Neuromuscular monitoring

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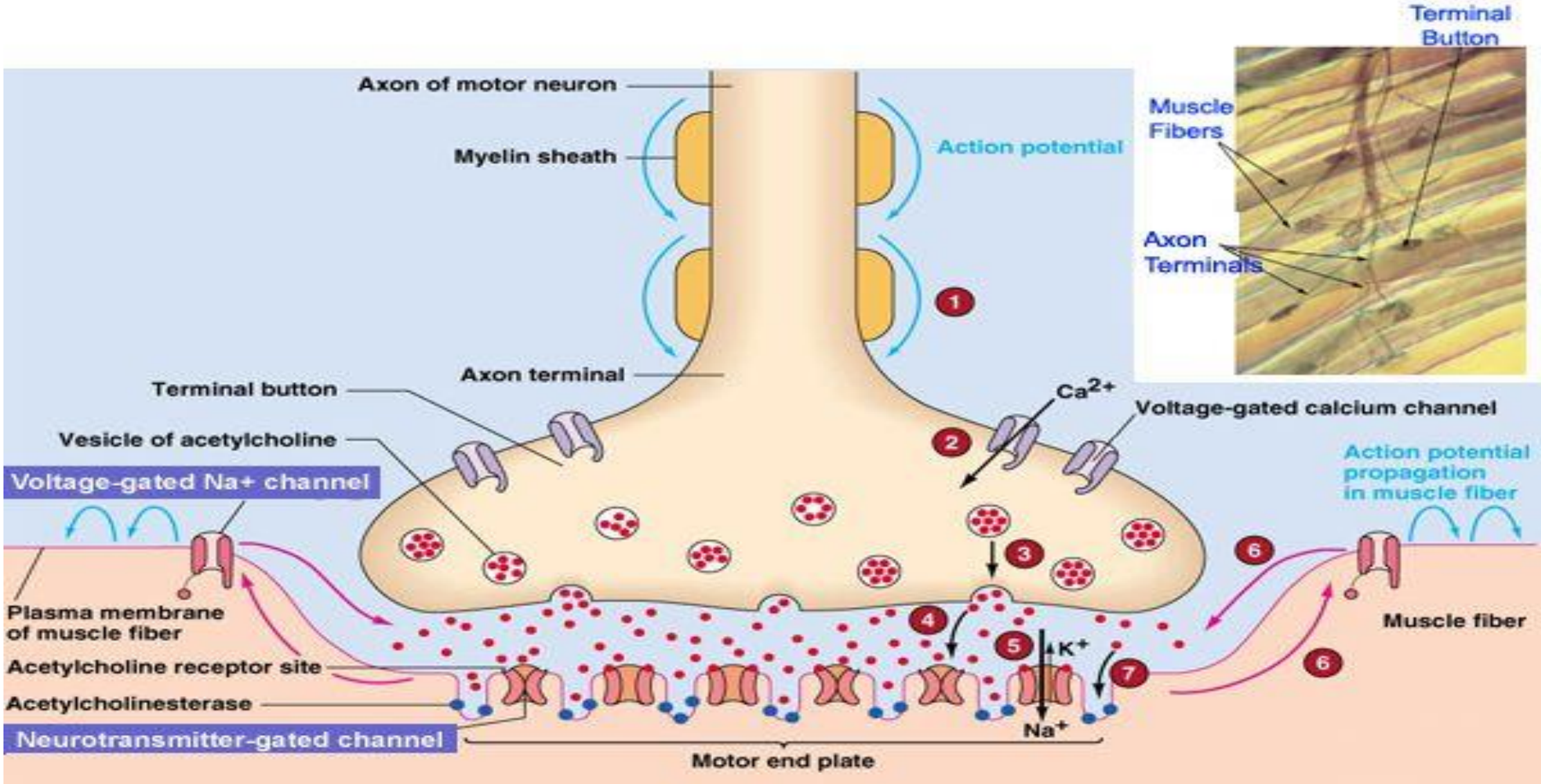
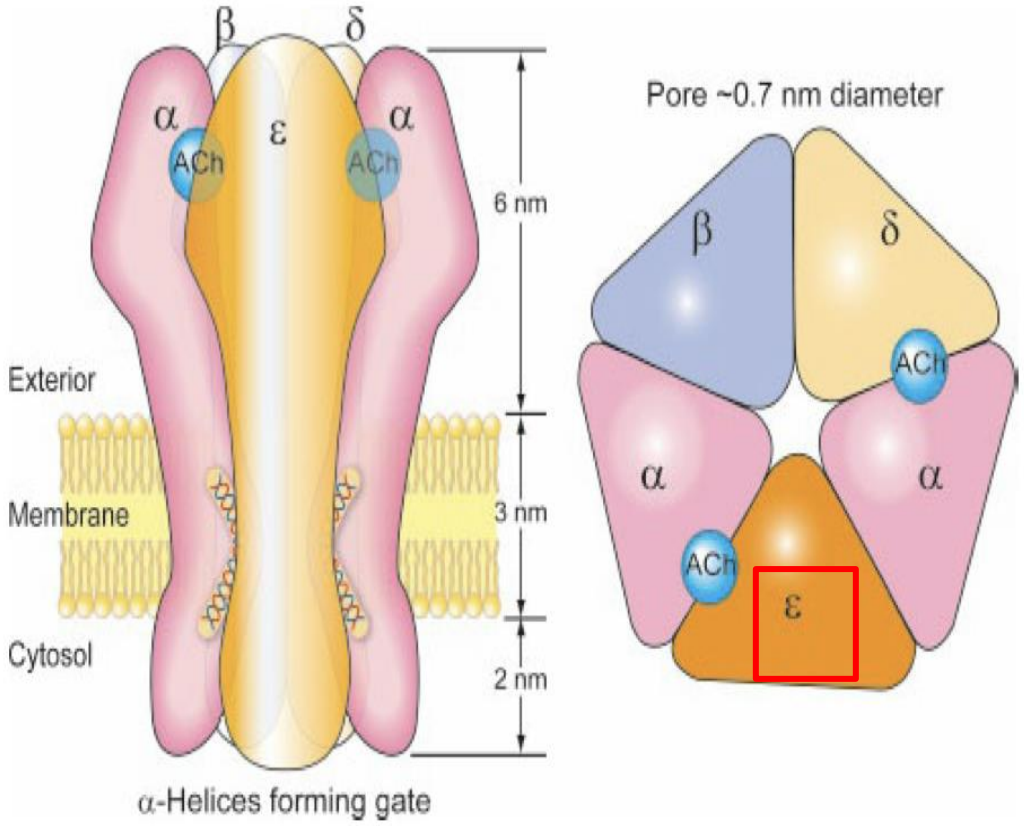
Outline

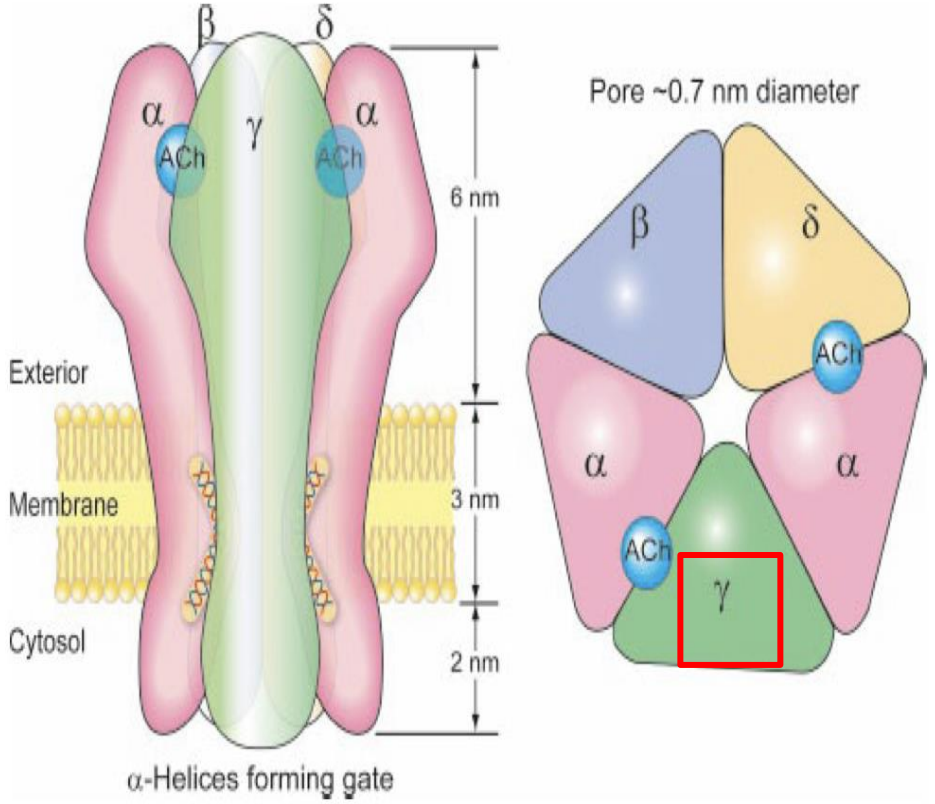
- Physiology of neuromuscular junction
- Indications and benefits
- Principles of peripheral nerve stimulation
- Patterns of nerve stimulation
- Clinical application of neuromuscular monitoring

The Neuromuscular Junction



Adult nAchRs VS Fetal nAchRs





Adult nAchRs

Fetal nAchRs (atypical)

Clinical anesthesia 8th edition 2017; neuromuscular blocking agent ; monitoring neuromuscular blockade

Indication & benefit of neuromuscular monitoring

Indication

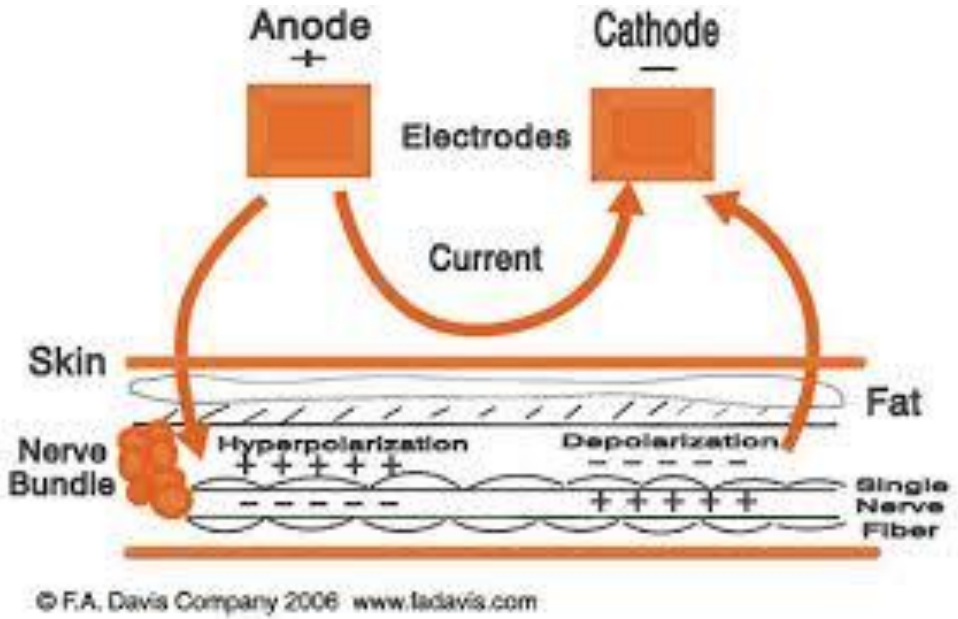
- Neuromuscular disease
- Critical illness
- Burn patient
- Morbid obesity
- Surgery that profound NM blockade

Benefit

- Onset of NMBA
- Level of NMBA during operation
- Predicted risk of residual paralysis

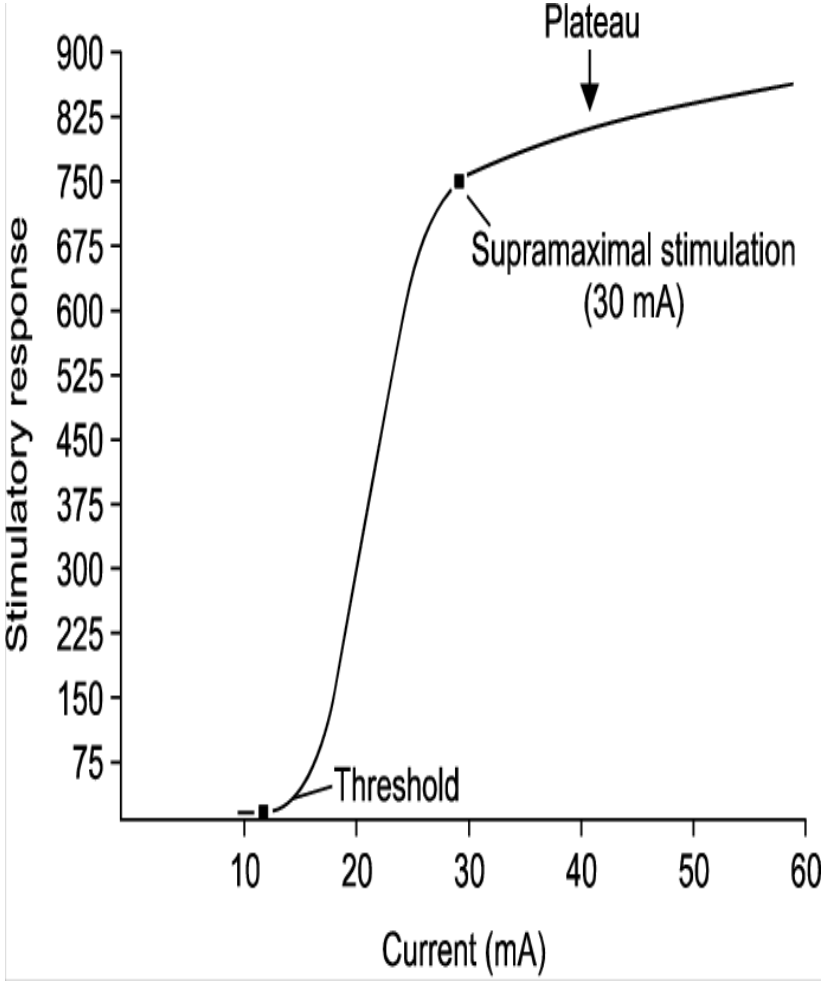
Principles of peripheral nerve stimulation

- Used to evaluate the effect of NMBA
- The muscle response after stimulation of corresponding motor nerve
- **Qualitative :** *peripheral nerve stimulator*
- **Quantitative :** *objective monitor*



Clinical anesthesia 8th edition 2017; neuromuscular blocking agent ; monitoring neuromuscular blockade

Supramaximal stimulation



- Reaction of a single muscle fiber to a stimulus (all or none)
- Muscle contraction depend on number of muscle fibers activated
- Reducing response during constant stimulation reflect the degree of neuromuscular block
- Maximal current : amplitude of muscle response no longer increases as current intensity increases
- The electrical stimulus applied at least 15-20% greater response for ensures that all the innervated nerve will depolarize

Miller's anesthesia : neuromuscular monitoring,9th ed;2020

Basic consideration

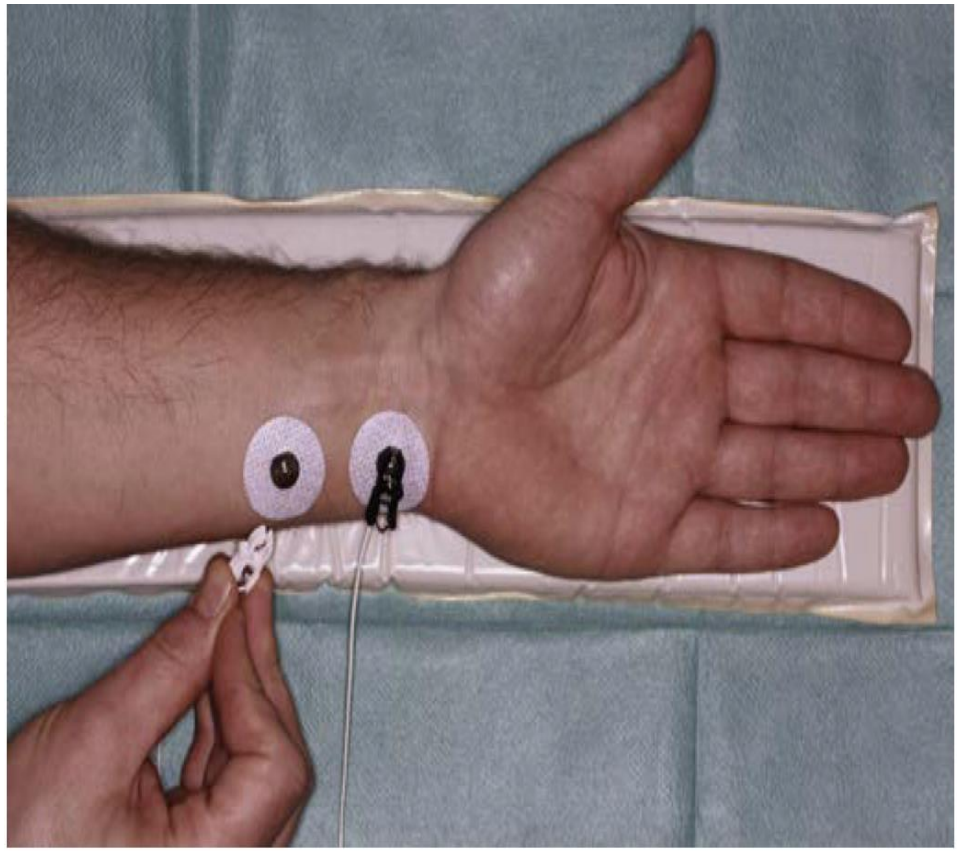


Fig. 43.1 Stimulating electrodes with the appropriate contact area in the correct position over the ulnar nerve of the left forearm.

Gold standard : ulnar nerve- adductor pollicis muscle

Electrical stimulation elicit only finger flexion and thumb adduction

Posterior tibial nerve – flexor hallucis brevis

Facial nerve – orbicularis oculi / corrugator supercilli

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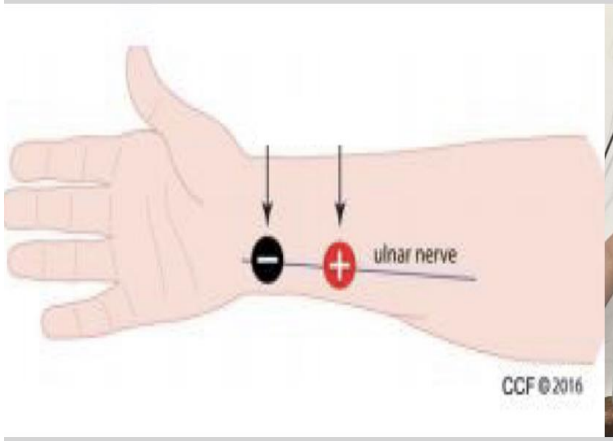
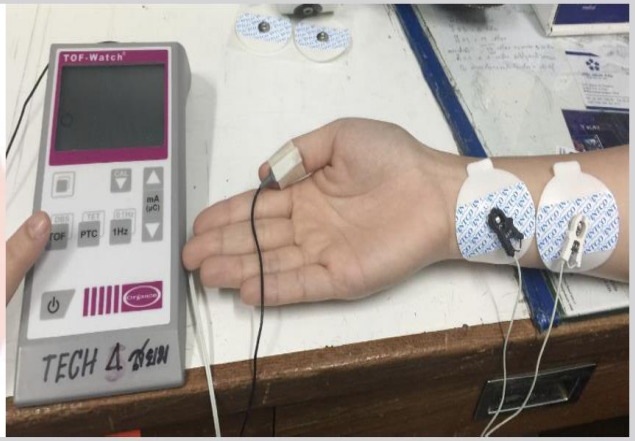
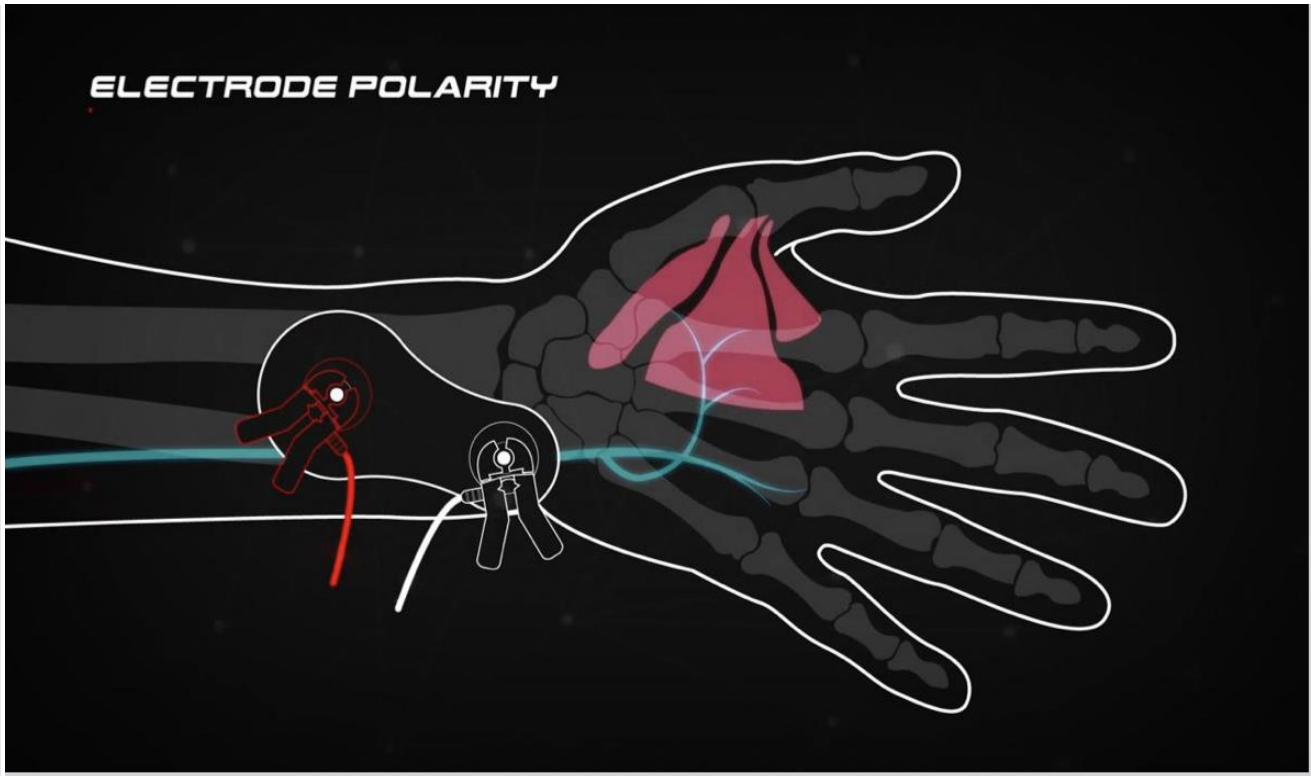
Ulnar nerve

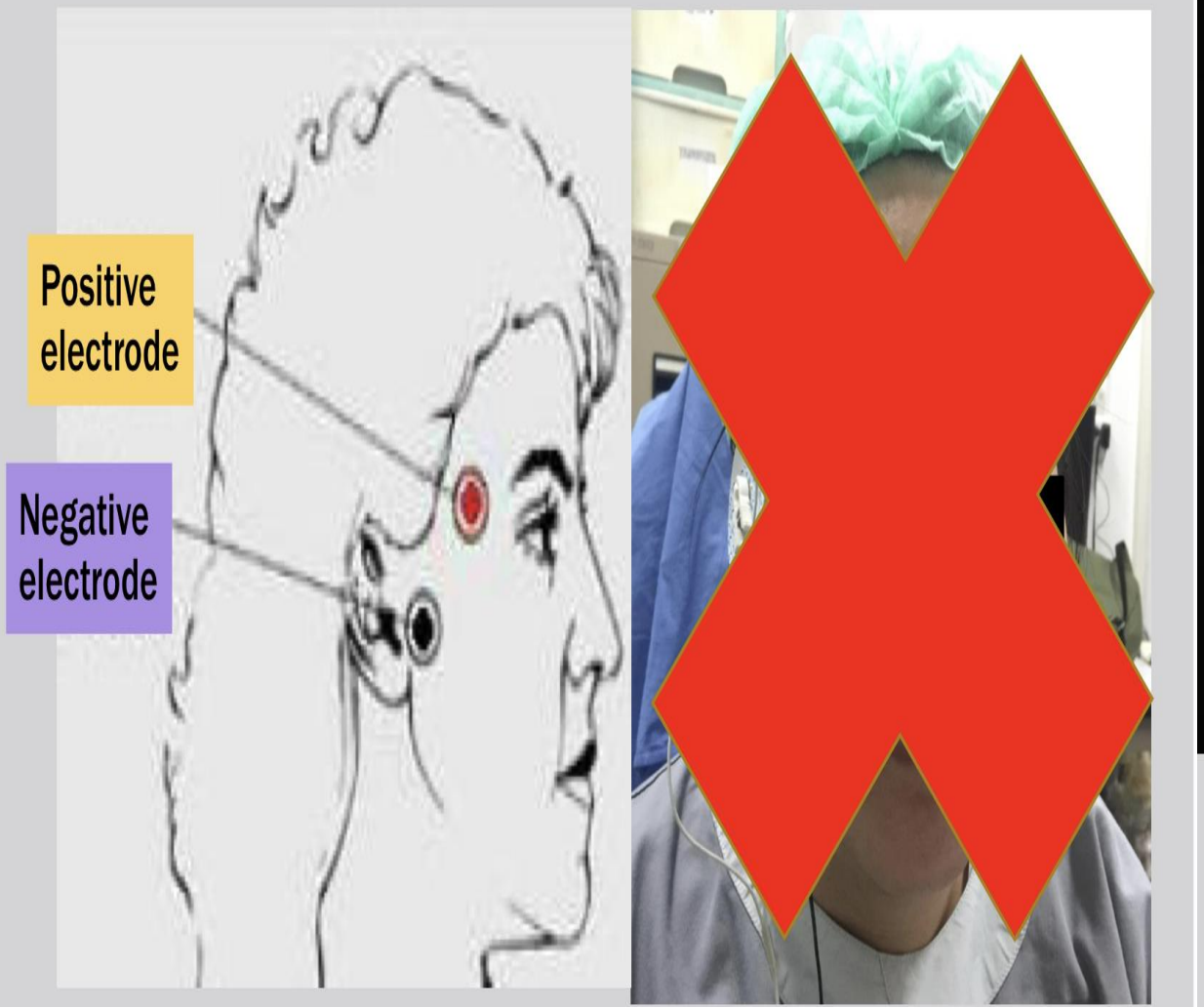


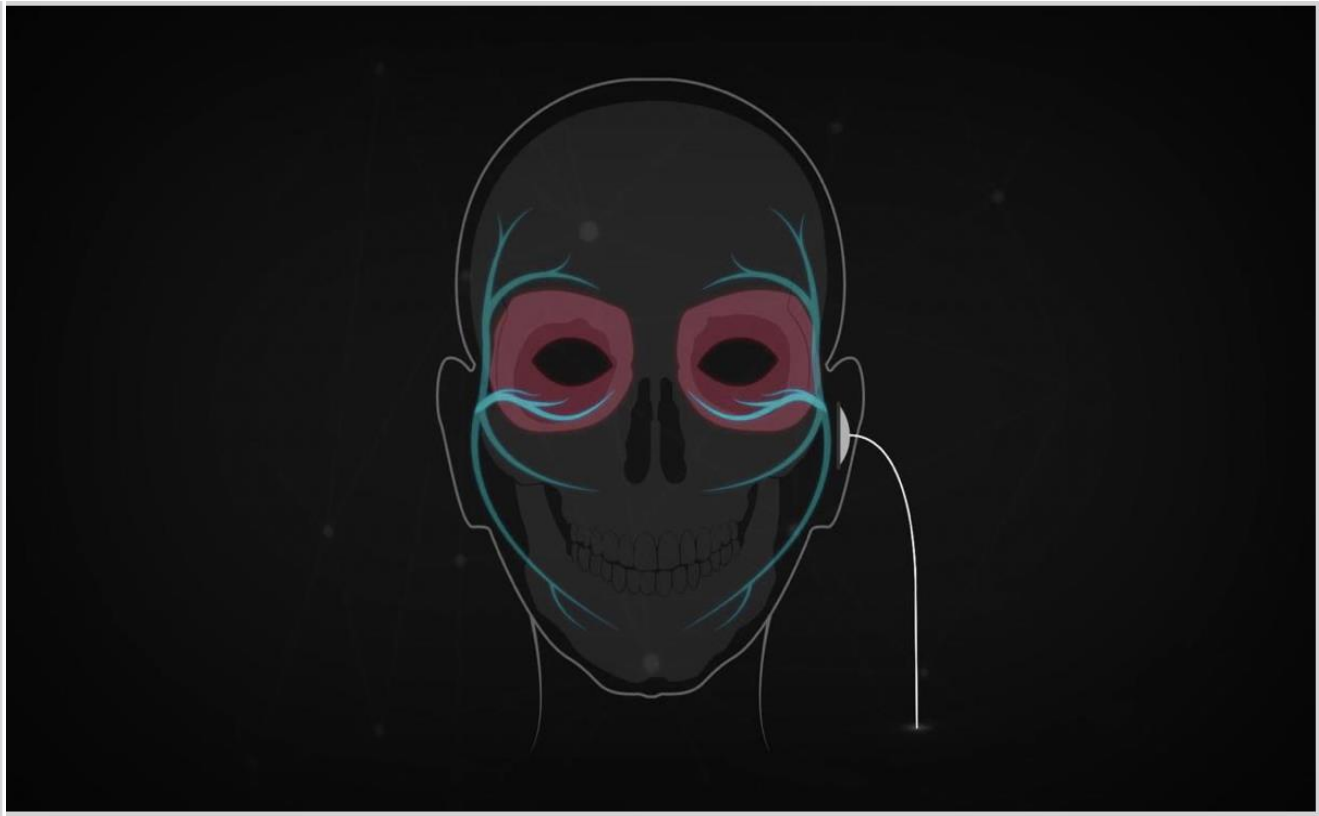




Response: Adductor pollicis muscle
→thumb adduction

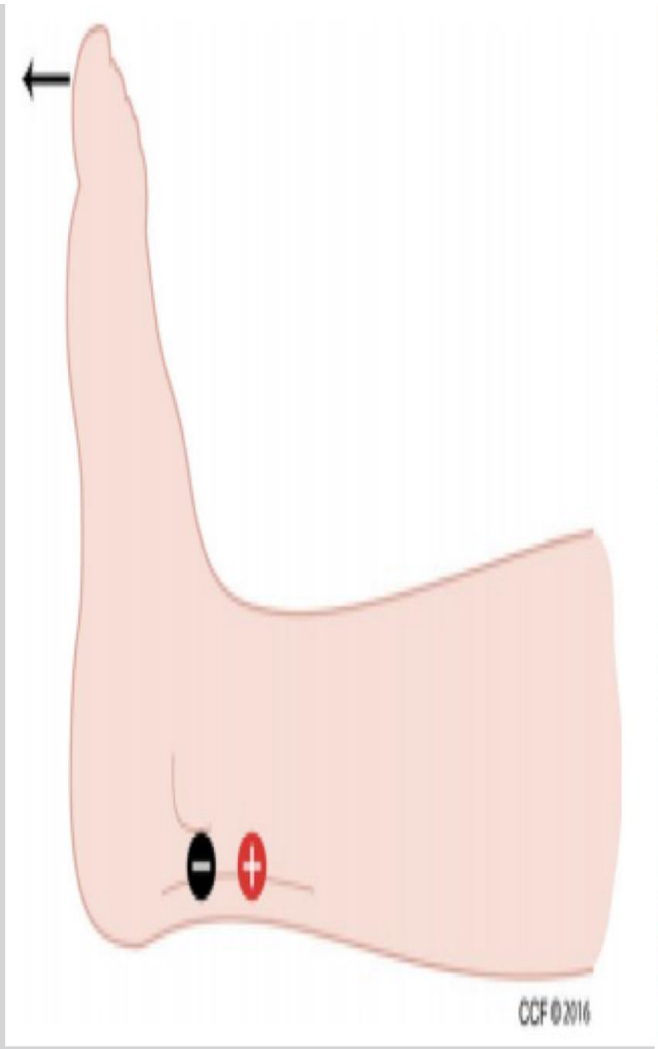
facial nerve

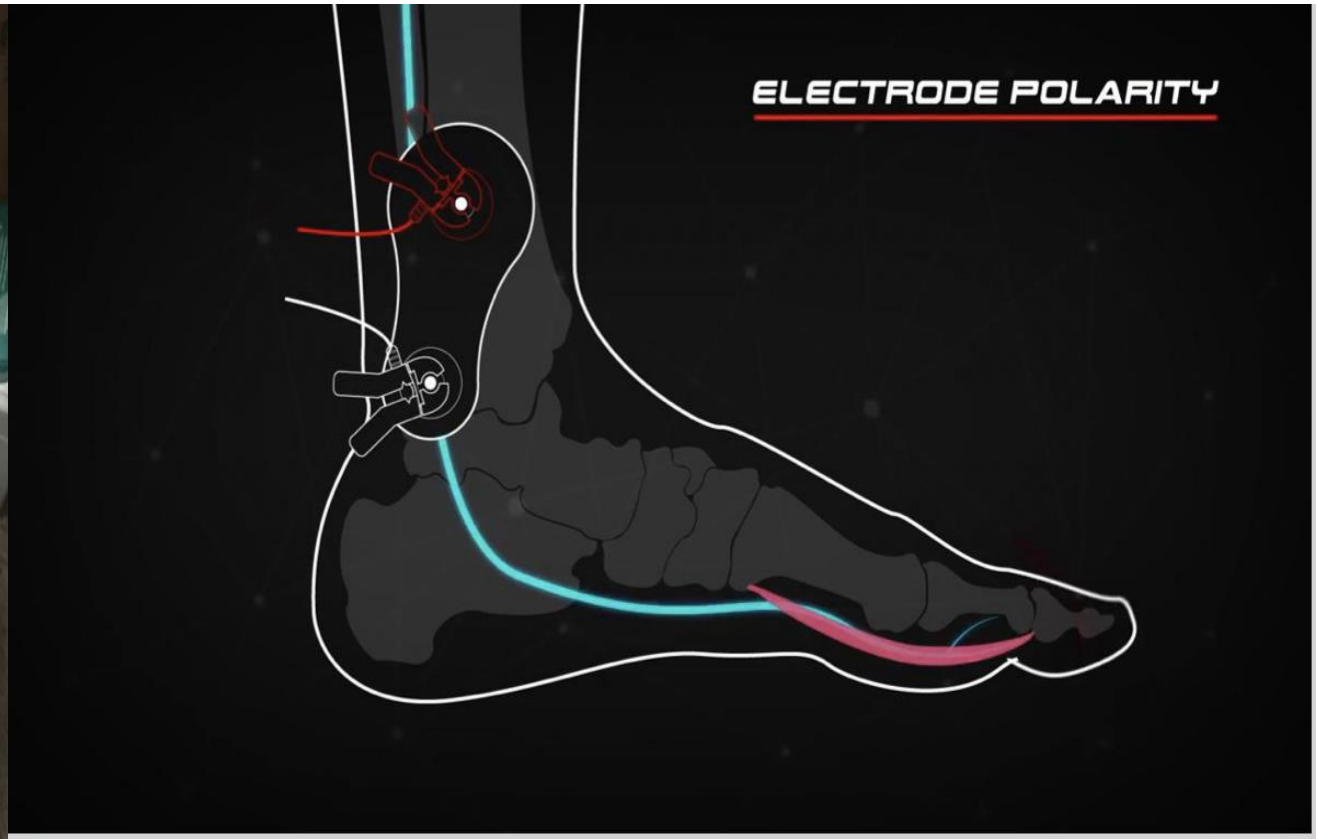




Response: Orbicularis occuli muscle
→Eyelid twitching

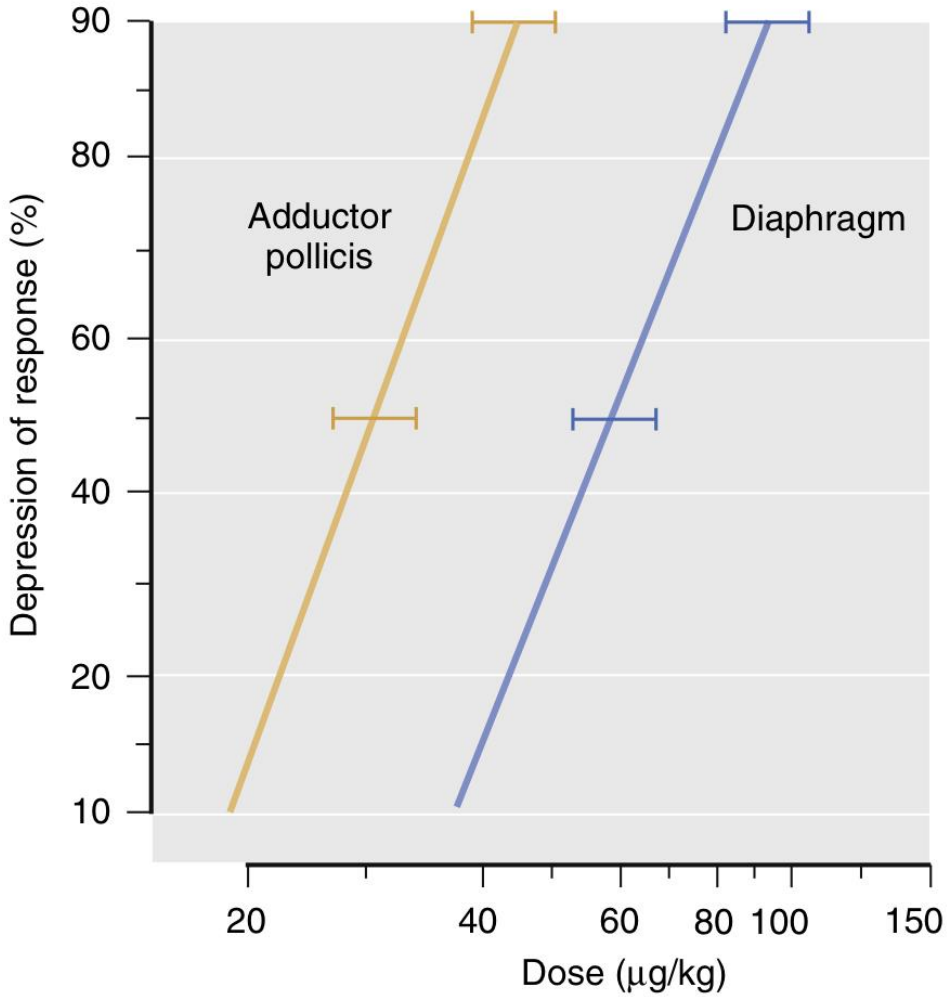
Posterior tibial nerve





Response: Flexor hallucis brevis muscle
→Plantar flexion of big toe

Basic consideration



Different muscle groups **have** **different sensitivities to NMBD**

Diaphragm *(most resistance of all muscles to NMBD)*

- require 1.4-2.0 fold of NMBD as adductor pollicis muscle for identical of block

Other respiratory muscle are less resistance than diaphragm
(larynx and corrugator supercilii muscle)

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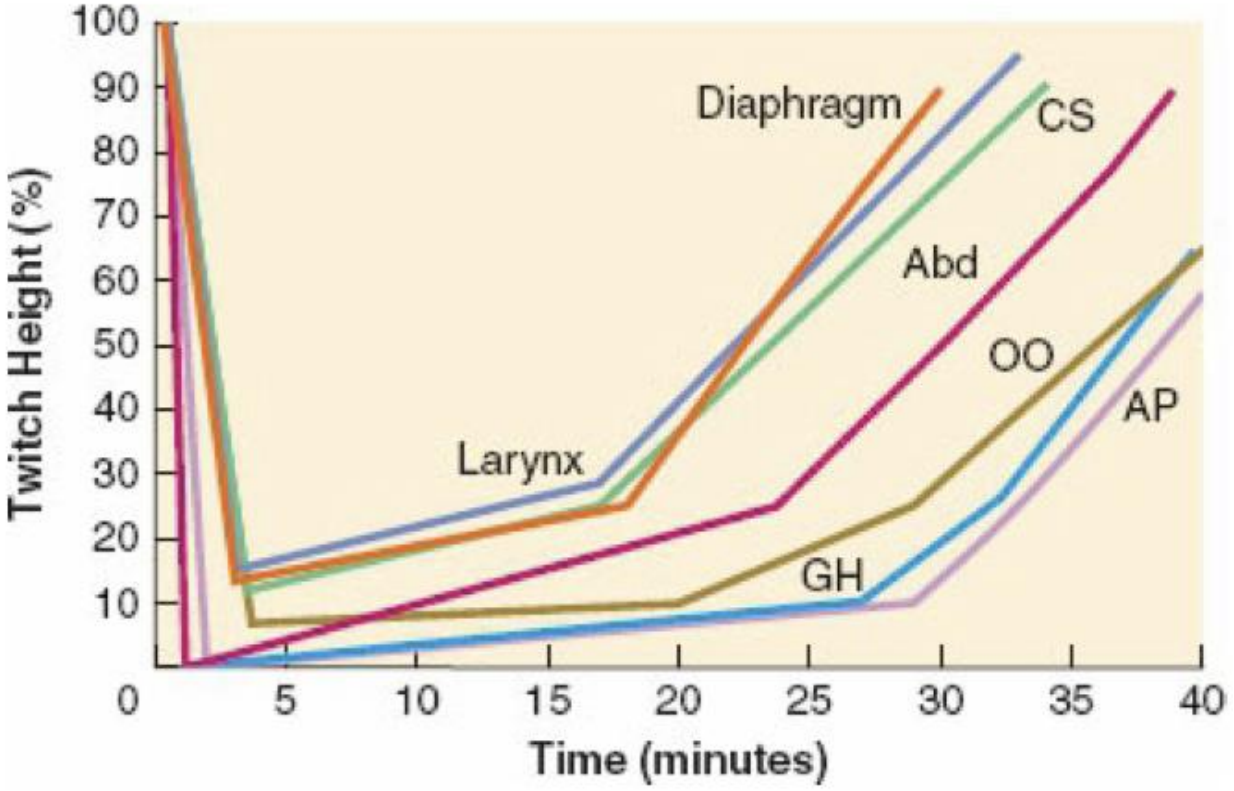
Different muscle sensitivity to rocuronium



AchR density , Ach release

AchE activity, Fiber composition

Innervation ratio , Blood flow

Muscle temperature

Fastest to slowest

Diaphragm > laryngeal muscle> corrugator supercilii (CS)> abdominal muscle > orbicularis oculi (OO)>geniohyoid muscle (GH)> adductor pollicis muscle (AP)

Clinical anesthesia 8th edition 2017; neuromuscular blocking agent ; monitoring neuromuscular blockade

Miller's anesthesia : neuromuscular monitoring,9th ed;2020

Basic consideration

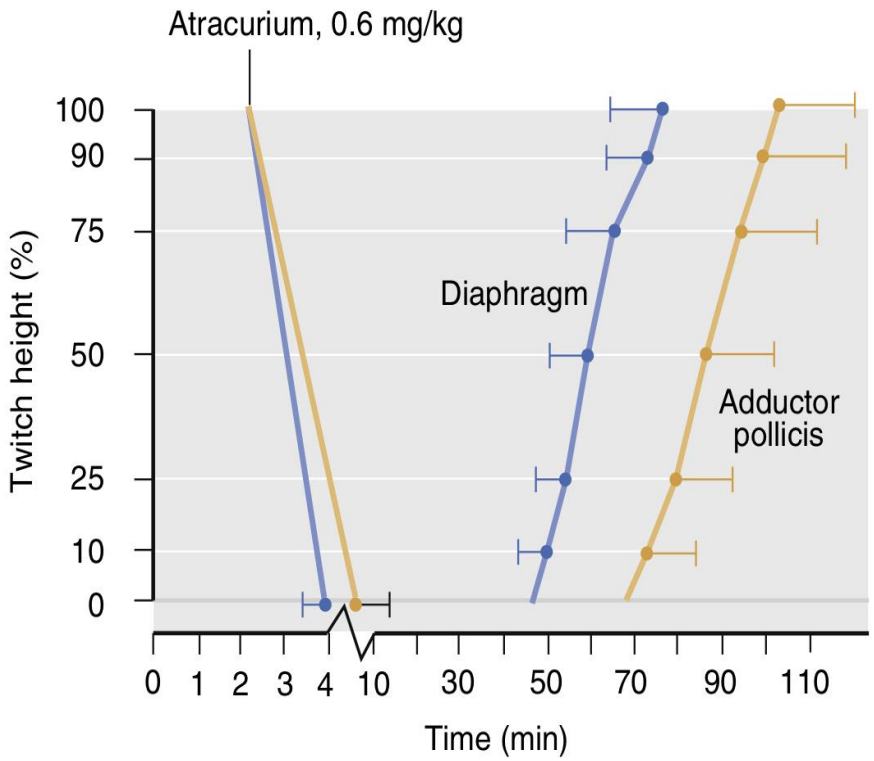


Fig. 43.3 Evolution of twitch height (mean ± SD) of the diaphragm *(blue circles)* and the adductor pollicis muscle *(yellow circles)* in 10 anesthetized patients after the administration of atracurium (0.6 mg/kg). (From Pansard J-L, Chauvin M, Lebrault C, et al. Effect of an intubating dose of succinylcholine and atracurium on the diaphragm and the adductor pollicis muscle in humans. *Anesthesiology*. 1987;67[3]:326–330.)

Diaphragm

- Onset shorter than adductor pollicis muscle
- Recovers from paralysis quickly than peripheral muscles

Respiratory muscle

- less resistance than diaphragm

Upper airway muscles

- more sensitive than peripheral muscle

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Quantitative neuromuscular monitoring

Measure and quantify the degree of neuromuscular blockade and display the results numerically

- Mechanomyography (MMG)
- Electromyography (EMG)
- Acceleromyography (AMG)
- Kinemyography (KMG)
- Phonomyography (PMG)

Mechanomyography

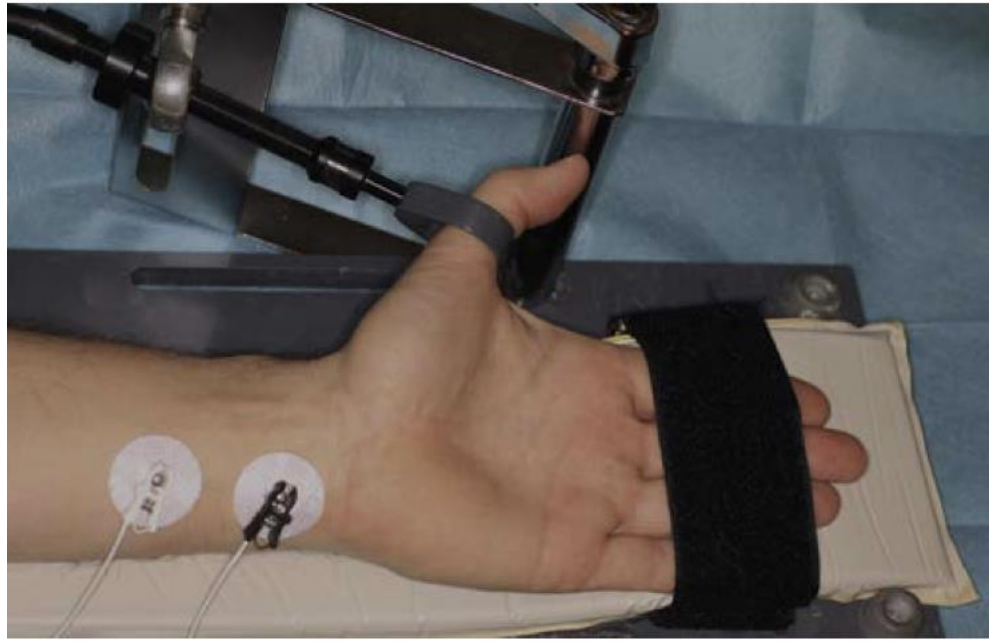

Fig. 43.10 The setup for mechanomyography. The response to nerve stimulation is measured using a force transducer (TD-100; Biometer, Odense, Denmark) placed at the proximal phalanx of the thumb.

MMG (gold standard)

- Measure the isometric contraction of adductor pollicis muscle after stimulation of the corresponding ulnar nerve
- Force of contraction converted to electrical stimulation
- Amplitude of signal is proportional to the strength of contraction

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Electromyography

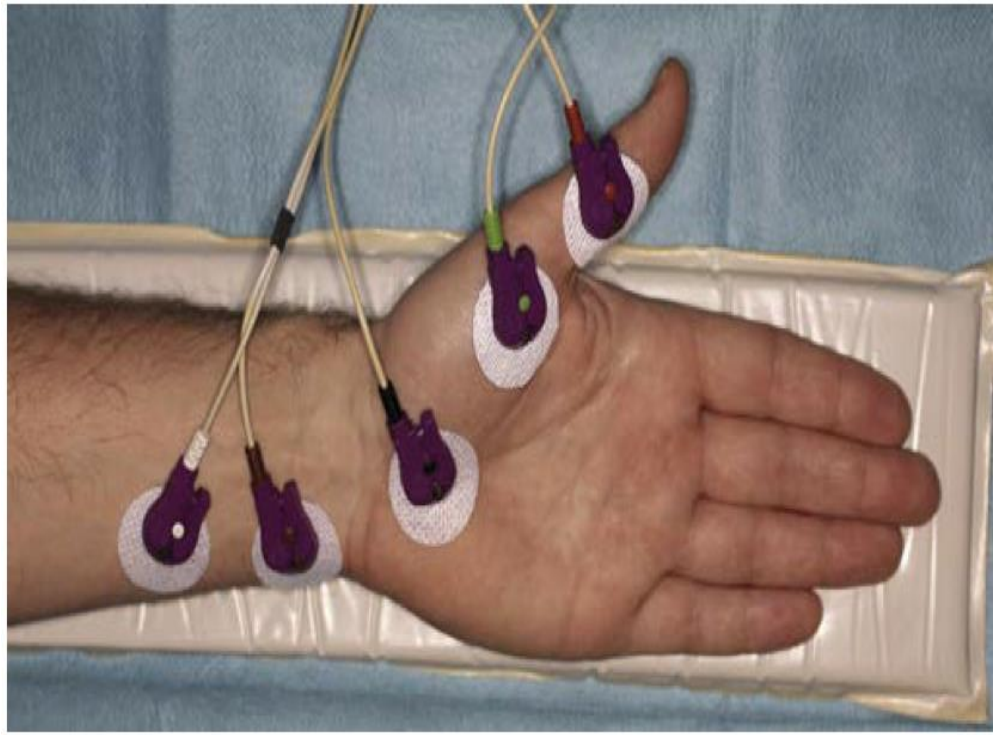

Fig. 43.11 The setup for electromyography (NMT ElectroSensor, Datex-Ohmeda, Helsinki, Finland) for recording the compound action potential from the adductor pollicis muscle.

- Measures the electrical response (compound muscle) following nerve stimulation
- *Peak amplitude of the signal or AUC*
- **Different muscle group :** adductor pollicis, diaphragm abductor digiti minimi laryngeal, orbicularis oculi
- **Limitation** *: interference from device (electrocautery) temperature, change in position of hand*

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Acceleromyography

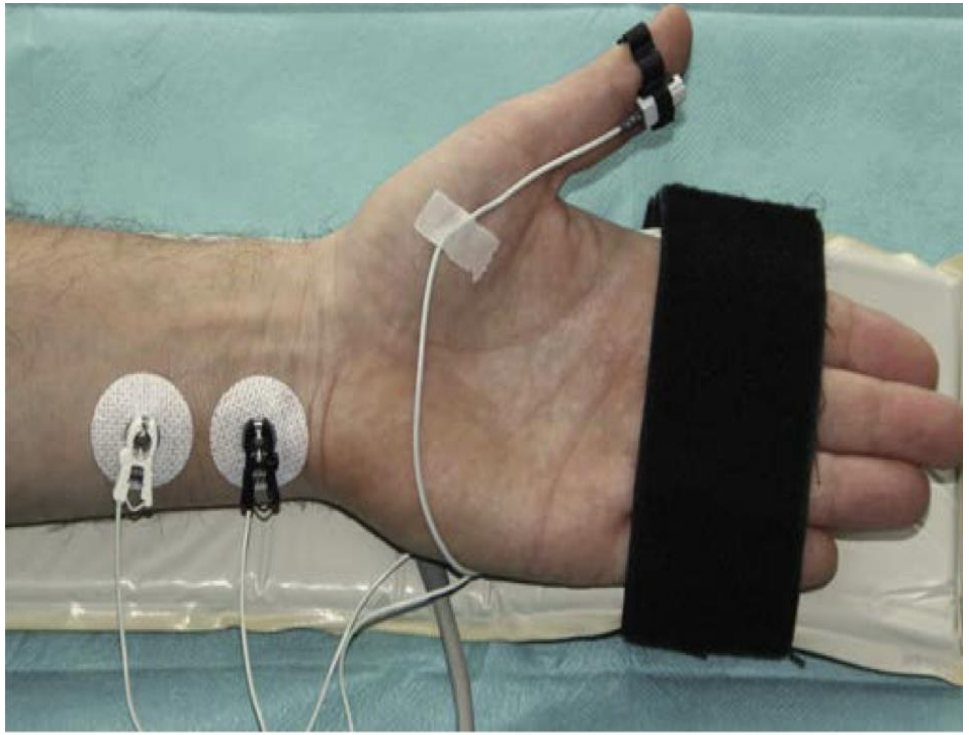

Fig. 43.13 The setup of acceleromyography without preload (TOF Watch, Biometer, Odense, Denmark). The response to nerve stimulation is measured with a small piezoelectric acceleration transducer placed distally on the volar site of the thumb.

- Measure acceleration of a stimulated muscle
- *Newton's 2nd Law : F=MA*
- Piezoelectric sensor (V proportional to A)
- Signal is analyzed and displayed on a monitor
- Facial nerve : orbicularis oculi, corrugator supercilia
  ulnar nerve : abductor pollicis muscle

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Kinemyography

Figure 53-17. The setup of kinemyography (NMT MechanoSensor, Datex-Ohmeda, Helsinki, Finland). The response to nerve stimulation is measured by the bending of a small piezoelectric sensor positioned between the index finger and the thumb.

Sensor : piezoelectric film (groove between thumb & index)

Measure : voltage proportional to the amount of stretching

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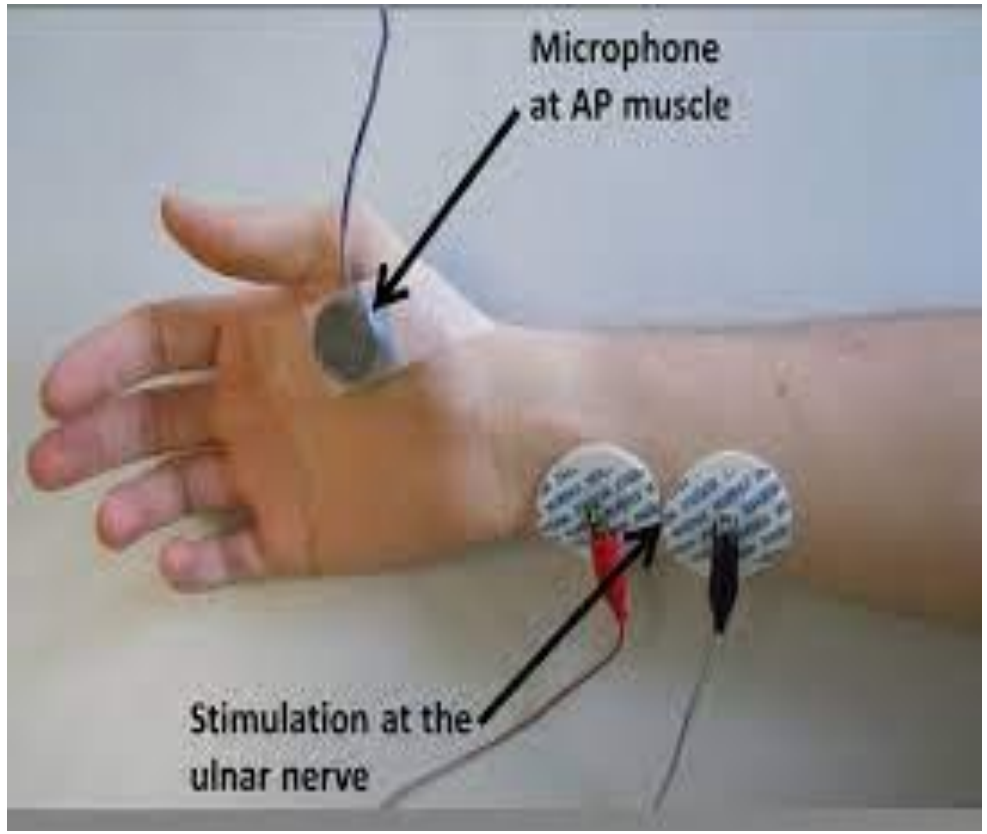
Phonomyography



Sensor : high-fidelity narrow bandwidth microphone placed along muscle

Measure : intrinsic low frequency sound of muscle contraction with special microphone

(Not currently commercially available & low clinical use)

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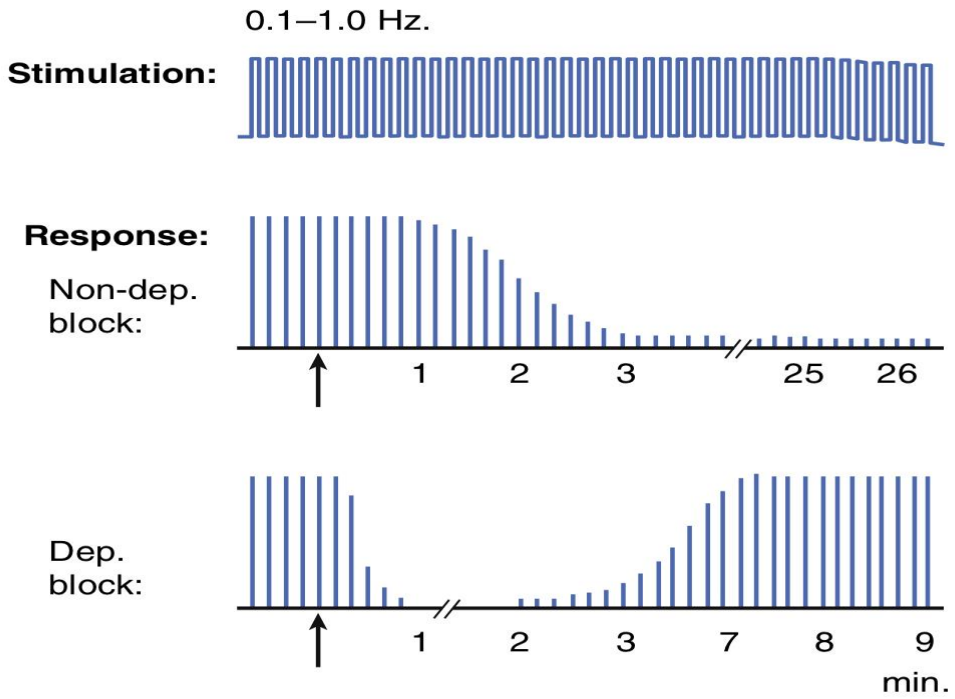
Patterns of nerve stimulation qualitative monitoring

- Single twitch stimulation
- Train of four stimulation
- Double burst stimulation
- Tetanic stimulation
- Posttetanic count stimulation

Single twitch stimulation



Stimulation pattern

- Single electrical stimuli at 0.1-1 Hz
- Supramaximal stimuli (20-30%)
- **Duration** 0.1-0.3 msec *(0.2 msec most common)*

(The response depend on the frequency of stimuli are applied)

- Frequency > 0.15 Hz, evoked response gradually decrease and stabilized

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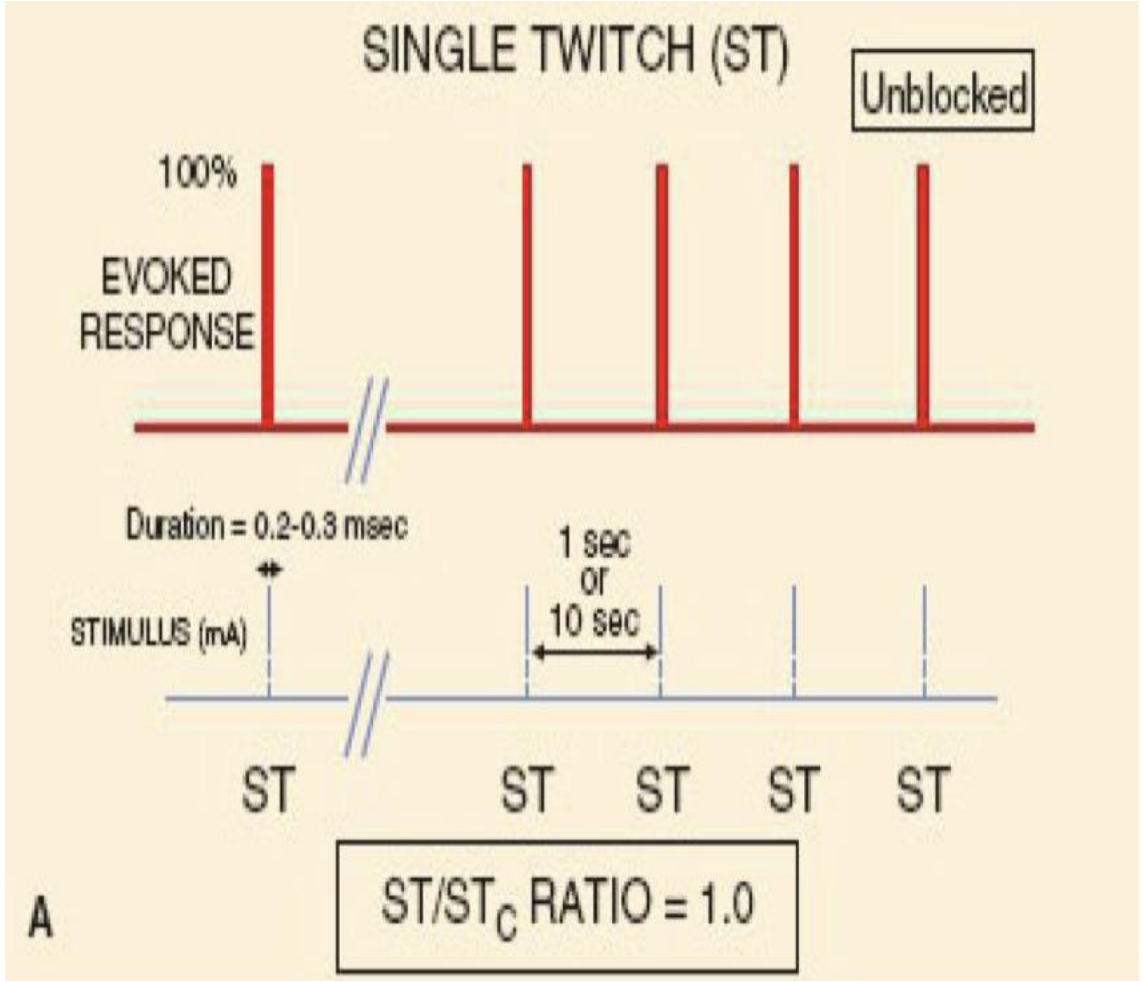
Single twitch stimulation



Application

- Reference value recorded before
- Onset of neuromuscular block

(insufficient information of the level of block)

- *Component of PTC* (limited as stand alone)
- Unable to differentiate depolarizing from nondepolarizing block

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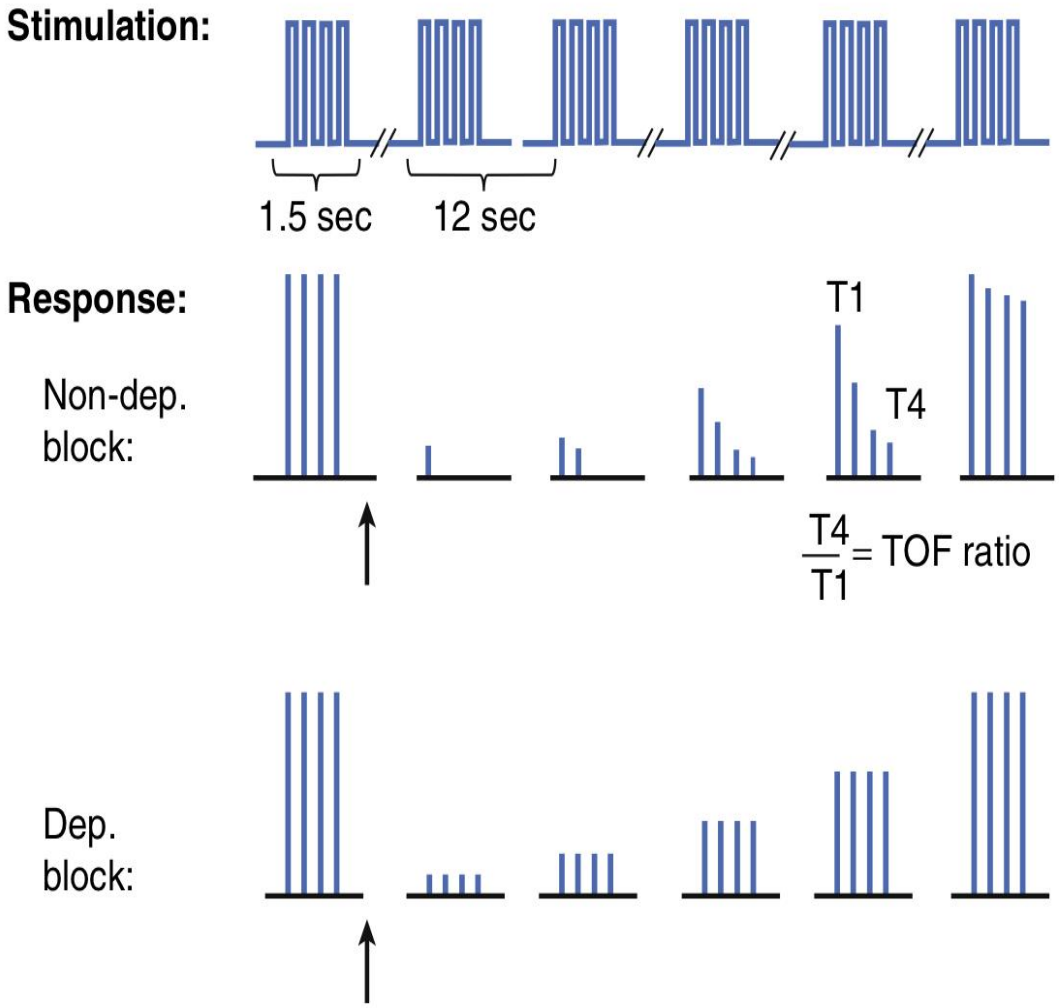
Train of four stimulation



Stimulation pattern

- 4 supramaximal stimuli given every 0.5 s (2 Hz)
- Trains delivered at 15-20 s
- **TOF count :** number of discernable response after TOF stimulation
- **TOF ratio :** T4/T1
- **Fade :** weaker T4 than T1

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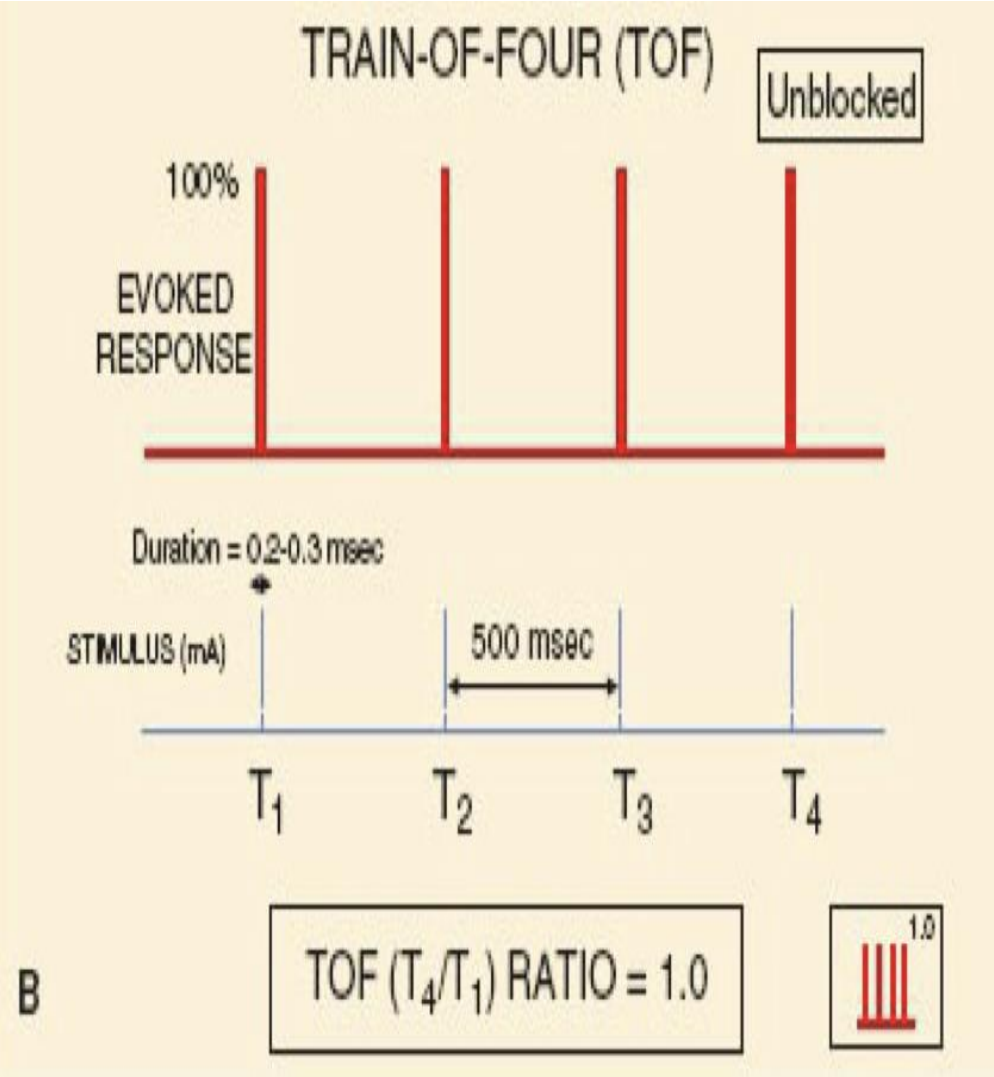
TOFScan - thumb

Train of four stimulation



Application

- degree of block of nondepolarizing NMBA

(able to differentiate depolarizing from nondepolarizing block)

- **TOF count :** onset of block & degree of neuromuscular blockade
- **TOF ratio :** recovery from nondepolarizing blockade
  (TOF > 0.9)
- **TOF 0.4-0.9 :** fade can't be detected either visually and tactically

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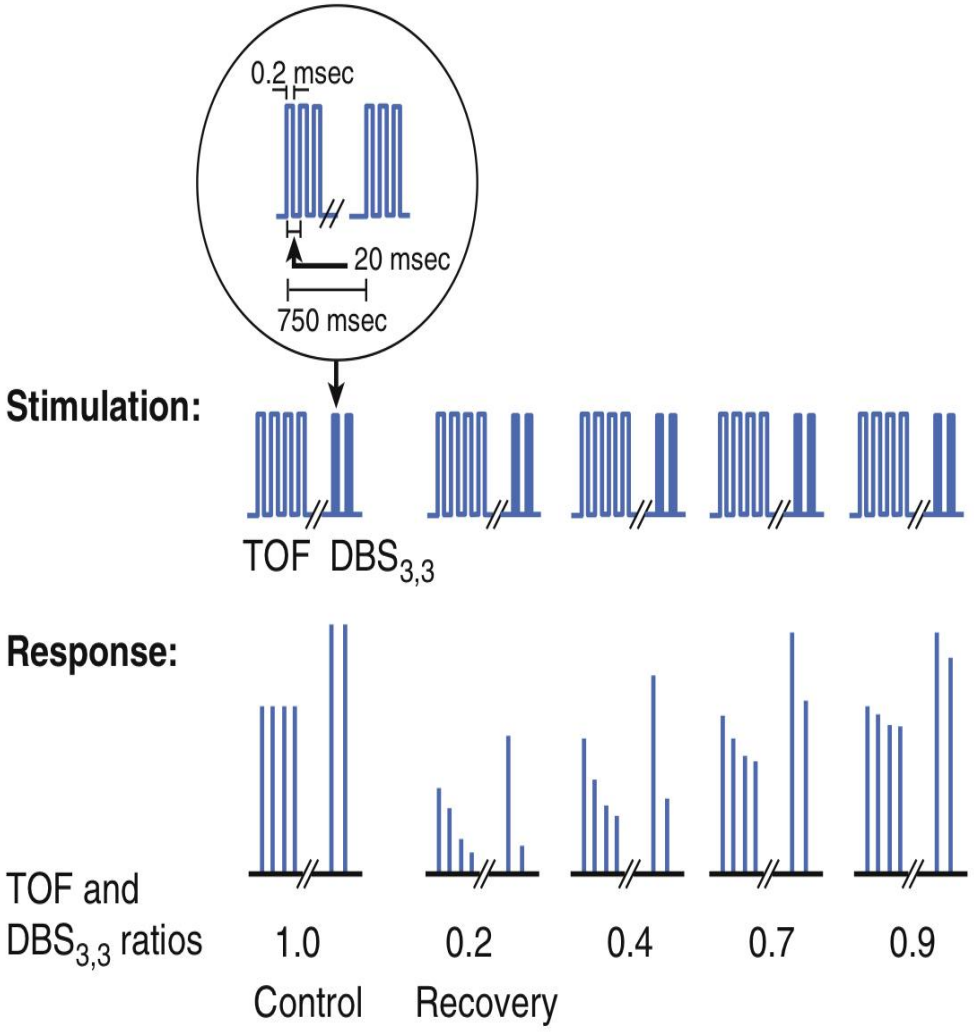
Double burst stimulation



Stimulation pattern

- 2 short bursts of 50 Hz tetanic stimulation separated by 750 s
- Duration 0.2 ms
- Interval 20 s (avoid potential of subsequence response)
- **DBS 3,3 :** 3 mini-tetanic bursts followed by 3 mini-tetanic bursts
- **DBS 3,2 :** 3 mini-tetanic bursts followed by 2 mini-tetanic bursts

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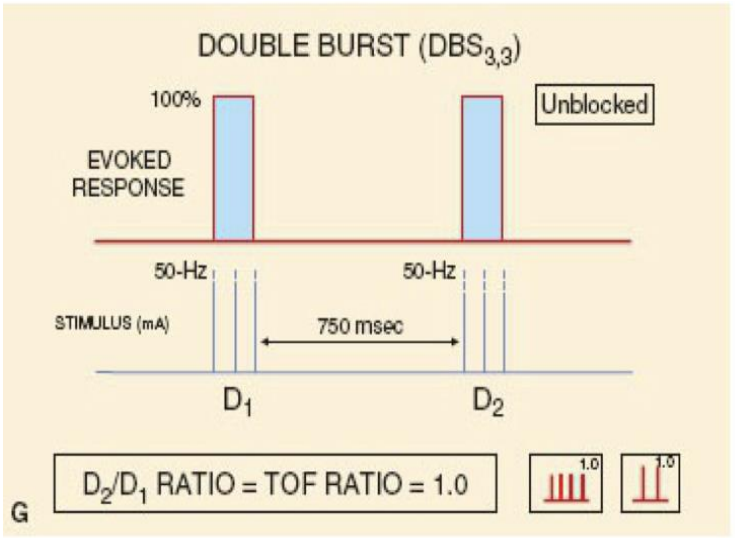
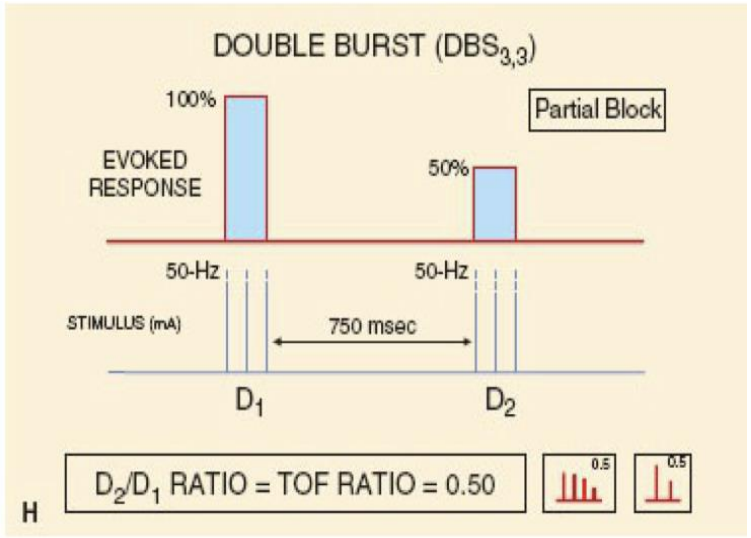
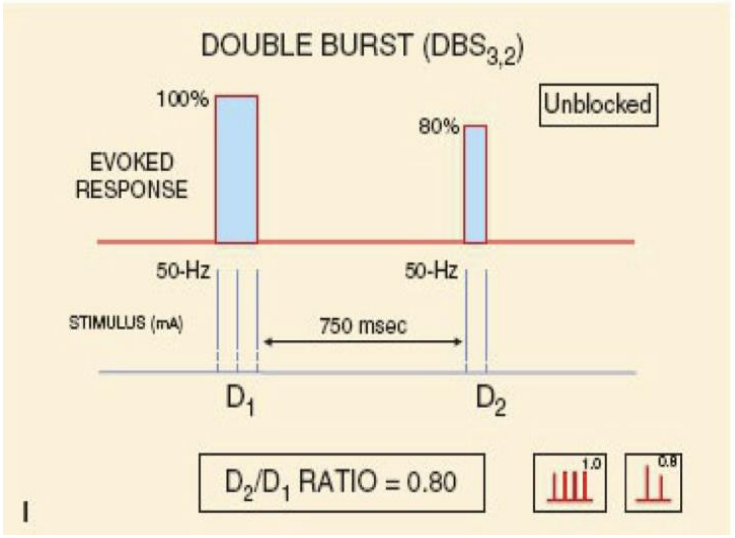
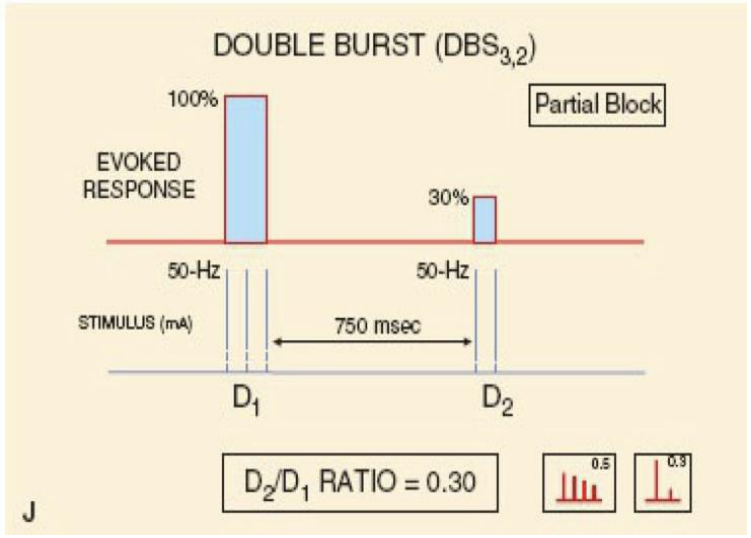
Double burst stimulation









Application

- **DBS ratio :** D2/D1
- **Fade :** weaker D2 than D1
- TOF >0.6 can't be detected subjectively
- *Able to differentiate depolarizing from nondepolarizing*
- Subjective evaluation of DBS fade superior to TOF fade

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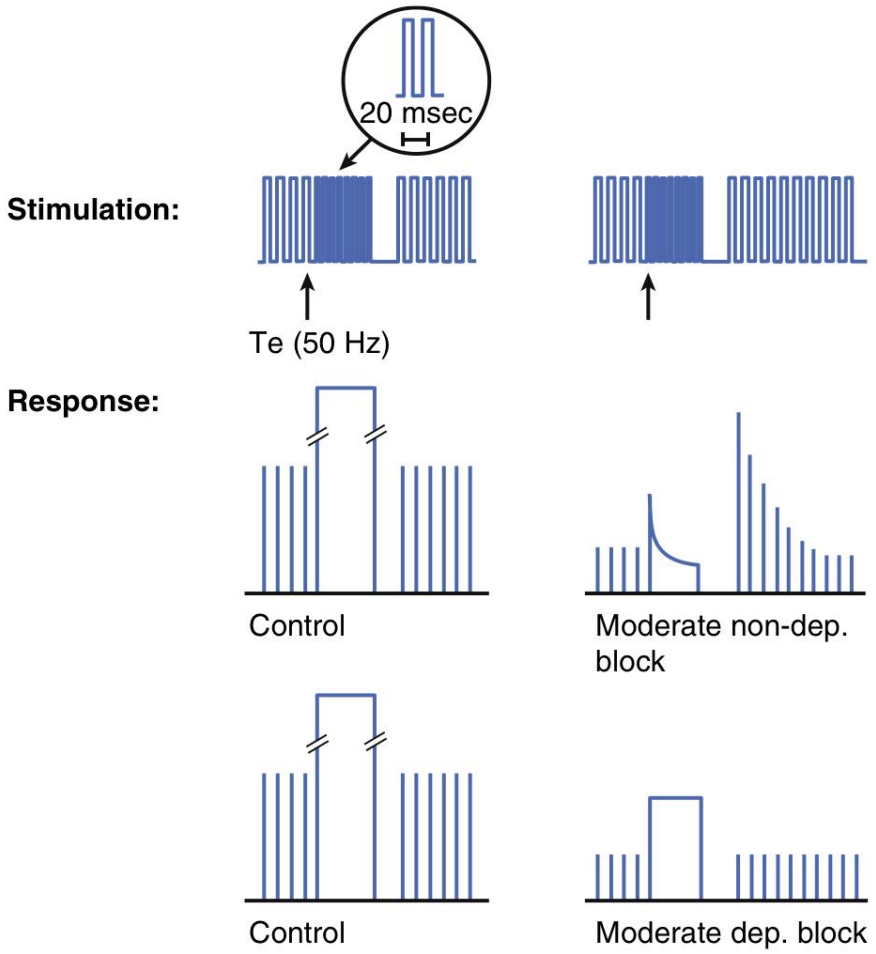
Tetanic stimulation



Stimulation pattern

- Frequency 50-100 Hz for 5 s (common 50 Hz for 5 s)
- **Tetanic stimulation :**
  - Ach in synaptic cleft => *positive feedback on presynaptic receptors*
  - Greater amount of Ach => *tetanic contraction*
- **Nondepolarizing block :** sustained muscle contraction
  fade after tetanic stimulation
- **Depolarizing block** : tetanic response is sustained
  no post-tetanic facilitation occurs

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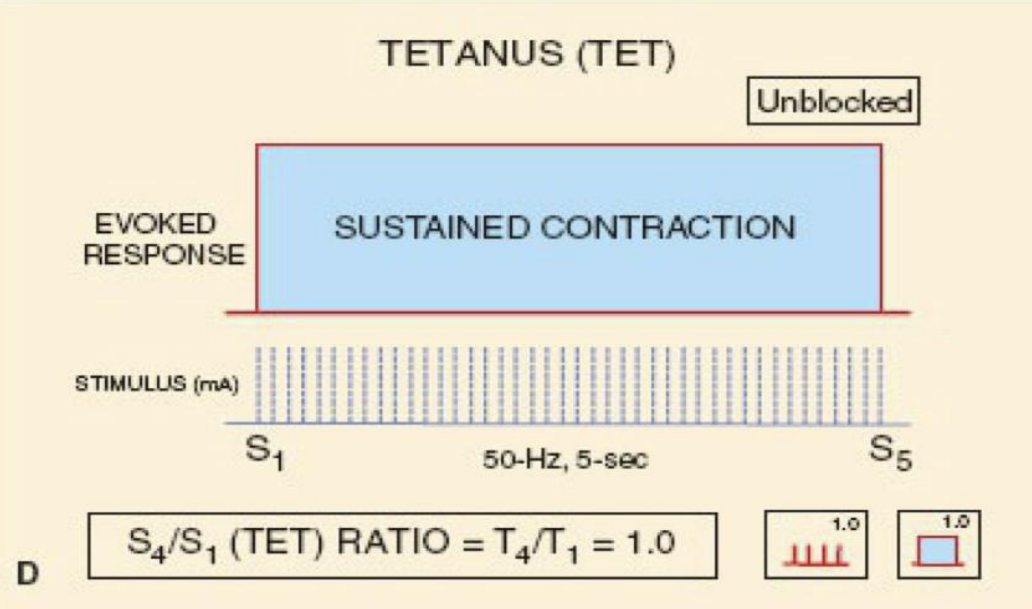
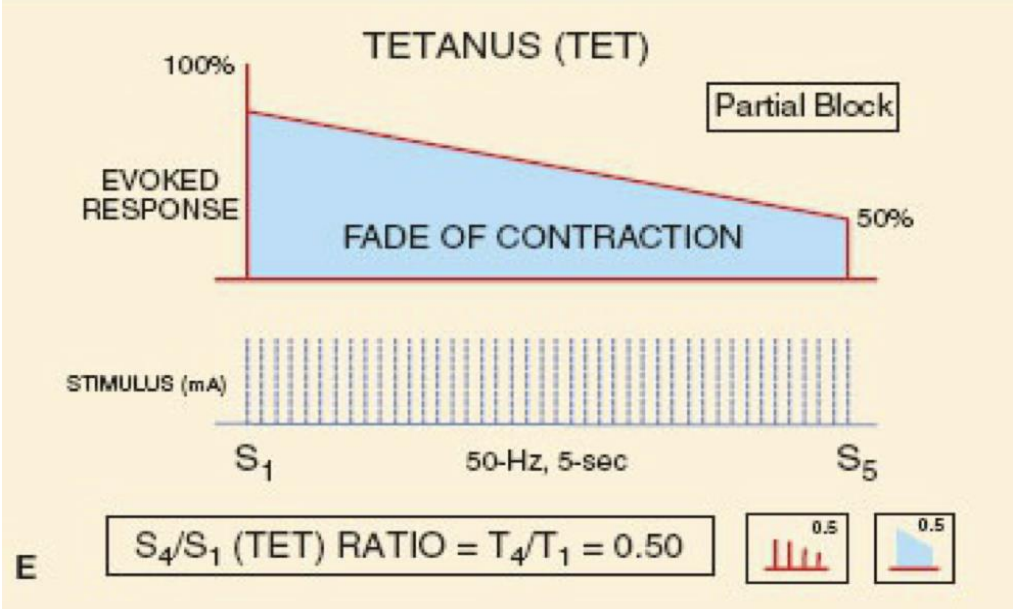
Tetanic stimulation





Application

- Evaluate residual block [sensitivity 70%, specificity 50%]
- *Able to differentiate depolarizing from nondepolarizing block*
- TET fade over 5 s = TOF fade

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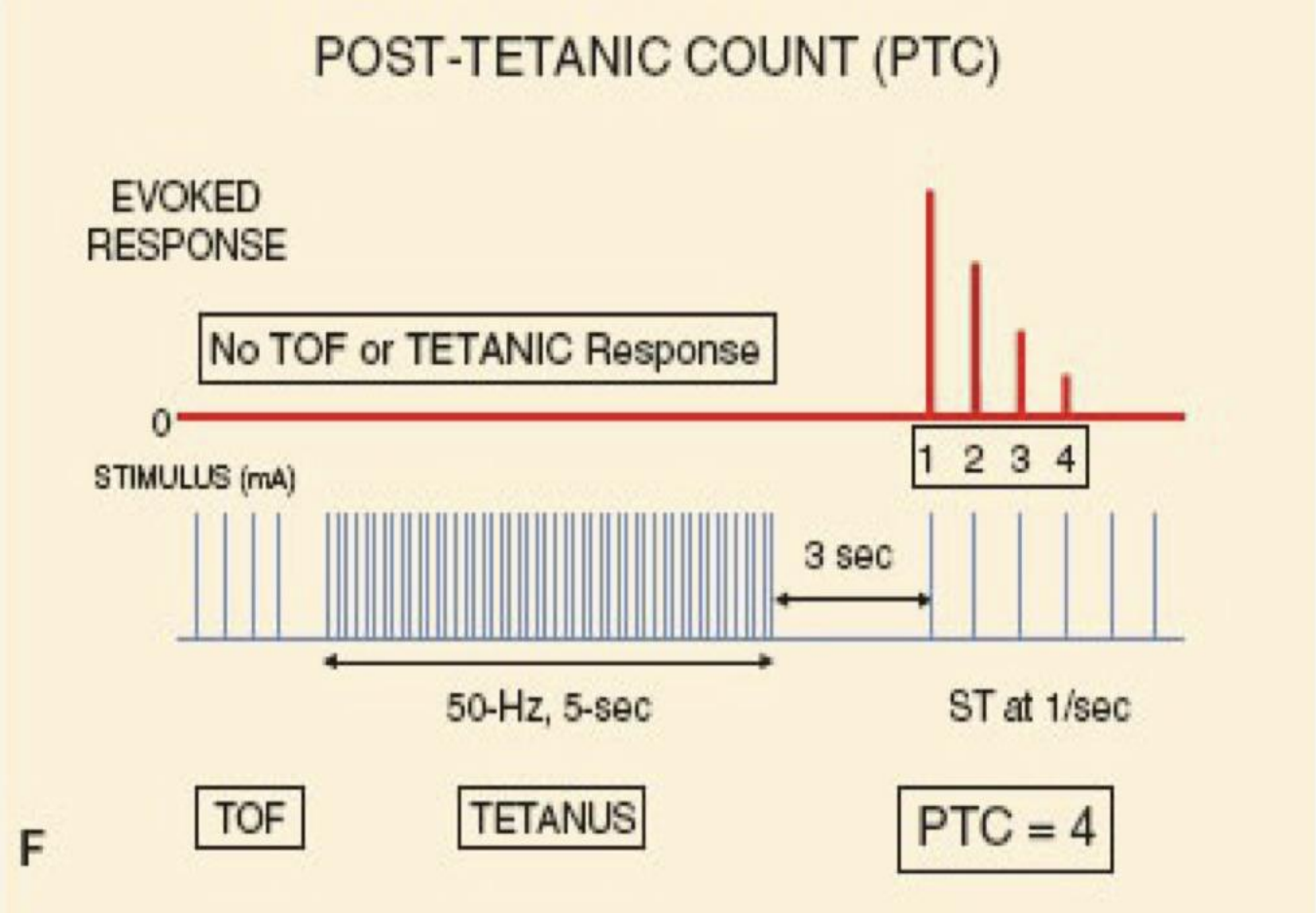
Post-tetanic count stimulation



Pattern

- TET at 50 Hz for 5 s followed 3 s later by 10-15 ST 1 Hz
- **PTC :** count of these discernible posttetanic twitches

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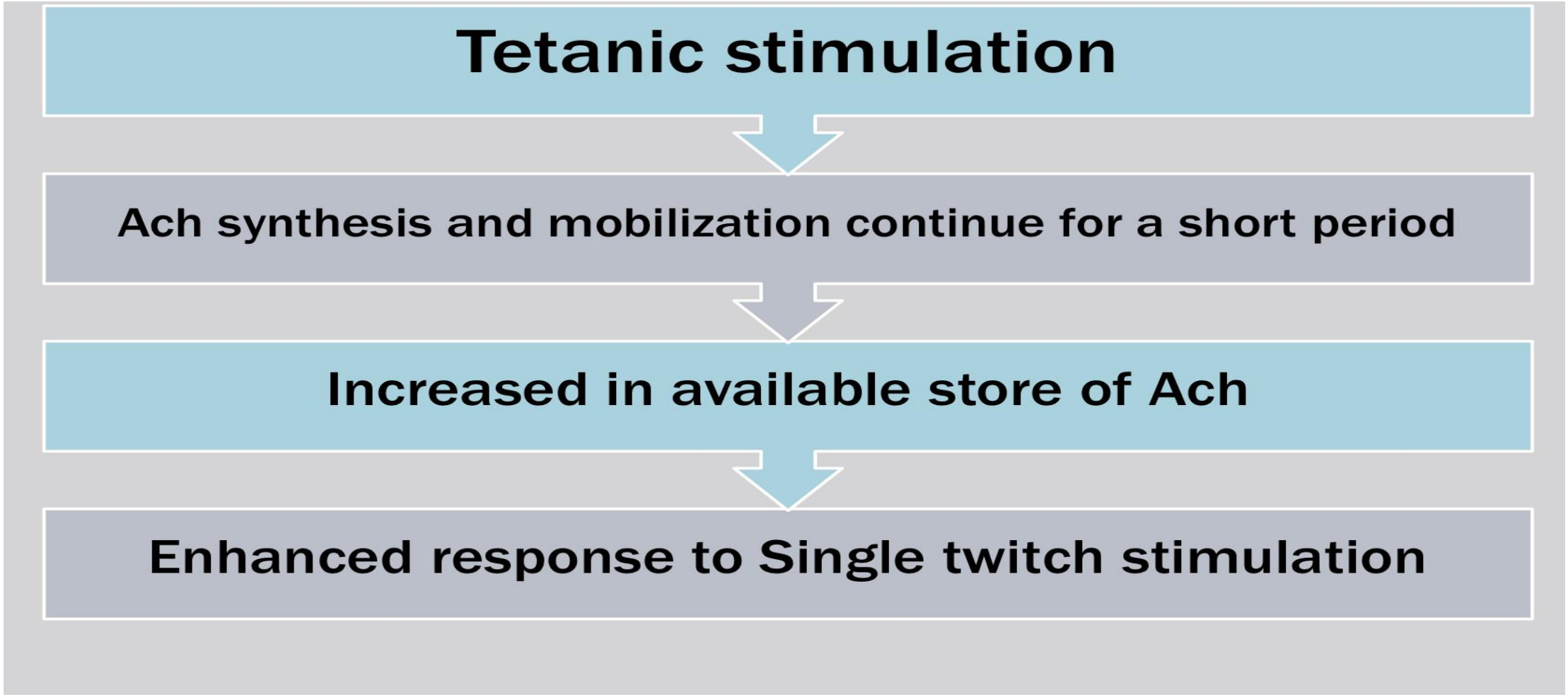
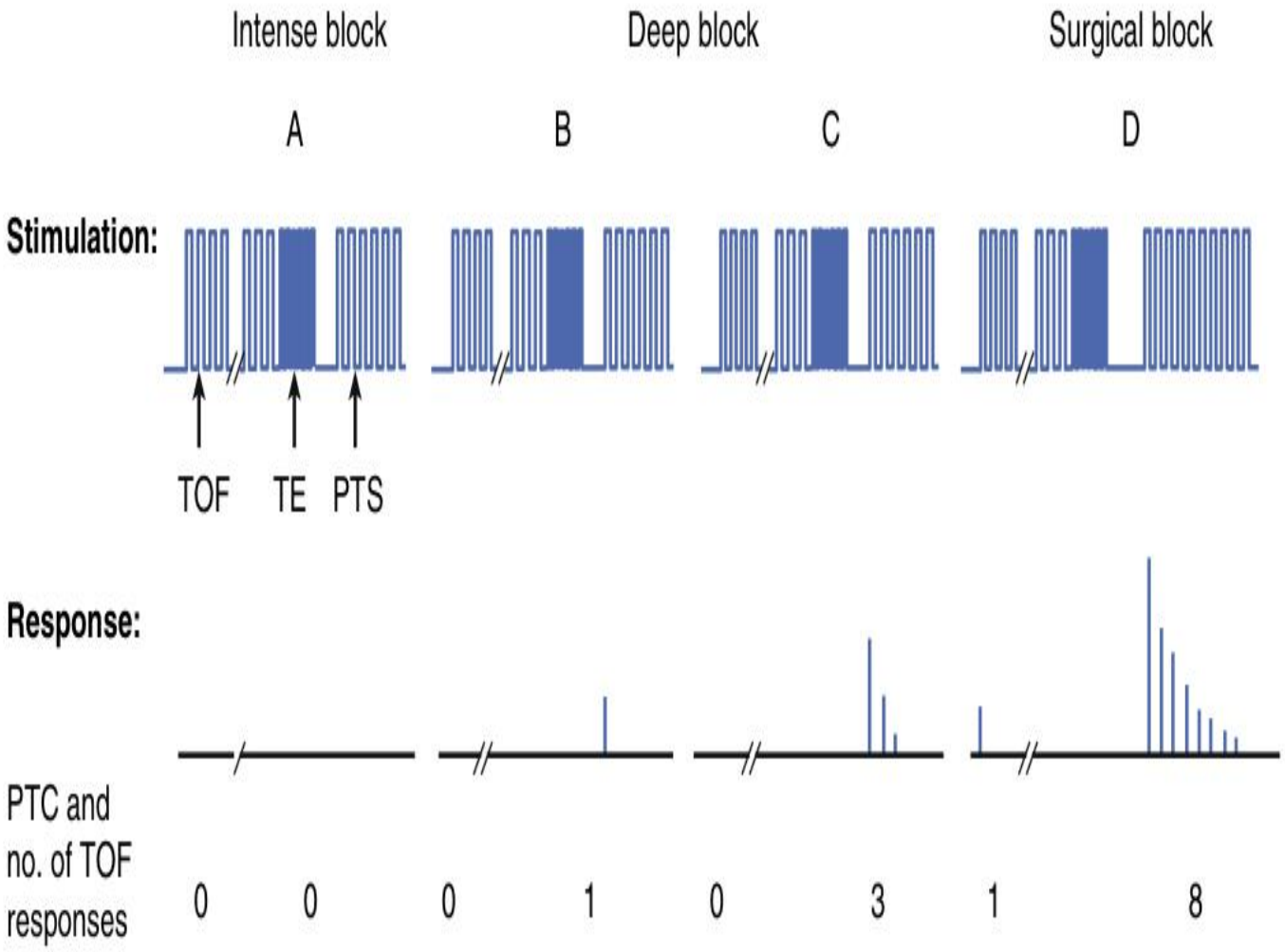
Post-tetanic count stimulation



Post-tetanic count stimulation



Application

- More PTC response indicate less block
- Profound block (TOFC =0)
- When PTC=0, NMBA administration is not recommended
- **Deep block :** PTC < 3
- 6-10 PTC = 1st TOF

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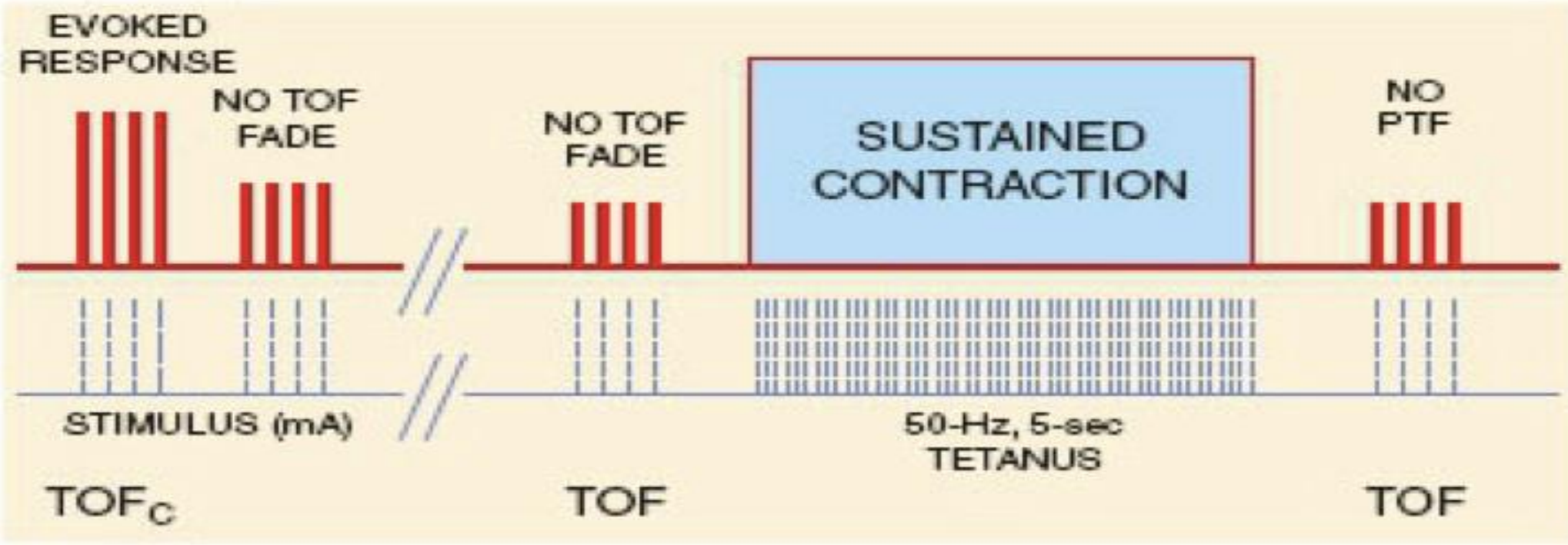
Post-tetanic count stimulation

- Interfere with neuromuscular block

- *not be performed more often than every 6 minutes*

- Clinical used : ophthalmic surgery, surgery in airways

Characteristic of depolarizing block



TOF amplitude : decreased without fade response

Lack of post-tetanic (5s) potentiation of evoked response

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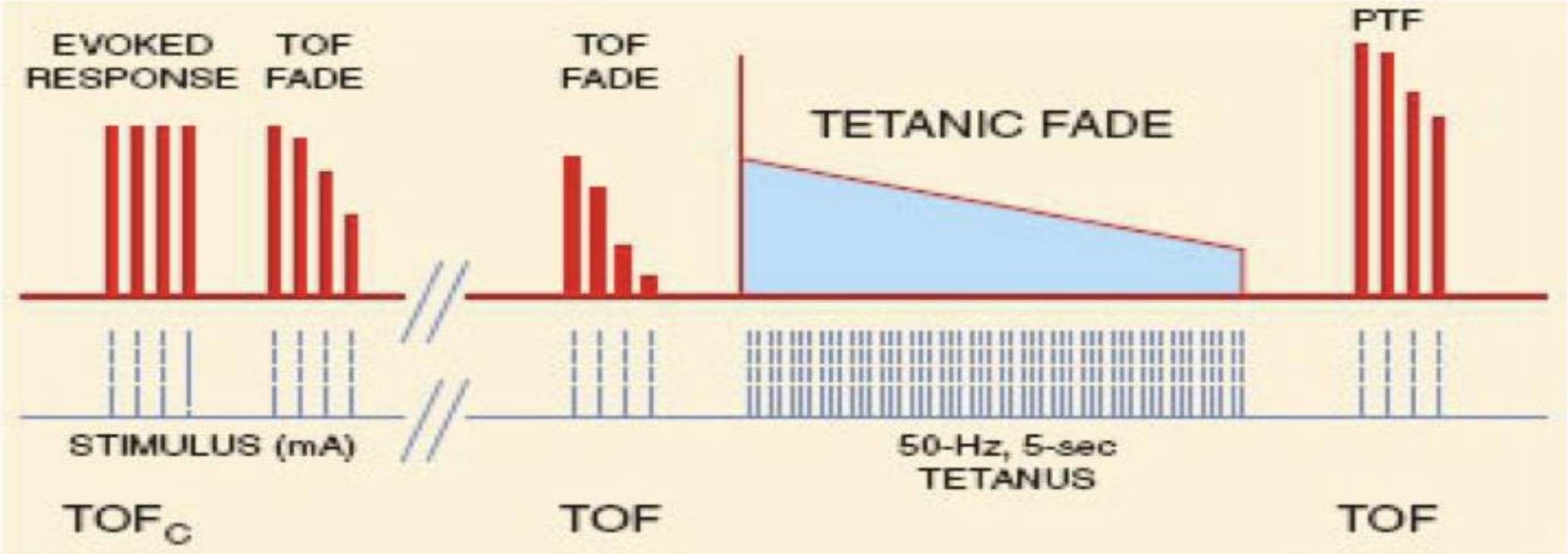
Characteristic of nondepolarizing block



TOF ratio : progressive decreased

TOF fade & tetanic fade (5s) followed by potentiation of evoked responses

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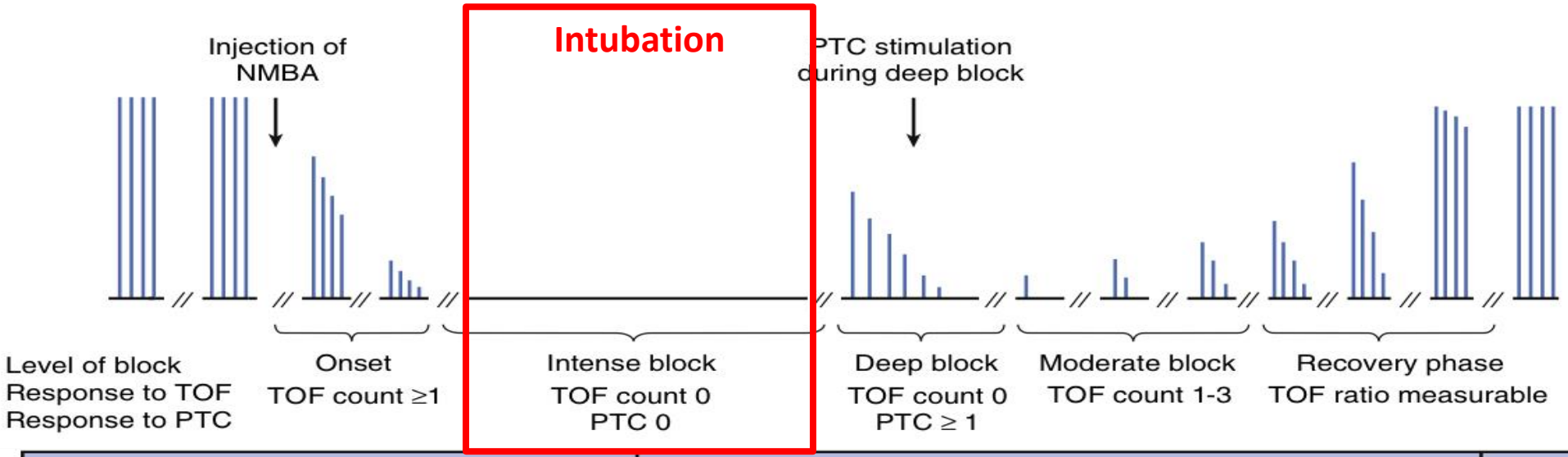
Clinical application of neuromuscular monitoring



	During induction			During surgery				In the recovery room
	Thiopental/ propofol	Supramaximal stimulation	Tracheal intubation	Intense blockade	Deep blockade	Moderate blockade	Reversal	
Single twitch		1.0 Hz	0.1 Hz					
TOF							?	
PTC								
DBS								

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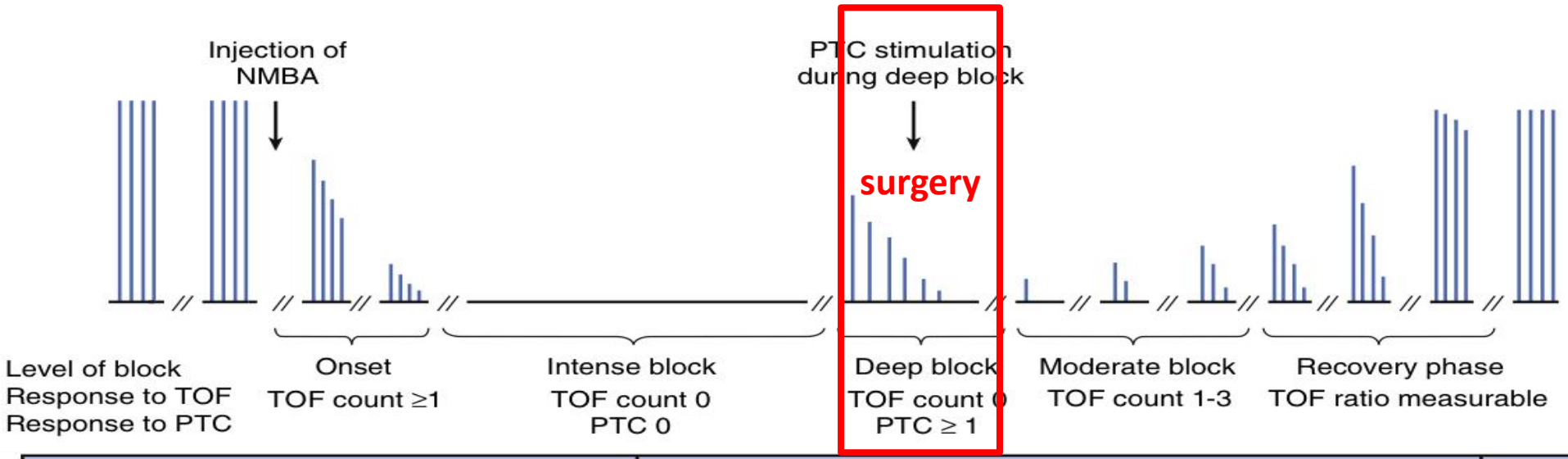
Clinical application of neuromuscular monitoring



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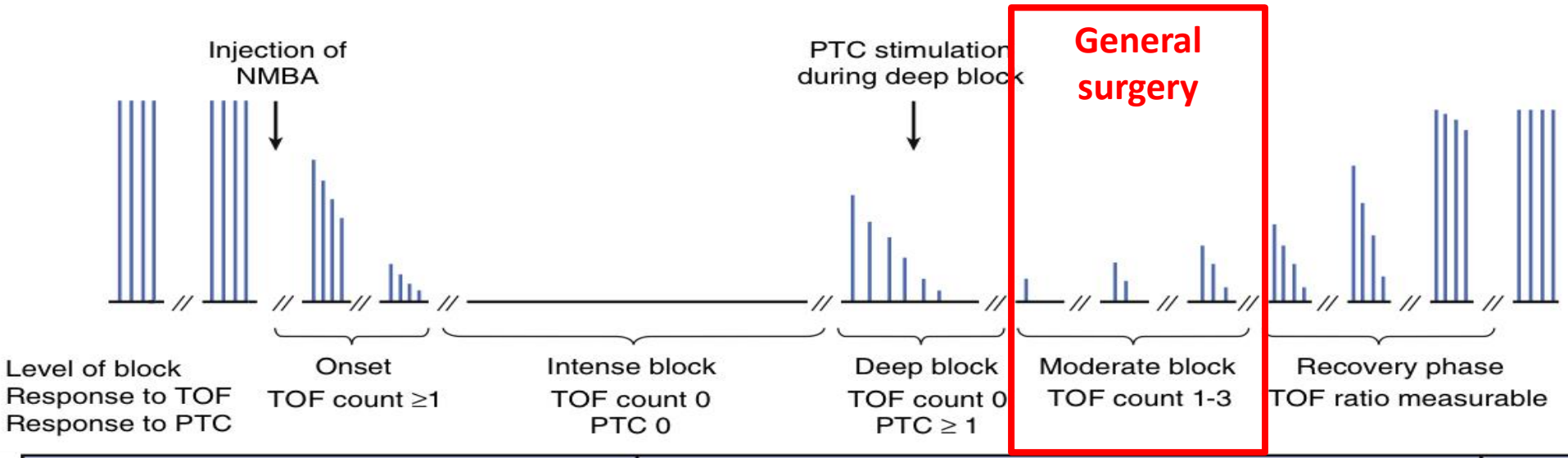
Single twitch		1.0 Hz	0.1 Hz					
TOF							?	
PTC								
DBS								

Miller's anesthesia : neuromuscular monitoring,9th ed;2020

Clinical application of neuromuscular monitoring



	During induction			During surgery				In the recovery room
	Thiopental/ propofol	Supramaximal stimulation	Tracheal intubation	Intense blockade	Deep blockade	Moderate blockade	Reversal	
Single twitch		1.0 Hz	0.1 Hz					
TOF							?	
PTC								
DBS								

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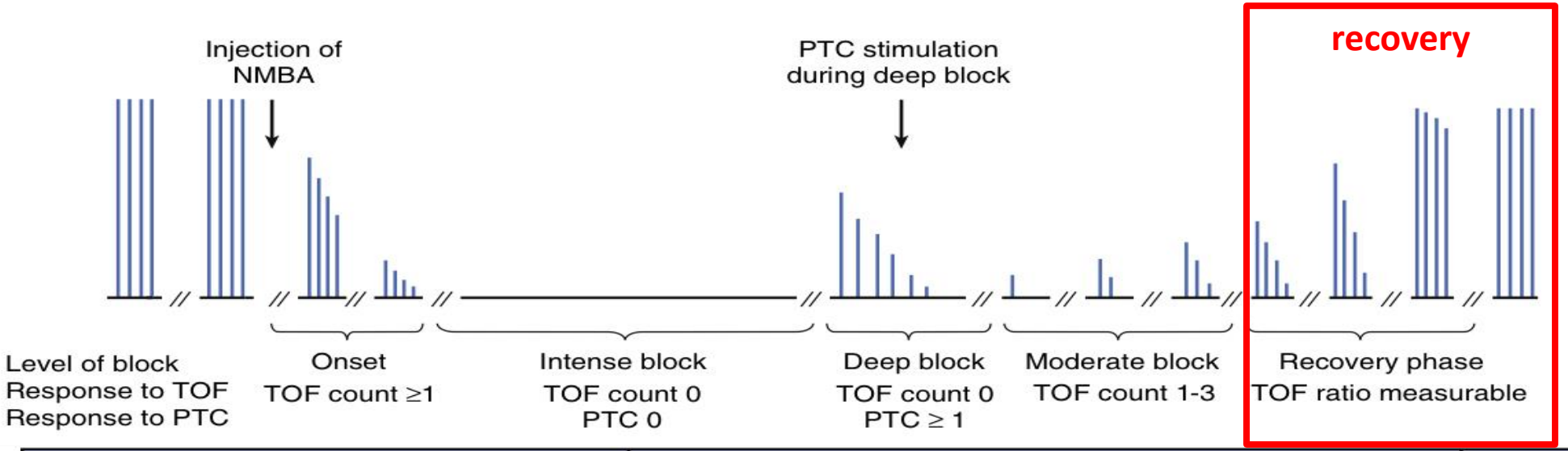

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Interpretations

BOX 43.1 Clinical Tests of Postoperative Neuromuscular Recovery

Unreliable

- Sustained eye opening
- Protrusion of the tongue
- Arm lift to the opposite shoulder
- Normal tidal volume
- Normal or nearly normal vital capacity
- Maximum inspiratory pressure less than 40-50 cm H_2O

More Reliable, But Still Not Excluding Residual Neuromuscular Block

- Sustained head lift for 5 s
- Sustained leg lift for 5 s
- Sustained handgrip for 5 s
- Sustained "tongue depressor test"
- Maximum inspiratory pressure

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Interpretations

TABLE 43.1 Clinical Signs and Symptoms of Residual Paralysis in Awake Volunteers after Mivacurium-Induced Neuromuscular Block

Train-of-Four Ratio	Signs and Symptoms
0.70-0.75	Diplopia and visual disturbances
	Decreased handgrip strength
	Inability to maintain apposition of the incisor teeth
	"Tongue depressor test" negative
	Inability to sit up without assistance
	Severe facial weakness
	Speaking a major effort
	Overall weakness and tiredness
0.85-0.90	Diplopia and visual disturbances
	Generalized fatigue

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TOFC & degree of neuromuscular block

Table 21-6 Relationship between % Receptor Occupancy and Train-of-Four Ratio during Nondepolarizing Block

Percent Receptor Occupancy (%)	First TOF Twitch (T_1) (% Baseline)	Fourth Twitch (T_4) (% Baseline)	TOF Ratio (T1–T4 Responses)	TOF COUNT (TOFC)
100	0%	0%	0	TOFC = 0
90–95	0%	0%	0 ($T_1 = 0$)	TOFC = 0
85–90	10%	0%	0 ($T_2 = 0$)	TOFC = 1
	20%	0%	0 ($T_3 = 0$)	TOFC = 2
80–85	25%	0%	0 ($T_4 = 0$)	TOFC = 3
	80%–90%	48%–58%	0.60–0.70	TOFC = 4
	95%	69%–79%	0.70–0.75	TOFC = 4
70–75	100%	75%–100%	0.75–1.00	TOFC = 4
	100%	100%	0.9–1.0	TOFC = 4
50	100%	100%	1.0	TOFC = 4
25	100%	100%	1.0	TOFC = 4

TOF, train-of-four; T_1, first twitch of TOF; T_2, second twitch of TOF; T_3, third twitch of TOF; T_4, fourth twitch of TOF; TOFC, train-of-four count.

TOFC = 1 : > 95% of nAchRs blocked

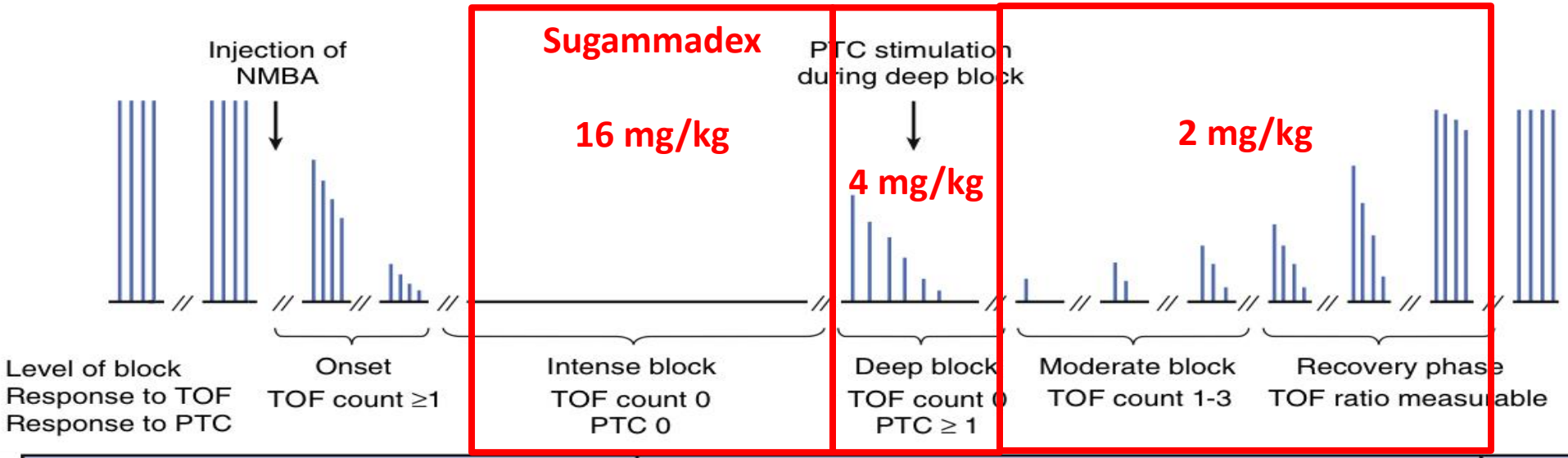
TOFC = 2 : 85-90% of nAchRs blocked

TOFC = 3 : 80-85% of nAchRs blocked

TOFC = 4 : 70-75% of nAchRs blocked

Clinical anesthesia 8th edition 2017; neuromuscular blocking agent ; monitoring neuromuscular blockade

Reversal when peripheral nerve stimulator available or quantitative NMM is unreliable



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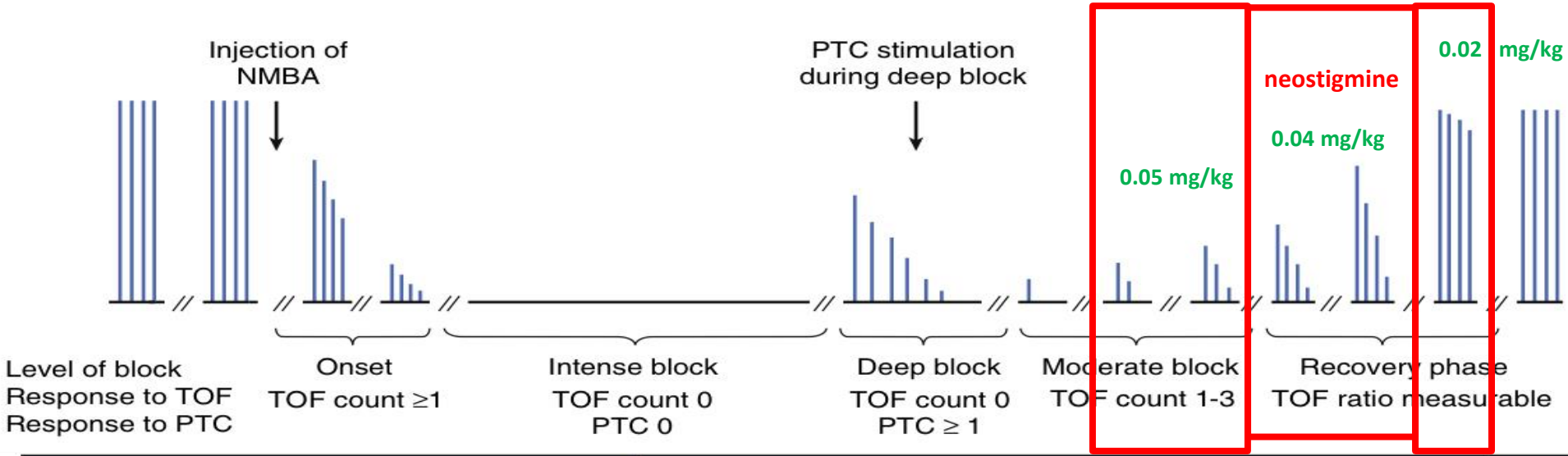

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Sensitivity pf patients with neuromuscular disease to NMBA

Disorder Type	Depolarizing NMBA Sensitivity	Nondepolarizing NMBA Sensitivity	Other Considerations
Neuromuscular transmission disorders[a]	Increased (myasthenia) Avoid use (Lambert–Eaton)	Increased	No increased risk of MH
Muscle and muscle membrane disorders[b]	Avoid use	Increased	No increased risk of MH (myotonic dystrophy, inflammatory myopathy, mitochondrial myopathy, Brody) Increased risk (Duchenne and Becker muscular dystrophy; central core and multiminicore disease; nemaline rod myopathy; King-Denborough and hyperCKemia)
Storage disorders (lipid, glycogen)[c]	Avoid use	Variable, avoid use if possible	Evidence of increased susceptibility to MH
Peripheral neuropathies[d]	Avoid use	Variable, avoid use if possible	No increased risk of MH
Central nervous system disorders with neuromuscular manifestations[e]	Avoid use	Increased	No increased risk of MH

Clinical anesthesia 8th edition 2017; neuromuscular blocking agent ; monitoring neuromuscular blockade

Take home message

Physiology of neuromuscular and disease that effecting to NMBA

Indication and benefit of neuromuscular monitoring

Proper application of each pattern of stimulation

Clinical application and prevent residual paralysis