Phonomyography on Perioperative Neuromuscular Monitoring

Subjects: Anesthesiology
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Muscle contraction by lateral movement of muscle fibers can create acoustic signals with a low frequency, and the signals that occur can be transmitted to the surface of the skin. After collection and filtration, these sound signals will be transferred into electric signals, which can be evaluated quantitatively for perioperative neuromuscular monitoring.

phonomyography acoustic myography neuromuscular monitoring

1. Introduction

Neuromuscular blockade (NMB), as the name implies, refers to a battery of agents that can specifically bind to the nicotinic receptor at the neuromuscular junction and thus block impulse transmission from the upper nerve to downstream muscle fibers, leading to transient or persistent skeletal muscle relaxation and aiding in easing endotracheal intubation and providing optimal conditions for operating and mechanical ventilation [1]. Many factors have been seen to affect the pharmacokinetics of NMB, such as age, organ function, or the apparent volume of distribution, requiring individualized NMB administration [2][3]. Hence, it is tricky for anesthesiologists to accurately maintain a shallow, moderate, or deep neuromuscular block at a proper time. However, an airway injury during endotracheal intubation, a sudden body-movement in surgical procedure, or a postoperative residual neuromuscular block (PRNB) during the reversal phase caused by the misjudgment of neuromuscular block may end in calamity [4][5][6]. Therefore, to reduce NMB-related complications, perioperative neuromuscular monitoring is highly recommended according to international guidelines to empower NMB with more controllability and to make NMB administration more individualized [7][8][9][10].

Typical perioperative neuromuscular monitoring methods (**Figure 1**) include acceleromyography (ACC), mechanomyography (MMG), electromyography (EMG), and kinemyography (KMG) [11]. ACC-based equipment chooses a sensor that can evaluate acceleration yielded by muscle contraction [12]. ACC can be applied in many muscles, such as the adductor pollicis muscle, the orbicularis oculi muscle, and the corrugator supercilii muscle [13]. It is currently regarded as the gold standard for scientific research and clinical practice. MMG, which measures force generated by muscle contraction, was once considered the gold standard of neuromuscular monitoring; however, it has been phased out due to its bulky setup. EMG-based equipment records compound action potentials from the target muscle. This technique is a desirable choice for neuromuscular monitoring in clinical settings and is also able to detect neuromuscular blocks at various muscles. KMG-based facilities utilize one kind of piezoelectric mechanosensory to obtain and reflect the contraction of the adductor pollicis muscle [13]. This method is easy to use and clinically reliable.

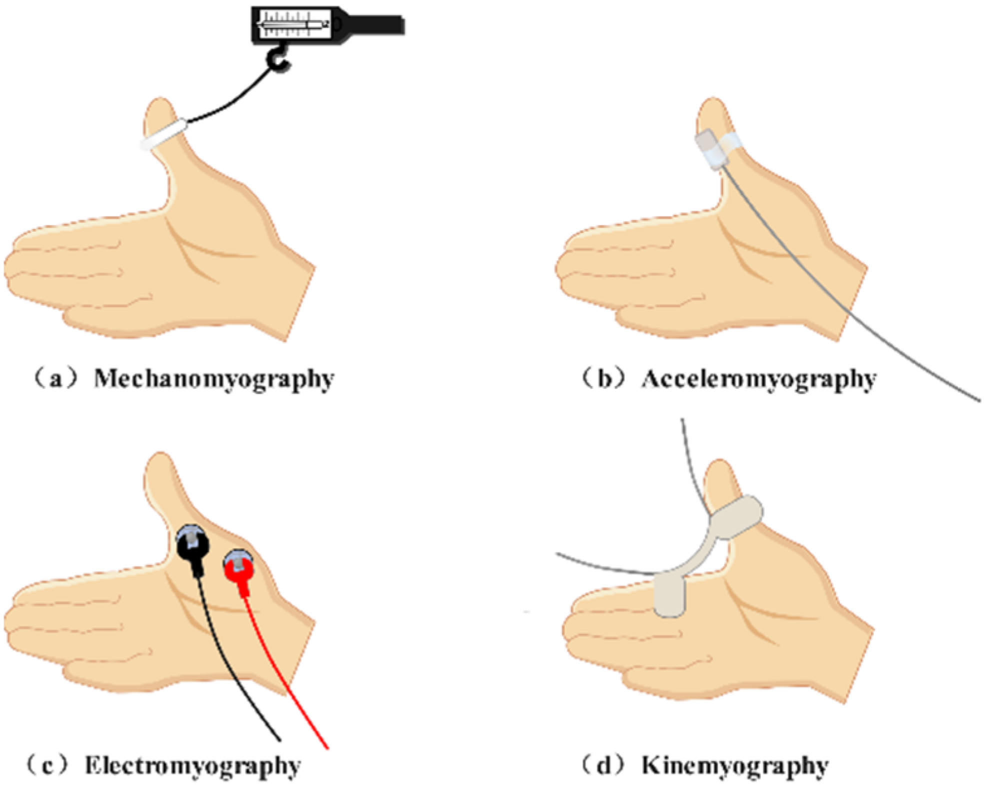

Figure 1. Typical neuromuscular monitoring patterns. (**a**) Mechanismography directly measures the force generated by the skeletal muscle. (**b**) Acceleromyography evaluates acceleration yielded by muscle contraction. (**c**) Electromyography records compound action potentials from the skeletal muscle. (**d**) Kinemyography employs a piezoelectric crystal to reflect muscle contraction.

However, frequently used neuromuscular monitoring patterns are always criticized for their diverse shortcomings (**Table 1**). Despite its universal utilization in clinical settings, ACC is susceptible to artifacts and will probably generate an overrated block degree [12][14]. A conventional ACC-based apparatus records the monaxial movement of the target muscle; therefore, signal quality relies heavily on the posture of the recording sites [15]. Recently, ACC-based equipment capable of estimating the multiplanar movement of the thumb has been developed. However, its feasibility exploration is still in progress [16]. The application of MMG demands a special posture of the hand and an elaborate setup [17]. In addition, this method can only record signals at the adductor pollicis muscle [18]. For EMG, the working principle limits its application intraoperatively owing to disturbances from other electronic equipment in the operating room [19]. In addition, the recording result of the EMG is an electromechanical compound instead of absolute mechanical contraction of skeletal muscle. Similar to MMG, KMG is also subjected to hand position [11]. Moreover, KMG is not interchangeable with MMG according to existing investigations [20].

Table 1. Features of classical neuromuscular monitoring patterns.

Neuromuscular Monitoring Methods	Objects Detected	Recording Sites	Drawbacks
Acceleromyography	Acceleration	Adductor pollicis muscle Corrugator supercilii muscle …	Miscalculation of the block degree Susceptible to outside interference Elaborate setup
Mechanomyography	Force	Adductor pollicis muscle	Harsh conditions for the hand posture Adductor pollicis muscle only
Electromyography	Compound action potentials	Adductor pollicis muscle Corrugator supercilii muscle Orbicularis oculi muscle Laryngeal muscle Diaphragm…	Susceptible to electrical interference Not purely reflection of mechanical contraction of muscles
Kinemyography	Movement	Adductor pollicis muscle	Harsh conditions for the hand posture Adductor pollicis muscle only Not interchangeable with MMG

Phonomyography (PMG), also named acoustic myography, is a little-known neuromuscular monitoring technique. However, previous studies suggested that PMG may be a feasible alternative neuromuscular monitoring method. The entry provides an overview of the evolutionary trajectory of PMG on perioperative neuromuscular monitoring chronologically and summarizes the advantages and drawbacks of PMG as a means to present an avenue for further research. Researchers performed a PubMed search using the keywords “phonomyography”, “acoustic myography”, and “muscle sounds” updated to December 2021. Articles describing PMG on perioperative neuromuscular monitoring are displayed in **Table 2**.

Table 2. Articles describing PMG on perioperative neuromuscular monitoring.

Author/Year	Sample Size	Sound Detector	Control	Muscle	Muscle Relaxant	Main Conclusion
Dascalu 1999 [21]	25	Air-coupled microphone	MMG EMG ACC	Adductor pollicis muscle	Tubocurarine Atracurium Succinylcholine	PMG could be used for perioperative neuromuscular monitoring
Bellemare 2000 [22]	13	Condenser microphone	MMG	Adductor pollicis muscle	Rocuronium	PMG was not an alternative method for neuromuscular monitoring at the adductor pollicis

Author/Year	Sample Size	Sound Detector	Control	Muscle	Muscle Relaxant	Main Conclusion
						muscle when compared with MMG
Hemmerling 2002 [23]	20	Condenser microphone	ACC	Corrugator supercilii muscle	Mivacurium	PMG was not an alternative method for neuromuscular monitoring at the corrugator supercilii muscle when compared with ACC
Hemmerling 2002 [24]	27	Condenser microphone	ACC	Corrugator supercilii muscle	Mivacurium	The best recording site at the corrugator supercilii muscle for PMG is located between the anterior midline and the lateral part of the forehead, over the eyebrow
Hemmerling 2003 [25]	28	Condenser microphone	Cuff pressure method	Laryngeal adductor muscles	Mivacurium	PMG was an alternative method for neuromuscular monitoring at the laryngeal adductor muscles when compared with the cuff pressure method
Hemmerling 2004 [26]	15	Condenser microphone	Balloon pressure MMG	Corrugator supercilii muscle	Mivacurium	PMG was an alternative method for neuromuscular monitoring at the corrugator supercilii muscle when compared with Balloon pressure MMG
Hemmerling 2004 [27]	12	Condenser microphone	MMG	Hand muscles	Rocuronium	PMG was an alternative method for neuromuscular monitoring at hand muscles muscle when compared with MMG

Author/Year	Sample Size	Sound Detector	Control	Muscle	Muscle Relaxant	Main Conclusion
Hemmerling 2004 [28]	28	Condenser microphone	MMG	Adductor pollicis muscle	Mivacurium	PMG was an alternative method for neuromuscular monitoring at the adductor pollicis muscle when compared with MMG
Hemmerling 2004 [29]	12	Condenser microphone	-	Posterior cricoarytenoid muscle /Lateral cricoarytenoid muscle	Mivacurium	The acoustic signals created by the posterior cricoarytenoid muscle and the lateral cricoarytenoid muscle after the administration of muscle relaxants are different.
Deschamps 2005 [30]	10	Piezo-electric microphone	MMG	Corrugator supercilii muscle/The first dorsal interosseus muscle	-	An apparent staircase phenomenon was found at the first dorsal interosseus muscle and the adductor pollicis muscle while no obvious staircase phenomenon occured at the corrugator supercilii muscle.
Hemmerling 2005 [31]	12	Piezo-electric microphone	-	Lateral cricoarytenoid muscle /Strap muscles of the neck	Mivacurium	PMG signals recorded were different outside and inside of the trachea for recovery time.
Michaud 2005 [32]	15	Piezo-electric microphone	-	Vastus medialis muscle Adductor pollicis	Mivacurium	The vastus medialis muscle is an alternative recording site for PMG
Michaud 2005 [33]	14	Piezo-electric microphone	-	Adductor pollicis muscle	Mivacurium	Whether it is the dominant hand would not influence the rustles of PMG recording at the

Author/Year	Sample Size	Sound Detector	Control	Muscle	Muscle Relaxant	Main Conclusion
						adductor pollicis muscle
Trager 2006 [18]	14	Piezo-electric microphone	MMG KMG	Adductor pollicis muscle	Mivacurium	PMG was an alternative method for neuromuscular monitoring at the adductor pollicis muscle when compared with MMG or KMG
Hemmerling 2008 [34]	28	Piezo-electric microphone	-	Adductor pollicis muscle	Mivacurium	The potency of mivacurium is greater after a 20 min infusion of propofol compared with a 5 min infusion of propofol
Wehbe 2012 [35]	1	Piezo-electric microphone	-	Adductor pollicis /Corrugator supercilii muscle	Not mentioned	“Relaxofon” may be a feasible neuromuscular monitoring device

2. The development of PMG on perioperative neuromuscular monitoring

The history of PMG-based equipment can be roughly divided into two categories (**Figure 2**): (1). Theoretical derivation and early exploration; (2). Applied research and technique renovation.

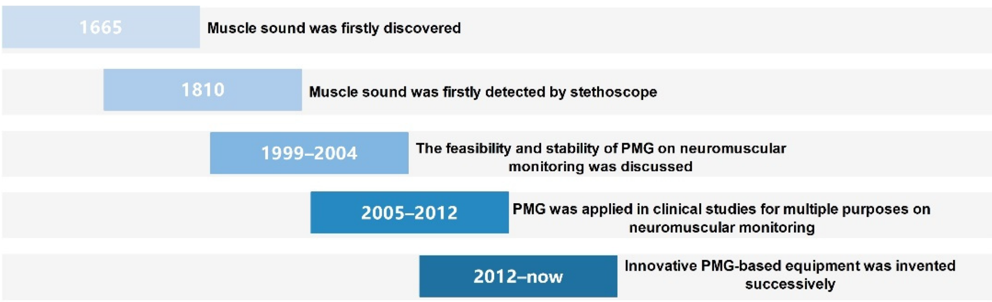

Figure 2. Timeline for the progression of PMG on perioperative neuromuscular monitoring.

3. The merits, demerits and challenges of PMG-based equipment on perioperative neuromuscular monitoring

The properties of PMG in perioperative neuromuscular monitoring are as follows: (1) PMG-based equipment is easy to install and apply; (2) PMG-based equipment may present a stable signal that is barely affected by outside factors owing to its low frequency quality; and (3) PMG-based equipment is able to assess neuromuscular monitoring at the adductor pollicis muscle, corrugator supercilii muscle, vastus medialis muscle, first dorsal interosseus muscle, hypothenar muscles, and laryngeal muscles.

The short board of the PMG is equally obvious. On the one hand, the same target muscle of different individuals may create dissimilar muscle sounds. This can be explained by different muscle qualities, internal environments of muscle cells, and firing rates of motor units in different patients. On the other hand, although high-frequency noises have been filtered, some coexisting low-frequency noises, such as heart sounds, breath sounds, and vascular sounds, may still be disturbances.

As the form of PMG-based equipment is still presently on the phase of the assembled prototype, problems related to signal gathering, analysis and display remain to be solved. First, the improvement of sound detectors is the main focus. Recently, microphones with cylindrical and conical acoustic chambers have been developed. This implies that the air-coupled microphones will soon return to the stage center. In addition, the most advanced microphones in previous studies are piezoelectric microphones and condenser microphones with a diameter of 1.6 cm. There is no question that current technology would give birth to more sophisticated sound detectors that are more suitable for gathering sound signals from other small muscles. It is worth noting that some delicate microphones with air chambers have been utilized in the study of prosthesis control [36]. Second, the data presented in previous studies are just filtered raw data. The method of data analysis is an unavoidable topic during the process of productization of PMG-based equipment. Information mining beyond amplitude from both the time and frequency domains of PMG is still a tricky problem. Researchers believe artificial intelligence will be a potential choice. Third, as calibration endows ACC-based equipment with individualized monitoring experience, PMG-based equipment may also need a calibration technique because of different muscle qualities and muscle masses in different individuals. Finally, only hand muscles, the corrugator supercilii muscle, the vastus medialis muscle, and the laryngeal muscles are not sufficient for the increasing number of surgical approaches. It is urgent to determine more alternative recording sites, such as the trapezius muscle, when the prone position is performed during nephrectomy or spinal surgery.

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