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ORIGINAL RESEARCH

Train-of-four monitoring with the twitchview monitor electctromyograph compared to the GE NMT electromyograph and manual palpation

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Abstract
The purpose of this study was to compare train-of-four count and ratio measurements with the GE electromyograph to the TwitchView electromyograph, that was previously validated against mechanomography, and to palpation of train-of-four count. Electrodes for both monitors were applied to the same arm of patients undergoing an unrestricted general anesthetic. Train-of-four measurements were performed with both monitors approximately every 5 min. In a subset of patients, thumb twitch was palpated by one of the investigators. Eleven patients contributed 807 pairs of train-of-four counts or ratios. A subset of 5 patients also contributed palpated train-of-four counts. Bland–Altman analysis of the train-of-four ratio found a bias of 0.24 in the direction of a larger ratio with the GE monitor. For 72% of data pairs, the GE monitor train-of-four ratios were larger. For 59% of data pairs, the GE monitor train-of-four counts were larger ($p < 0.0001$). For 11% of data pairs, the GE monitor train-of-four count was 4 when the Twitchview monitor count was zero. When manual palpation of train-of-four count was compared to train-of-four count determined by the monitors, 70% of data pairs were identical between palpation and TwitchView train-of-four count, while 30% of data pairs were identical between palpation and GE train-of-four count. For 7% of data pairs, the GE monitor train-of-four count was 4 when the palpation count was 0. The GE electromyograph may overestimate the train-of-four count and ratio. The GE electromyograph frequently reported 4 twitches when none were actually present due to misinterpretation of artifacts.

Keywords Neuromuscular blockade: assessment · Electromyography · Train-of-four ratio · Train-of-four count

1 Introduction

Quantitative monitoring of train-of-four count (0–4 twitch responses evoked by a train-of-four stimulus) and train-of-four ratio (ratio between the fourth and first evoked twitch response) has been widely recommended for managing neuromuscular blockade and assessing the adequacy of recovery [1–3]. Quantitative monitoring has been most commonly performed with acceleromyography or electromyography in the clinical setting. Mechanomyography is usually considered to be the laboratory "gold standard" for quantitative monitoring [3–5], although it is not suitable for clinical monitoring and is not commercially available. Comparative studies have suggested that electromyography may be very similar or interchangeable with mechanomyography [6, 7]. We have previously validated the TwtichView Monitor electromyograph against mechanomyography, and found comparable results for both train-of-four counting [8] and train-of-four ratio [9]. The performance of the GE Healthcare NeuroMuscular Transmission Module (NMT) electromyograph has been questioned by several authors. Stewart et al. [10] and Salminen et al. [11] concluded that GE electromyography and kinemyography were not "interchangeable". Dubois et al. reported a case in which artifacts were incorrectly interpreted as twitches by the GE monitor. This resulted in the monitor incorrectly reporting a train-of-four ratio in the absence of 4 twitches [12]. A study of

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implemention of the GE electromyograph in an academic medical center by Todd et al. also suggested operational issues with the GE monitor, particularly the possibility of sometimes misinterpreting artifacts as twitches. Todd et al. noted that— "Artifactual recordings are also common, and users must be trained to recognize these. Accurate use was not possible when only the bar graph display was used. We hence reconfigured all our monitors to routinely display the EMG waveforms." [13] To further assess the performance of the GE electromyograph, we compared train-of-four count and train-of-four ratio measurements to simultaneous measurements with the TwitchView electromyograph, and to manual palpation of the thumb twitch count.

2 Methods

Our institutional review board approved this study and patients gave written, informed consent. Patients with known neuromuscular abnormalities were excluded.

We compared the TwitchView Monitor (Blink Device Company, Seattle WA, USA) to the GE Healthcare Neuromuscular Transmission Module (E-NMT-01; GE Healthcare, Waukesha WI, USA). TwitchView electromyography electrode arrays (Blink Device Company, Seattle, WA, USA) were used for the TwitchView Monitor. For the GE electromyograph five electrocardiogram electrodes (3 M Red Dot, 3 M Healthcare, St. Paul MN) were applied, two over the ulnar nerve for stimulation, one over the medial nerve at the wrist, one on the distal end of the first digit, and one over the adductor pollicis as described in the instructions for use (Fig. 1). The electrodes for both monitors were placed on the same arm, in order to minimize arm-to-arm differences in response that may occur under some circumstances [14]. The amplitude of the train-of-four stimulus was set to 60 mA in all cases. No skin prep was performed prior to attaching any of the electrodes. Temperature homeostasis was maintained through the use of active warming. End tidal CO2 was maintained between approximately 32 and 40 mmHg. The anesthesia technique including the choice of anesthetic and neuromuscular blocking agents was at the discretion of the anesthesia care team and included propofol, opioids (mainly fentanyl and hydromorphone), sevoflurane, isoflurane, rocuronium and vecuronium.

Whenever possible, baseline measurements of twitch count and train-of-four ratio were taken with each device after anesthetic induction but prior to initial administration of neuromuscular blocking drug. However, in some cases it was not possible to complete baseline measurements before the neuromuscular blocking drug was given. All train-of-four measurements were made in duplicate (i.e. two measurements were taken in a time span of less than 2 min) for each device approximately every five minutes from induction

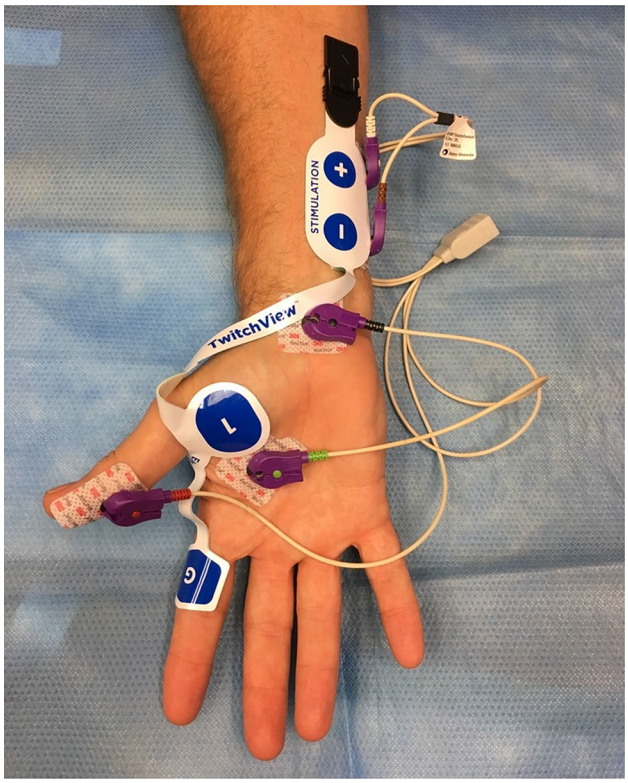

Fig. 1 Electrodes were attached to the same arm according to the instructions for use for the TwitchView Monitor and GE NMT

of anesthesia until just before emergence from anesthesia. Measurements were not made for 10 min following administration of neuromuscular blocking drugs or reversal agents in order to avoid periods when the extent of neuromuscular blockade was changing very rapidly. In a subset of 5 patients, twitch count was determined by palpation by one of the investigators (LB) as well as by the twitch monitors.

3 Results

Eleven patients participated in this study. Patient characteristics are shown in Table 1. A total of 807 pairs of train-of-four counts or ratios were collected.

3.1 Train-of-four ratio

Bland–Altman analysis found a bias of 0.24 with the GE monitor displaying a higher train-of-four ratio than the TwitchView monitor (Fig. 2). For 72% of data pairs, the GE monitor train-of-four ratios were larger than the TwitchView monitor train-of-four ratios. For 17% of data pairs GE values were ≥ 0.9 (representing recovery) while the TwitchView values were < 0.9 (representing that recovery has not been reached). For 23% of data pairs GE values were ≥ 0.7

Table 1 Patient characteristics

Number of patients	11
Age (mean, SD, range)	47.5, 12.2, 31–71
Sex (F)	7 (64%)
BMI (mean, SD, range)	30.1, 3.4, 18.2–38.5
ASA (1–5)	
1	0
2	3 (27%)
3	6 (54%)
4	2 (18%)
5	0
Duration of surgery, min (mean, SD, range)	375, 182, 67–627
Types of surgery	
Gen	7(64%)
Gyn	4 (36%)
Individual ratio measurements per patient (with 4 twitches present across any compared devices) (mean, SD, range)	16, 17, 0–53
Individual count measurements per patient (0–4 twitch responses) (mean, SD, range)	67, 64, 16–235
Number of patients with manual palpation	5 (45%)
Number of patients receiving rocuronium	9 (82%)
Number of patients receiving vecuronium	2 (18%)
Number of patients receiving neostigmine	6 (54%)
Number of patients receiving sugammadex	5(45%)

but < 0.9 (indicated residual neuromuscular blockade that is not severe), while the TwitchView values were < 0.7 (indicating severe residual blockade).

3.2 Train-of-four counting

For 59% of the data pairs, the GE monitor train-of-four count was larger than the TwitchView monitor train-of-four count, while for only 4% of data pairs, the TwitchView monitor train-of-four count was larger than the GE monitor train-of-four count ($p < 0.0001$) (Fig. 3). For 11% of data pairs, the GE monitor train-of-four count was 4 when the Twitchview monitor count was zero. When manual palpation of train-of-four count was compared to train-of-four count determined by the GE and TwitchView monitors, there was close agreement (70% of data pairs identical) between palpation and TwitchView train-of-four count (Fig. 4), while there was frequent disagreement (30% of data pairs identical) between palpation and GE train-of-four count (Fig. 5). For 7% of data pairs, the GE monitor train-of-four count was 4 when the palpation count was 0.

We observed numerous instances in which the GE monitor electromyography signal appeared to show artifact that was counted as twitches, often at a time when there were no twitches or fewer twitches detected by the TwitchView monitor. An example of this observation is shown in the screenshots of Fig. 6.

4 Discussion

In this study we compared the GE electromyograph to the TwitchView electromyograph monitor. While mechanomyography is the traditional "gold standard" for twitch measurement, electromyography has been suggested to be similar or interchangeable with mechanomyography [6, 7]. In previous studies of the TwitchView monitor we found that train-of-four counting [8] and train-of-four ratio measurement [9] were very similar to mechanomyography. On this basis, we believe that it is reasonable to use the TwitchView monitor in this study as a standard for comparison to the GE electromyograph monitor. In addition, we compared both monitors to palpation for train-of-four counting.

We found that the GE electromyograph monitor is prone to erroneously interpreting artifact, especially signal artifact from ulnar nerve stimulation, as twitch data. This results in the GE monitor frequently counting a larger train-of-four count than the TwitchView monitor or palpation. It was not uncommon for the GE monitor to count 4 twitches when none were found with TwitchView or palpation. Our results agree with anecdotal observations made previously by others [12, 13].

When four twitches were present, allowing calculation of a train-of-four ratio, the GE monitor tended to measure a larger train-of-four ratio than the TwitchView monitor, as indicated by a bias of 0.24 (Fig. 2). The reason for this is unclear. If electrical artifact is not adequately distinguished

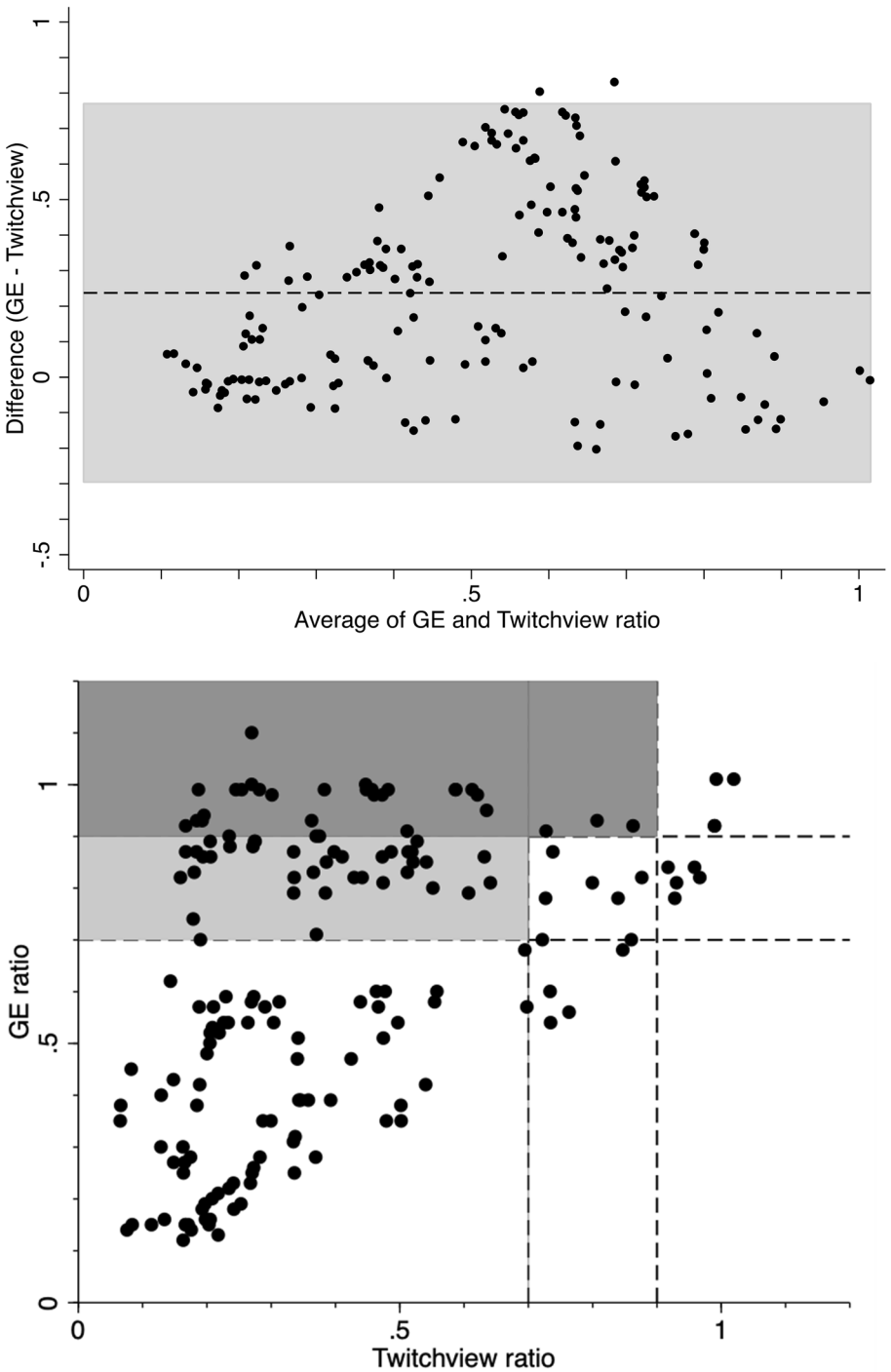

Fig. 2 Upper panel. The Bland–Altman plot of the average difference between the TwitchView and GE train-of-four ratio is shown. There is a bias of 0.24 with the GE having a larger train-of-four ratio. Lower panel. A scatter plot of the TwitchView and GE train-of-four ratios. In order to better appreciate the clinical significance of the differing results from the monitors, 2 greyscale zones have been indicated on the plot, as follows. A train-of-four ratio of ≥ 0.9 is considered to represent clinical recovery from neuromuscular blockade. Values < 0.9 at the time of extubation would represent residual neuromuscular blockade, with a value of < 0.7 representing "severe" residual blockade [16]. Therefore, the data pairs in which the GE values are ≥ 0.9 (representing recovery) while the TwitchView values are < 0.9 (representing that recovery has not been reached), have been designated by a greyscale box. Another greyscale box indicates the data pairs in which the GE values are ≥ 0.7 but < 0.9 (indicated residual neuromuscular blockade that is not severe), while the TwitchView values are < 0.7 (indicating severe residual blockade)

from twitch signal, artifact could make the twitch signal appear larger than it actually is, and this could inflate the train-of-four ratio.

There are several limitations. We aimed to follow good clinical research practice for studies of neuromuscular blocking drugs, as recommended by Fuchs-Buder et al. [4]. However, we deliberately chose not to standardise the anesthetic care or neuromuscular blocker administration, in order to obtain results that would be applicable to routine anesthetic care. One of the disadvantages of this approach was that in some cases, patients were managed under deep block for most of the surgical procedure, limiting the opportunity to measure train-of-four. Because of this, some patients contributed more data points than others. We deliberately chose not to prepare the skin prior to applying electrodes, because in our experience this measure is not widely used in

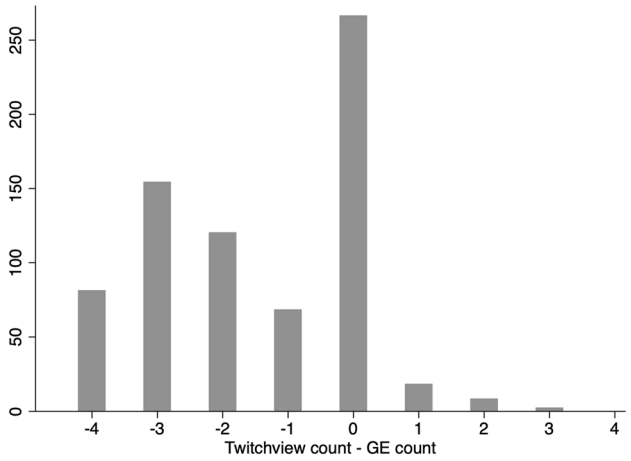

Fig. 3 The difference in train-of-four count for each pair of TwitchView and GE counts is shown. The GE count was subtracted from the TwitchView count, therefore when the GE count was larger it is displayed as a negative difference, and when the GE count was smaller it is displayed as a positive difference. Note that for 81/717 data pairs the TwitchView count was zero while the GE count was 4

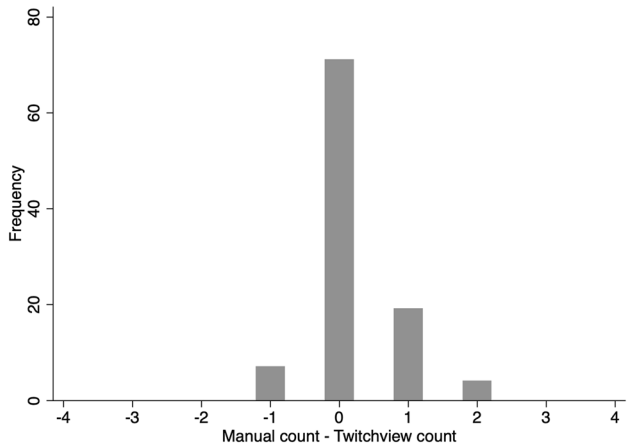

Fig. 4 The difference in train-of-four count for each pair of TwitchView and palpation counts is shown. The TwitchView count was subtracted from the palpation count, therefore when the TwitchView count was larger it is displayed as a negative difference, and when the TwitchView count was smaller it is displayed as a positive difference

anaesthesia practice. We compared electromyograph signal quality on a number of healthy volunteers before and after skin preparation using either alcohol or mild skin abrasion.

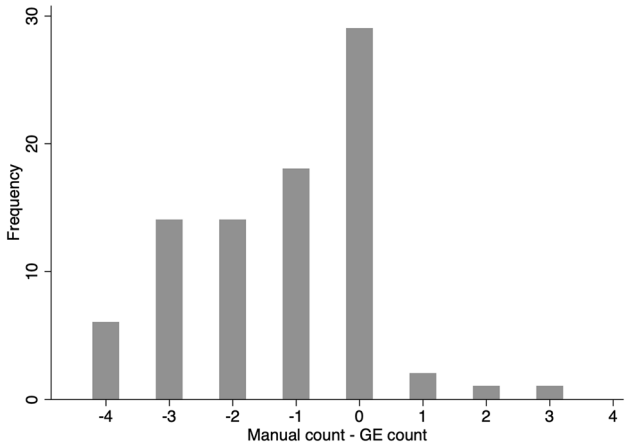

Fig. 5 The difference in train-of-four count for each pair of GE and palpation counts is shown. The GE count was subtracted from the palpation count, therefore when the GE count was larger it is displayed as a negative difference, and when the GE count was smaller it is displayed as a positive difference. Note that for 6/85 data pairs the manual count was 0 when the GE count was 4

Although the skin impedance was reduced with skin preparation, it did not result in an appreciably larger amplitude signal.

The palpation of twitch was performed by only one of the investigators. We believe that this could contribute to the consistency of palpation measurements, however it is possible that another individual performing palpation could obtain a different result. In addition, the investigator performing the palpation was not blinded to the quantitative twitch measurements. Bhananker et al. compared the results of twitch palpation by attending anaesthesiologists, anaesthesiology residents and certified registered nurse anaesthetists and found no significant differences between the three types of providers, suggesting that twitch counting by palpation may be relatively robust [15].

Users of the GE electromyograph should be aware that overestimation of the train-of-four count and overestimation of the train-of-four ratio may occur. Careful inspection of the displayed electromyograph signal may help to mitigate this, since electrical artifacts and electromyograph waveforms may be distinguished visually (Fig. 6). When electrical artifacts rather than electromyograph waveforms are detected, train-of-four count determined by the monitor should be considered as possibly incorrect.

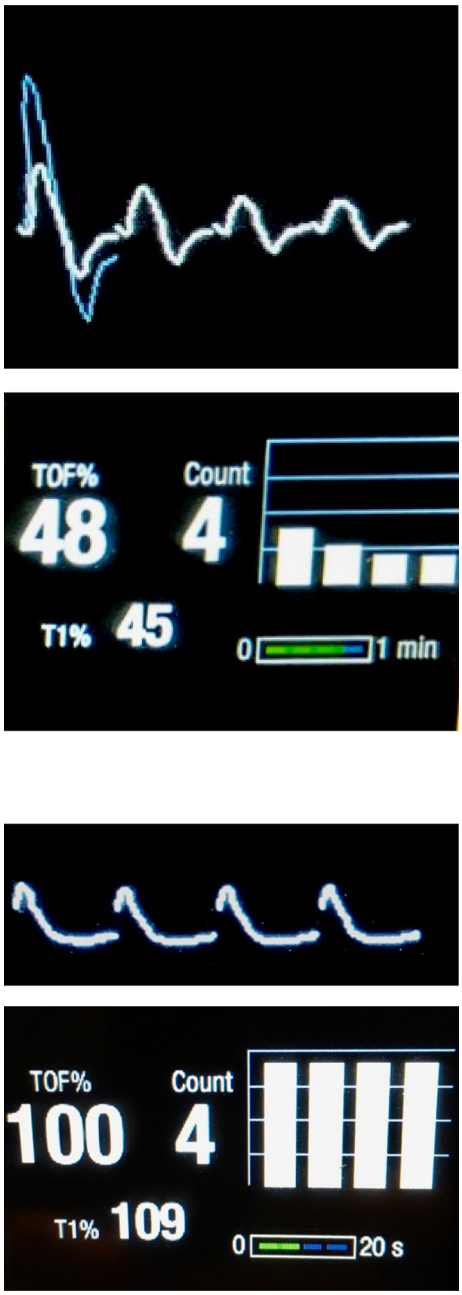

Fig. 6 Upper panel. A screenshot from the GE monitor shows a train-of-four ratio, which was similar to the train-of-four ratio determined by the TwitchView Monitor (not shown). Lower panel. A screenshot from the GE monitor shows stimulus artifact that was interpreted by the monitor as a train-of-four ratio of 100% when there was 0 twitch detected by the TwitchView Monitor (not shown)

Compliance with ethical standards

Conflict of interest Author JH has a financial interest in Blink Device Company (Seattle, WA, USA) which supplied the TwitchView and GE electromyograph monitors used in this study.

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