AP → Premature ventricular contraction or full-blown ventricular tachyarrhythmias**

4. An interesting case

74 years old male, a chronic smoker was evaluated for Polydypsia, Polyuria, Fatigue and Pain abdomen. Physical examination was unremarkable. X-ray Chest PA normal. Blood Sugar, Urea, Serum Creatinine , Na+, K+, Cl- and HCO3 - were all normal but serum calcium 12 mg/dL.



Source : Prof. Dr. A.N. Rai , Former Prof. & Head of Medicine and Principal ANMMCH , Gaya Bihar ; Chairman AIMS, Gaya

ECG findings :

I. Shortening of QT interval (0.34s) with a virtual absence of ST segment which is hardly discernible.
II. QRS blends with widened T (see over lead V3) – as pseudo myocardial infarction (in true STEMI , elevation usually in context with involved vascular territory with reciprocal changes)
III. There is widening of T wave

Comments : These ECG findings are consistent with Hypercalcemia.

5. Take Home Message

- ☐ A short QT is the ECG's whisper of hypercalcemia – don't overlook it ; it can herald dangerous ventricular arrhythmias if calcium climbs too high.
- ☐ Excessive extracelluar calcium ions inactivate L-type calcium channels , abbreviating the plateau (ST segment) , the result is a shortened QT interval
- ☐ Altered kinetics of repolarization during phase 3 : potassium efflux dominates here to restore resting cardiac action potential towards its maximum propensity.
- ☐ Osborne (J) wave at J-point : marker of severe hypercalcemia and arrhythmic risk (premature ventricular contraction or full-blown ventricular tachyarrhytmias)

In nutshell , short QT comes first ; alteration in T-wave configuration is the next and osborne wave is the last.

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WHEN CALCIUM DROPS, THE NATURAL INTELLIGENCE OF CARDIAC ACTION POTENTIAL COMES INTO PLAY

WHEN CALCIUM DROPS , THE NATURAL IONIC INTELLIGENCE OF CARDIAC ACTION POTENTIAL COMES INTO PLAY

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When calcium drops , the natural ionic intelligence of cardiac action potential comes into play

A Narrative Review

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The ECG is more than a tracing; it is the soul-script of the 'Heart', with each component reflecting its own ionic truth. The delicate balance of these ions is the essential prerequisite for life itself, and its understanding demands intelligent integration. So brilliantly is this ionic choreography woven across the cardiac membrane that one is compelled to look at its natural intelligence, a sequencing both precise and purposeful.

This would be true to say that in hypocalcemia there is altered expression in cardiac action potential , usually confined to phase 2 .

- ☐ **In hypocalcemia the plateau phase (ST segment) is prolonged due to the more time taken for the lesser quantum of calcium to enter from extracellular to intracellular compartment.**
- ☐ **The extended ST segment lengthwise is responsible for the prolongation of QT interval. Hypocacemia does not touch here the phase 3 , therefore there is no alteration in T-wave morphogenesis and no added repolarization heterogeneity. The lack of repolarization heterogeneity makes Torsades de Pointes unlikely.**

The heart does not merely beat ; it writes its own autobiography whenever there exists electrolyte imbalance.

1. Introduction (keypoints)

- Ionic choreography is the inner voice of heart, reflected as cardiac action potential with its intervals as sequential disciplined pauses. When calcium drops, the disciplined ST run of cardiac action potential is showing somewhat breakup in the sense that it withdraws its steadying impact upon the plateau phase (ST segment).
- In hypocalcemia the lengthening of the QT interval reflects uniform prolongation of the plateau phase (phase 2) of the action potential due to delayed closure of calcium channels..
- This ionic imbalance does not touch the phase 3 , there is no added repoarization heterogeneity–all the layers of myocardium (epicaridum , endocardium and mid-myocrdium) are repolarized smoothly. It is worthwhile to say that potassium-mediated repolarization remains relatively intact , and so preserving T-wave integrity. T-wave configuration is usually normal in width and amplitude.

- There is the rarity of Torsades de Pointes in hypocalcemia – a kind of natural ionic intelligence which seems to be governed by normal coordinated repolarization of phase 3 without repolarization heterogeneity.
- The purpose of writing this article on hypocalcemia aims at showing – how ST segment lengthening causes the prolongation of QT interval to allow subquantum of calcium ions to enter slowly from extracelluar to intraellular compartment and despite this delay , the potassium – mediated repolarization phase 3 proceeds in a relatively uniform and synchronous manner across the myocardium.
  This phenomenon illustrates a remarkable natural safeguard within cardiac electrophysiology. When calcium availability is reduced , the **"ionic intelligence"** of the action potential relies on the stability of potassium-driven repolarization to preserve electrical synchrony. In this way the cardiac action potential demonstrates natural intelligence , maintaining rhythmical integrity even in the face of electrolyte imbalance.

2. Impact of hypocalcemia on cardiac action potential : It writes its own autobiography

Cardiac depolarization is the spark tuning the myocardium to be electrically active. Repolarization is its graceful reversal – a journey towards restoring ionic balance. Together , all these phases embody the natural ionic intelligence endowed with cardiac action potential : to rise ....to rest in succession.

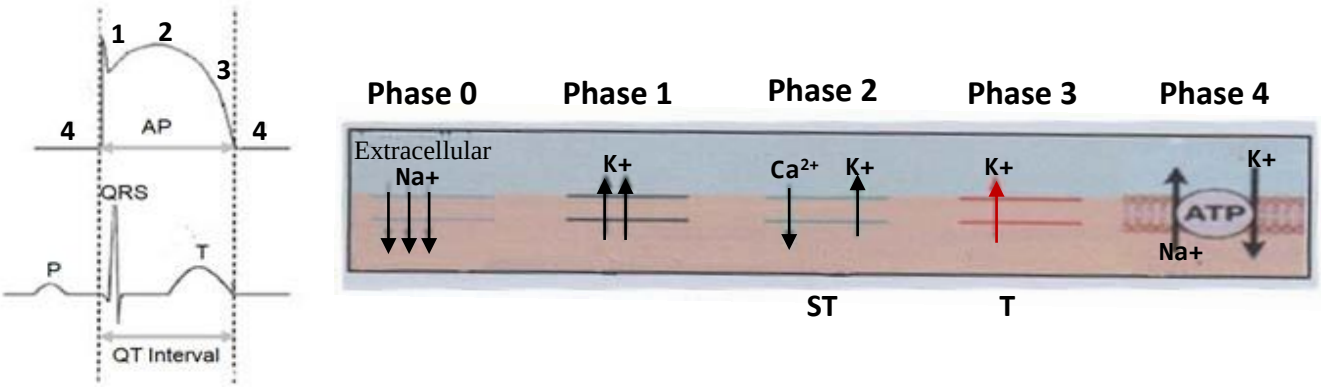


Fig. 1.1

The phasewise display of ionic expression in hypocalcemia is illustrated as below :

- **Phase 0** : The rapid inward flow of Na^+ during Phase 0 is governed by negative resting potential at about -90 mV : **No any alteration**
- **Phase 1** : A brief outward flow of K^+: **No any alteration**
- **Phase 2** : The inflow of calcium ions balances outward potassium currents , keeping the plateau steady and concise.
  Hypocalcemia stretches the ST segment by delaying the closing of calcium channels.
- **Phase 3** : Cessation of Ca^{2+} inflow followed by outflow of K^+**.**

There is no touch of phase 3 in hypocalcemia with no resultant heterogeneity. The absence of heterogeneity does not disturb the normal configuration of T-wave.

- **Phase 4** : And at the end there is restoration of resting phase brought about mostly by Na^+-K^+ ATPase pump

3. Antiarrrhythmic implication in hypocalcemia

The following considerations are essential to be kept in mind in this context :

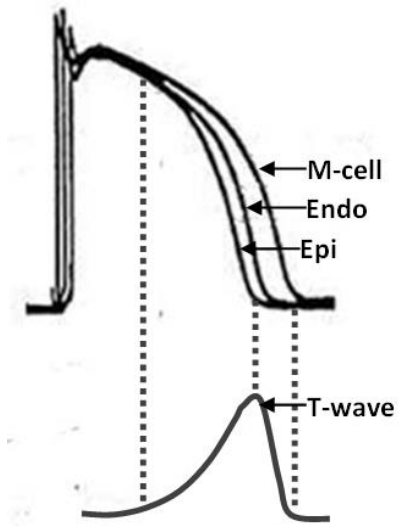
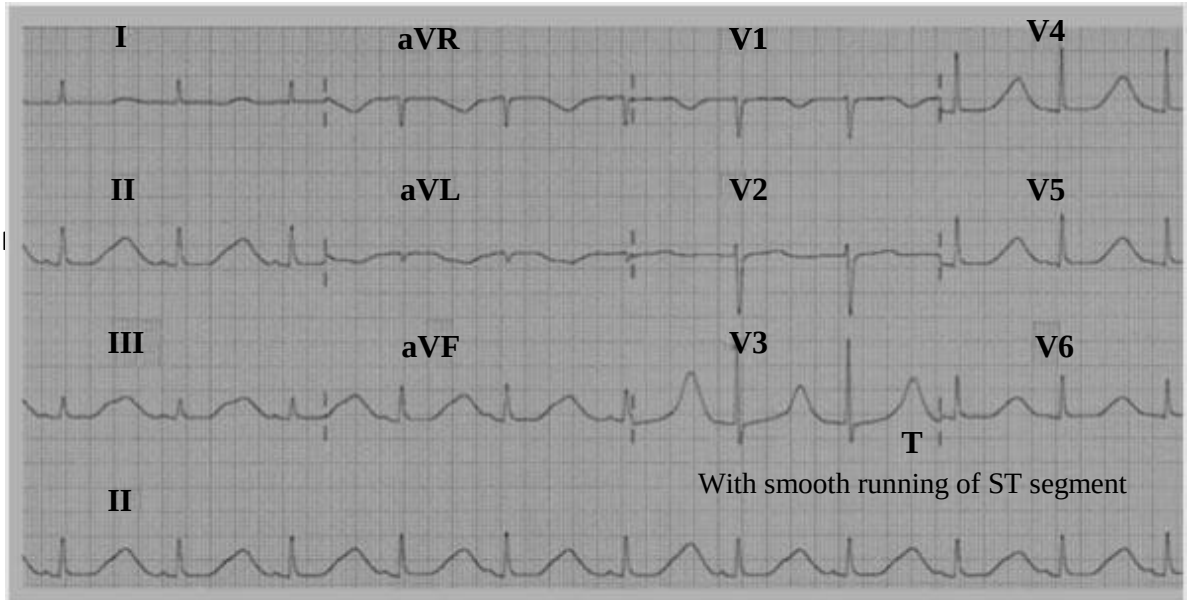


Fig. 1.2

- All the layers of myocardium (epicardium, endocardium and mid-myocardium) are repolarized synchronously and smoothly → lack of repolarization heterogeneity → It does not create any substrate for re-entry in Torsades de Pointes.
- In fact , the smooth run of plateau phase is having a stablizing antiarrhythmic effect because under circumstances , it gets extended without concomitant dispersion of repolarization.
- This contrasts sharply with hypokalemia or drug induced long QT syndromes , where heterogenous prolongation of phase 3 possesses arrhythmogenic potential.

4. An interesting case

45 years Female presented to the emergency department with recurrent seizures since 1 day. She was diagnosed with epilepsy 6 years back and was put on sodium valproate 300 mg bd. No proper workup for seizure was done. Her ECG shows as follows :



Source : Prof. Dr. A.N. Rai , Former Prof. & Head of Medicine and Prinicipal ANMMCH , Gaya Bihar ; Chairman AIMS, Gaya.

ECG findings :

This ECG reveals marked QT prolongation with T-wave extending beyond the mid of corresponding RR interval , with smooth running ST segment. These changes point directly toward prolonged repolarization –consistent with hypocalcemia.

In view of strongly suspected case of hypocalcemia on ECG , a search for the metabolic causes of seizure was done :

Biochemical investigations done :

- Blood sugar , blood urea , serum creatinine : Normal
- Serum calcium 7.5mg/dl (normal range 8.5-10.5 mg/dl)
- Serum albumin 4.5gm/dl (3.4-5.4 gm/dl)
- Serum Phosphate 8.5mg/dl (Normal range 3.4 to 4.5 mg/dl)
- Vitamin D 40 ng/ml
- Serum Mg 1.8mg/ml (Normal range 1.7-2.3 mg/dl)
- Serum PTH 3pg/ml (Normal value in adult : 10-69 pg/ml)

CT Brain

Bilateral basal ganglia calcification – a classical radiological marker of **chronic hypoparathyroidism with hypocalcemia**. It ties the whole story together – seizures , ECG , biochemical and imaging.

Discussion :

- This is indeed an interesting clinical case – it ties together the neurogenic manifestations (seizures) with the electrocardiographic imprint of QT prolongation , confirmed biochemically by low serum calcium (hypocalcemia) in the background of hypoparathyroidism.
- In the brain hypocalcemia diminishes the threshold of neuronal membranes by reducing sodium channels thresholds→ Sodium channels get activated more easily → Neurons fire repetitively predisposing to the recurrent cycles of seizures.
- When calcium drops , the heart narrates its own story on ECG and at times the brain sparks with seizures – the expression of the same ionic choreography.

5. Take Home Message

☐ Impact over cardiac action potential

- Reduced extracellular calcium →reduced inward calcium current → prolonged phase 2 (plateau) of the cardiac action potential
- Reporization (phase 3 , K^+-driven) remains intact and synchronous.

☐ Accordingly ECG changes

- QT prolongation due to ST segment lengthening ‘
- Smooth , horizontal ST prolongation (no sagging /bowing)

- T wave : usually normal in amplitude /shape (may flatten slightly , but not widened or inverted as in hypokalemia)

☐ Arrhythmia risk

- No significant dispersion of repolarization (homogenous run across epicardium, endocardium , and mid-myocardium) . Therefore , Torsades de Pointes is the rarity.
- QT prolongation here is relatively antiarrhythmic in nature

☐ Brain vs Heart paradox

- Heart (cardiowisdom) : prolong plateau phase without dispersion → protective natural ionic intelligence
- Brain (Neurostupidity) : lowers sodium neuro channels threshold→Neuronal hyperexcitability→seizures.

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CARDIAC ACTION PTOETNIAL AND ELECTROLYTE DISTRURBACNES : As JOURENY INTO IONIC INTELLIGENCE

CARDIAC ACTION POTENTIAL AND ELECTROLYTE DISTURBANCES : A JOURNEY INTO IONIC INTELLIGENCE

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OUTLINE

Introduction
Understanding how the cardiac action potential normally functions and how it becomes disorganized by ionic disturbances is essential to know.

Electrophysiology of cardiac action potential under normal condition
- Fast Action Potential
- Slow Action Potential

Ionic choreography perturbances dependent on resting membrane potential (RMP) : destablished or stablished

FUNDAMENTAL RULE
Electrolyte disturbances first determine whether the RMP (resting membrane potential , phase 0) is destablished (mainly K^+ impact) or not. Then the further journey in relation to ECG changes depends on which action potential phase 2 or 3 is primarily involved by the particular electrolyte ionic handling. Potassium disturbances affect phase 3 (potassium dependent) and calcium disturbances affect phase 2 (calcium dependent).

Hyperkalemia and the corresponding ECG changes

Hypokalemia and the corresponding ECG changes

Hypercalcaemia and the corresponding ECG changes

Hypocalcaemia and the corresponding ECG changes

Take Home Message

References

Cardiac Action Potential and Electrolyte Disturbances : A Journey into ionic intelligence

A Narrative Review

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Intelligence is not measured by how much the brain knows, but in what way it tackles the situation to let the life run smoothly. An efficient intelligent approach dealing with the alarming situations makes the life to shine like a rainbow and one may exclaim with joy - WAH!.

The way the cardiac action potential writes the story of different electrolyte disturbances with reorientation of ionic choreography on its curve , one is amazed to see its intrinsic intelligence. There are two phases of cardiac action potential : depolarization and repolarization.

- ☐ **Depolarization primes the heart to be active for its ownward journey and it is dependent upon the availability of fast acting Na^+ channels (phase 0).**
- ☐ **The repolarization phase is concerned mainly with cardiac contractibility (plateau phase 2) and to bring the cardiac action potential again to its resting phase , passing through phases 3 and 4.**

The intelligent display of cardiac action potential with different electrolyte disturbances paves the way of understanding – how the situation is tackled as per ionic perturbances.

1. Introduction (Keypoints)

- Ionic chorography is the inner voice of heart , reflected as cardiac action potential with its different phases as sequential pauses. There are two main phases of cardiac action potential : depolarization and repolarization.
- The rhythmic beating of the human heart is sustained to life by the disciplined ionic display across the cardiac cellular membrane.
- Understanding how the cardiac action potential normally functions and how it becomes disorganized by ionic disturbances is essential to know. This is worthwhile to mention here that such disturbances in ionic choreography may be reflected on ECG as the earliest indicators of its coherence breaking.
- In nutshell , it would be wiser to keep in memory the concerned fundamental rule : **Electrolyte disturbances first determine whether the RMP (resting membrane potential , phase 0) is destablished (mainly K^+ impact) or not. Then the further journey in relation to ECG changes depends on which action potential phase 2 or 3 is primarily involved by the particular electrolyte ionic handling. Potassium disturbances affect phase 3 (potassium dependent) and calcium disturbances affect phase 2 (calcium dependent).**

2. Electrophysiology of cardiac action potential under normal condition

The Cardiac Action Potential is a series of brief changes in voltage across the cardiac cell membrane, brought about by fluxes of ions through ion channels.

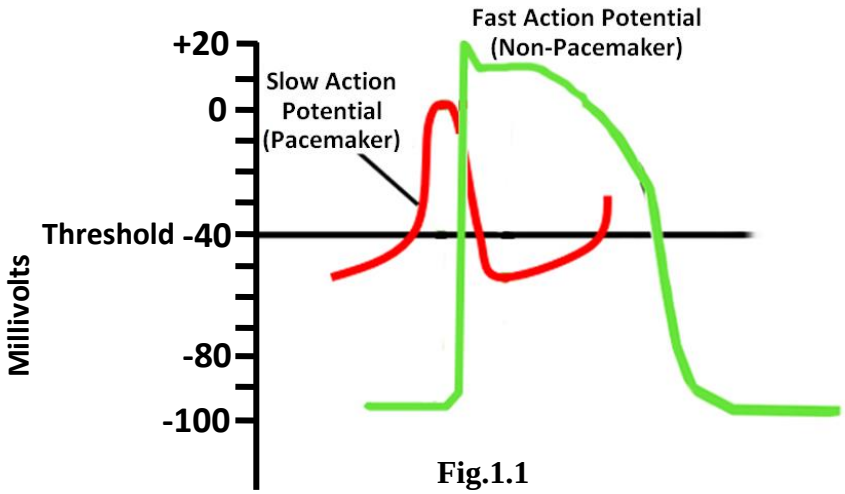


Fig.1.1

There are two sets of action potential :

- **Fast Action Potential** : This potential is seen in contractile cells (atria and ventricles) that are backed up by rapid depolarization due to the opening of fast **Na^+**channels. Since HIS bundle - purkinje system is connected to the ventricular myocytes , it also shares the fast action potential to allow the impulses to pass rapidly through it.

- **Slow Action Potential** : The SA and AV nodes , being rich in slow **Ca^{2+}** channels cause different ion channel kinetics. The initial potential of this nodal system is less negative compared to the RMP of the contractile units of myocytes. This lesser negativity allows the action potential to be automatically activated in a slowly rising semi-curve manner (SA node activation automatically) → AV node via atrial tissue with transient delay – 0.10 sec therein to facilitate the atrial empty into the ventricles.

The cardiac action potential gets operated through SA node with the spread of its impulses through intermediate steps to the ventricular myocytes, as stated below :

SA node → passing through atrial tissue → AV nodal delay (0.10 sec to empty the atrial contents into the ventricles) → HIS bundle-purkinje system →ventricular myocytes (in a well synchronized way).

It would be quite reasonable to mention first some facts related to slow action potential :

- The spontaneous depolarization of the slow pacemaker potential during its phase 4 imparts the SA node its auto-rhythmicity through Na^+ + K^+ channel , mainly Na^+ (through funny current – details here is not mentioned).
- The depolarization of SA/AV node is governed by increase in Ca^{++} conduction and the repolarization is caused by increase in K+ conductance
  (the details of this slow action potential is illustrated on the next page)

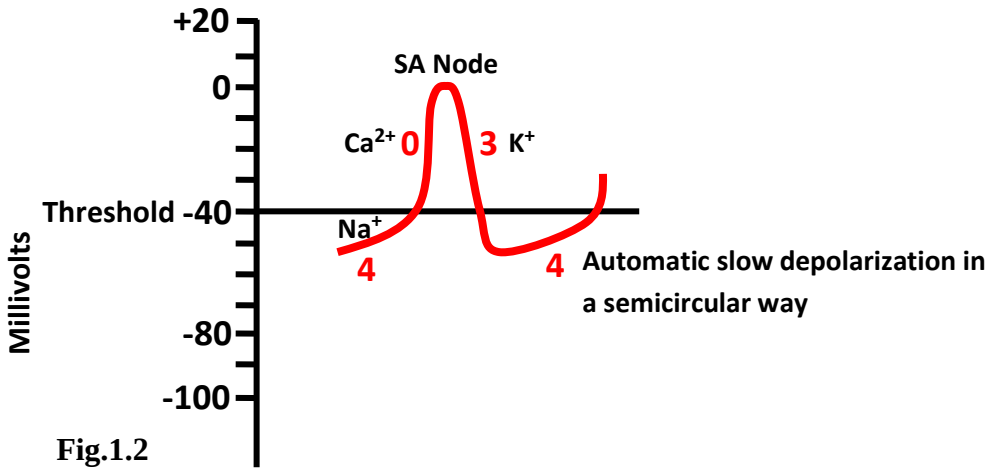


Fig.1.2

The next important consideration is to understand relevant steps in relation to fast action potential.

The phases of normal cardiac action potential are illustrated by the following sketch :

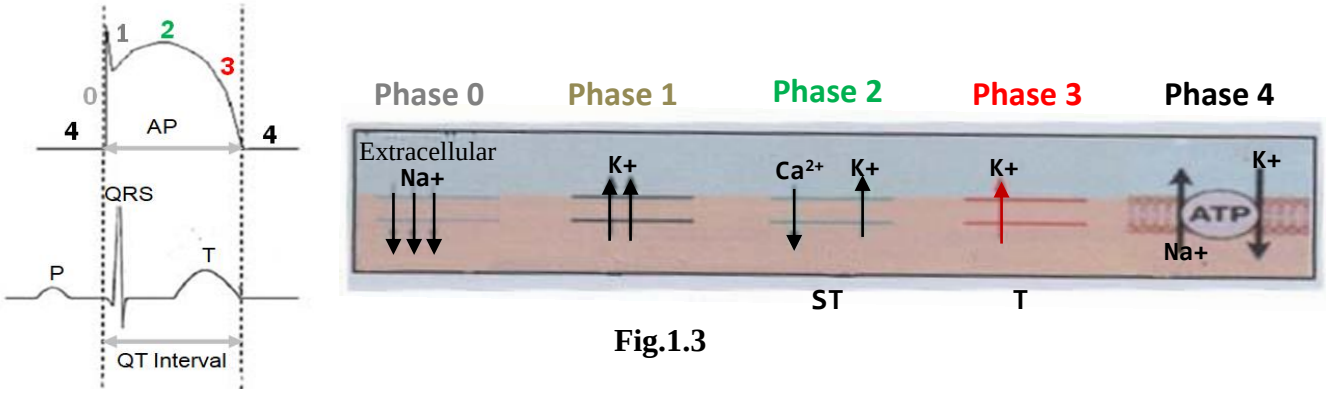


Fig.1.3

- ☐ The rapid inward flow of Na^+ during **Phase 0** , governed by negative resting potential at about -90 mV
- ☐ A brief outward flow of K^+ during **Phase 1**
- ☐ The inflow of Ca^{2+} with simultaneous outflow of K^+ during **Phase 2** (Plateau Phase) – concerned with ventricular contraction.
- ☐ Cessation of Ca^{2+} inflow followed by outflow of K^+ during **Phase 3**

And at the end there is restoration of resting phase (**Phase 4**) brought about mostly by Na^+-K^+ ATPase pump.

NB :

SA and AV Nodes operate at negative action potential (-60 to -70) while fast action potential curve operates through further more negative potential (-80 to -90). Atrial myocytes - HIS bundle-purkinje system – Ventricular myocytes complex constitutes the group of Fast Action potential.

3. Ionic choreography perturbances dependent on resting membrane potential (RMP) : destabilised or stablished

- **Destablished RMP**
  With potassium ionic disturbances , potassium is the main determinant of RMP. Better to say it is the presence of K^+ions in extracellular compartment , which determines the status of RMP polarity. This RMP polarity is destablished in either hyperkalemia or hypokalemia.
  - **Hyperkalemia** : RMP becomes less negative (depolarized) → Na+ channels partially inactivated → slowed conduction (phase 0) with accelerated phase 3.
  - **Hypokalemia** : RMP becomes more negative (hyperpolarized) → conduction disturbed a bit , but repolarization delayed (phase 3).
- **Stablished RMP**
  Calcium does not significantly change the polarity of RMP
  - **Hypercalcaemia** : Shortens plateau phase (early inactivation of L-type calcium channels). In addition with severe hypercalcemia adaptive K^+ efflux may lead to heterogeneous prolongation of phase 3 → arrhythmias.
  - **Hypocalcaemia** : Prolongs plateau phase (sustained Ca^{++} influx)

4. Hyperkalemia and the corresponding ECG changes

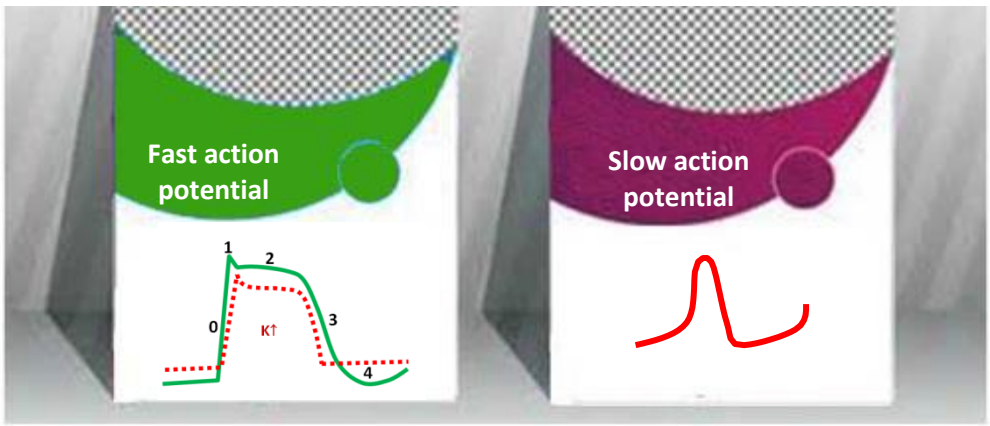


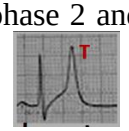
Fig.1.4

- Fast action potential is affected first
  RMP becomes less negative (depolarized) → Na^+ channels partially inactivated → slowed conduction (phase 0) with accelerated phase 3.
- SA and AV nodes are relatively spared in the initial stage :
  They use slow Ca^{++} channels which are less sensitive to early K^+ rise but they may be affected later , initially protected by their self-automaticity. Later on , excess K^+ in extracellular fluid reduces the initial automatic drive induced by Na^+ ions , that's why it causes impairment of these nodes either partially or completely.

Fast Action Potential	Slow Action Potential
• In hyperkalemia → resting potential is less negative , with Na+ channels partly inactivated → the overall effect is smaller upstroke, shortened plateau, faster repolarization • Speeding up repolarization phase 2 and 3 → tall , peaked T-wave with shorter ST segment and QT interval.	• SA and AV nodes are less affected initially They use slow Ca^{++} channel , which are less sensitive to early K^{+} rise but they may be affected later , initially protected by their self automaticity • The overall effect is its flattened phase 4 slope , concerned with automaticity

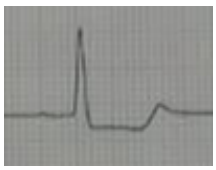
Sequential steps may be summarized as below :

❒ **T-Wave Changes & QT Shortening**

Extra potassium outside cells speeds up repolarization phase 2 and 3. This causes tall, peaked T-waves and shorter ST segment and QT interval 

❒ **Slowed Atrial Conduction**

Hyperkalemia makes atrial cells less negative, affecting fast Na+ channels first . Atrial myocytes depolarize earlier, but with slower and weaker conduction , ultimtately sweeping to atrial paralysis (flattened or low-amplitude P-wave with prolonged PR interval).



Flattened P-wave→Atrial standstill

❒ **Internodal Tracts Stay Functional Longer**

They do have Ca^{2+} dependent depolarization and so resist early effects of hyperkalemia.

❒ **SA & AV Nodes Are Less Affected Initially**

They use slow Ca++ channels, which are less sensitive to early K+ rise but they may be affected later , initially protected by their self automaticity.

❒ **Blockade**

Bundle branch block , AV block

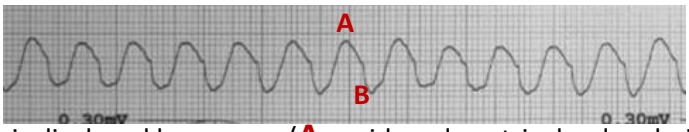
❒ **Ventricular Conduction**

His–Purkinje and ventricles use fast Na+ channels

✓As extracellular potassium rises, it lays its heaviest hand on the most distal segments—be it the Purkinje arborization or the terminal ventricular myocytes.

This descending suppression paints a different electrophysiological spectrum , as illustrated below :

Secondary pacemaker capability of Purkinje fibres is suppressed → infranodal escape pacemaker is unreliable due to its downregulated conduction (either of bundle branches) → associated diffuse intraventricular conduction delay → sine wave → asystole (the pattern of sine wave is illustrated on the next page)



Classical sine wave is displayed here as up (**A** – widened ventricular depolarization phase) and down (**B** – widened ventricular repolarization phase) oscillation

5. Hypokalemia and the concerned ECG changes

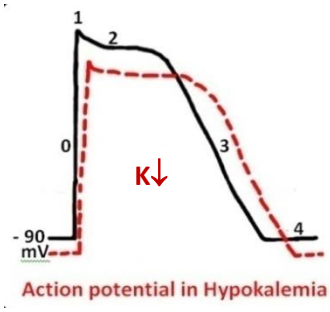


Fig.1.5

- RMP becomes more negative (hyperpolarized) → this increases the threshold for depolarization , it tends to slow its conduction a bit.
- Repolarization phase 3 is delayed

ECG changes are mainly attributed to delayed repolarization phase 3

Firstly the decreased T-wave amplitude , with the corresponding increase in U-wave amplitude (a progressive inverse relationship in between T and U wave morphology) , all these lead to a fusion of T with U resulting in pseudo prolongation of QT (QU) interval. The next immediate signature is ST segment depression.

NB :

U wave reflects delayed repolarization of the HIS-Purkinje system or mid-myocardial M-cells

Illustration of inverse relationship in between the T and U waves :

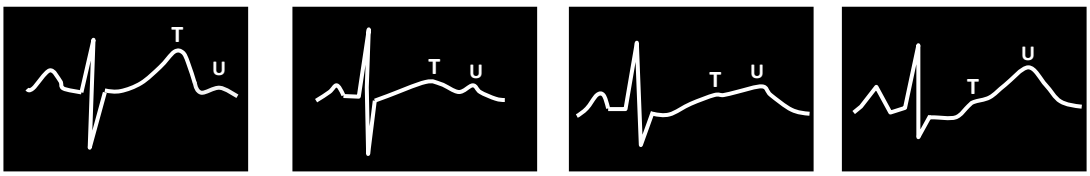


Fig.1.6

- The ECGs may show a characteristic “dip (T) and rise (U) pattern” reflecting these waveform perturbations.
  Hypomagnesaemia is often associated with hypokalemia , which may increase the risk of malignant ventricular arrhythmia.

6. Hypercalcaemia and related ECG changes

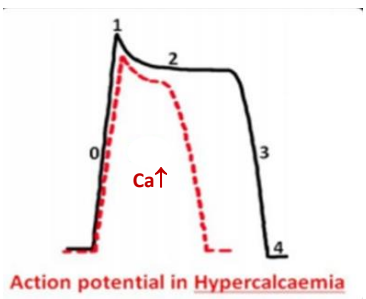
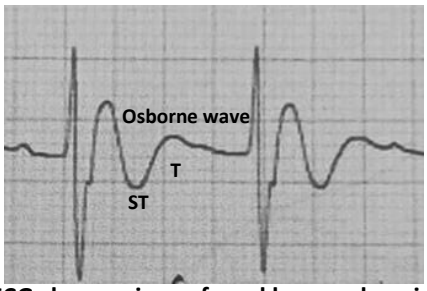


Fig.1.7

- Shortens plateau phase (early inactivation of L-type calcium channels).
- In addition with severe hypercalcemia adaptive K^+ efflux which may lead to heterogeneous prolongation of phase 3 → arrhythmias.

Corresponding ECG changes

It is worth mentioning at the outset that in hypercalcemia elevated calcium serum level accelerates the closure of the L-type calcium channels, effectively shortening the plateau phase (phase 2) of the cardiac action potential. Due to the adapted repolarization kinetics there is more potassium efflux during phase 3 resulting in changes in T-wave configuration. But in more profound cases there is more exaggerated J-point , witnessed as J-wave (Osborne wave) at the junction in between QRS and abbreviated ST segment.
Shortening of the plateau phase (phase 2) is reflected on ECG as abbreviated ST segment with shortening of the QT interval (shortening of ST segment may be to the extent that ST segment at times is hardly discernible),

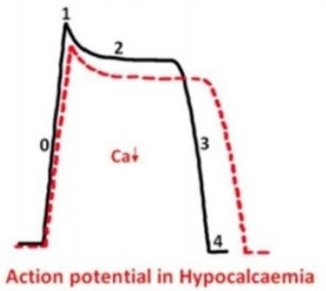


ECG changes in profound hypercalcemia

- Abbreviated ST segment
- Superimposed Osborne wave (at the junction between QRS and abbreviated ST segment)
- Widening of T-wave

Fig.1.8

7. Hypocalcalcemia and the corresponding ECG changes



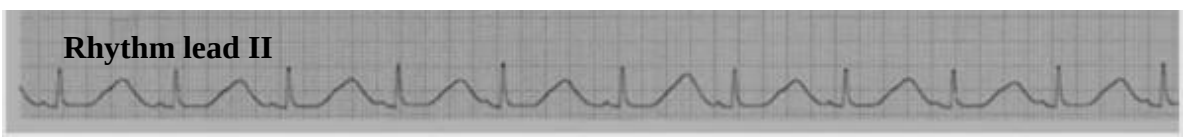
Action potential in Hypocalcaemia

- Prolongation of plateau phase (sustained Ca^{++} influx)
- With extended plateau phase there is no repolarization hetereogeneity during phase 3→ usually normal configuration of T-wave.
- The smooth run of plateau phase is having a stablizing anti-arrhythmic effect

Fig.1.9

Corresponding ECG changes

In collaboration with extended phase 3 , there is prolongation of ST segment , accompanied with QT prolongation.



This ECG tracing reveals marked QT prolongation with T-wave extending beyond the mid of corresponding RR interval , with smooth running of prolonged ST segment.

8. Take Home Message

- ☐ Ionic chorography is the inner voice of heart , reflected as cardiac action potential with its different phases as sequential pauses. There are two main phases of cardiac action potential : depolarization and repolarization.

- Understanding how the cardiac action potential normally functions and how it becomes disorganized by ionic disturbances is essential to know. This is worthwhile to mention here that such disturbances in ionic choreography may be reflected on ECG as the earliest indicators of its coherence breaking.

- **Fundamental rule concerned with electrolyte disturbances**
  Electrolyte disturbances first determine whether the RMP (resting membrane potential , phase 0) is destablished (mainly K^+ impact) or not. Then the further journey in relation to ECG changes depends on which action potential phase 2 or 3 is primarily involved by the particular electrolyte ionic handling. Potassium disturbances affects phase 3 (potassium dependent) and calcium disturbances affect phase 2 (calcium dependent).

- **Ionic choreography perturbances dependent on resting membrane potential (RMP) : destablished or stablished**

  - **Destablished RMP**
    With potassium ionic disturbances , potassium is the main determinant of RMP. Better to say it is the presence of K^+ions in extracellular compartment , which determines the status of RMP polarity. This RMP polarity is destablished in either hyperkalemia or hypokalemia.
    - **Hyperkalemia** : RMP becomes less negative (depolarized) → Na+ channels partially inactivated → slowed conduction (phase 0) with accelerated phase 3.
    - **Hypokalemia** : RMP becomes more negative (hyperpolarized) → conduction disturbed a bit , but repolarization delayed (phase 3).

  - **Stablished RMP**
    Calcium does not significantly change the polarity of RMP
    - **Hypercalcaemia** : Shortens plateau phase (early inactivation of L-type calcium channels). In addition with severe hypercalcemia adaptive K^+ efflux may lead to heterogeneous prolongation of phase 3 → arrhythmias.
    - **Hypocalcaemia** : Prolongs plateau phase (sustained Ca^{++} influx)

- Some points with special reference to hyperkalemia
  - Fast action potential governed by fast Na+ channels is affected first
  - SA and AV nodes are relatively spared in initial stage :
    They use slow Ca^{++} channels which are less sensitive to early K^+ rise but they may be affected later , initially protected by their self-automaticity. Later on , excess K^+ in extracellular fluid reduces the initial automatic drive induced by Na^+ ions , that's why it causes impairment of these nodes either partially or completely.

- Concerned ECG changes have been well described with the corresponding ionic disturbances (see the preceding pages for details).

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