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ORIGINAL ARTICLE

Accuracy of a disposable compared to a non-disposable infant T-piece resuscitator

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Abstract Both disposable and non-disposable T-piece resuscitator (TPR) devices are used. Accuracy of the disposable and non-disposable infant TPR was compared. Peak inspiratory pressures (PIP) and positive end-expiratory pressures (PEEP) were measured during ventilation of a test lung. Measured PIP ±1 cmH_2O and PEEP ±0.5 cmH_2O of the desired pressures were considered acceptable. We tested the following: (A) Accuracy of setting pressures using built-in manometers of three disposable TPRs, (B) Minimal and maximal PIP and PEEP levels for the non-disposable and disposable TPR were measured using different gas flow rates, and (C) Accuracy of 25 caregivers setting pressures (PIP 25 cmH_2O and PEEP 5 cmH_2O). The results of the tests performed were as follows: (A) With pressures set: PIP 20, 25, 30, and 40 cmH_2O and PEEP 5–8 cmH_2O with 1 cmH_2O stepwise increment, measured PIPs and PEEPs were in acceptable range. (B) At gas flow rates 5, 8, 10, and 15 L/min (disposable vs. non-disposable), min-max PIP were 4.0–43.2 vs. 2.9–77.1 cmH_2O and min-max PEEP were 0.3–22.3 and 0.6–59.7 cmH_2O. (C) Set PIP (cmH_2O) by participants using disposable vs. non-disposable TPR was 25.8 (0.8) vs. 25.9 (1.3) (ns). PEEP was 5.4(0.5) vs. 4.7(0.5); $p<0.001$. *Conclusion*: The accuracy of the disposable TPR is comparable to that of the non-disposable TPR.

Keywords T-piece resuscitator device · Newborn · Resuscitation · Positive pressure ventilation

Abbreviations

TPR	T-piece resuscitator
PIP	Peak inspiratory pressure
PEEP	Positive end-expiratory pressure
PPV	Positive pressure ventilation

Introduction

T-piece resuscitators (TPRs) are increasingly being used for neonatal resuscitation [10, 12]. Studies have shown that non-disposable TPRs can be preferred over self- and flow-inflating bags as they are reliable in giving accurate pressures [6, 13], deliver the most consistent pressures [2, 14] provide more constant tidal volumes [13, 14], are capable to deliver a sustained inflation and continuous positive airway pressure if needed [2]. Also, the caregivers are able to ventilate with one hand and have the other hand free to maintain a patent airway [3].

A disposable TPR (Neo-Tee (1050810; Mercury Medical, Clearwater, FL, USA)) has been introduced (Fig. 1) and is increasingly used as an alternative for the non-disposable TPR. It is especially attractive as only a gas flow output is needed, which allows you to have a resuscitation device at every bed without having to buy a non-disposable device and tubing. The Neo-Tee TPR is a disposable infant TPR with a built-in manometer and pressure relief valve. It is flow-controlled and pressure-limited.

The accuracy, advantages, and disadvantages of the non-disposable TPR (Neopuff (RD 1300–10; Fisher & Paykel

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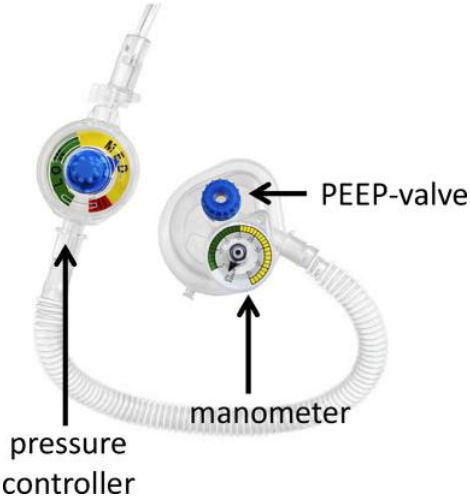

Fig. 1 Neo-Tee® Infant T-Piece Resuscitator with in-line pressure controller and manometer

Healthcare, Auckland, New Zealand)) have been described in several recent studies [6–8, 13, 14], but so far, the accuracy of the disposable TPR (Neo-Tee) is not known. Before the disposable TPR can be advised as an alternative for the standard non-disposable TPR, it is important to compare the accuracy and ability of the Neo-Tee to provide pressure at various gas flow rates with the Neopuff device.

We aimed to compare the accuracy of the Neo-Tee's built-in manometer and the accuracy with which caregivers could set pressures using the disposable vs. the non-disposable TPR.

Materials and methods

This benchtop study was performed at the neonatal intensive care unit of the Leiden University Medical Center, the Netherlands. Due to the observational character of this study in which no patients were involved, approval by the Institutional Review Board of our hospital was not necessary.

A Florian Neonatal Respiratory Monitor (Acutronic Medical Systems AG, Hirzel, Switzerland) was used to measure peak inspiratory pressure (PIP) and positive end-expiratory pressure (PEEP) during positive pressure ventilation (PPV) of the test lung (Dräger, Lübeck, Germany, compliance of 0.66 mL/mbar). Pressure was measured between the T-piece of the Neo-Tee (built-in manometer 0–40 cmH_2O) or Neopuff and the test lung. Before the experiment, the Florian was calibrated using a water column. Also, the Neopuff was calibrated using an industry standard BioTek VT plus gas flow analyzer (BioTek Instruments, Winooski, VT, USA). The pressure monitor was zeroed each time gas flow rate was changed. The signals of PIP and PEEP were digitized and recorded at 200 Hz using the Spectra physiological recording program (Grove Medical Limited, Hampton, UK). PIP was determined by measuring the average pressure during the plateau phase of the squared wave which is measured caused by inflation of the test lung.

For this experiment, the Neo-Tee was connected to a gas flow meter which could dispense a gas flow rate of up to 20 L/min. PEEP was set by blocking the gas flow outlet and adjusting the PEEP valve. PIP was set by blocking both the gas flow outlet and PEEP-valve and turning the pressure controller (Fig. 1).

The following measurements were performed:

(A) To test the accuracy of the built-in manometers (0–40 cmH_2O) of the Neo-Tees, the PIP was set to 20, 25, 30, and 40 cmH_2O and PEEP was set to 5, 6, 7, and 8 cmH_2O. These increments would reflect the situation in which clinicians increase pressures during resuscitation. Three similar Neo-Tees were used for this experiment. A gas flow rate of 10 L/min was used and inflations were provided to the test lung at a rate of 40–60 inflations per minute, according to the Dutch resuscitation guideline [9]. At each set PIP and PEEP, 30 s of PPV was recorded.

(B) We tested the minimum and maximum PIP and PEEP levels that could be reached with both devices using a gas flow rate of 5, 8, 10, and 15 L/min. For each gas flow rate, 30 s of PPV was recorded. The pressure limit of the Neopuff was set to maximum level.

(C) To test how accurate caregivers could set pressures using a Neo-Tee device compared to a Neopuff device, 25 caregivers (randomly chosen consultants, neonatal fellows, residents, and NICU nurses) were asked to set pressures on both devices to PIP 25 cmH_2O and PEEP 5 cmH_2O (conform to the initial pressures stated in our local guidelines) starting from 0 cmH_2O. All caregivers were trained in neonatal resuscitation. Prior to the recording, a short verbal instruction on how to use the Neo-Tee was provided. After setting the pressures, the caregivers ventilated the test lung using the Neo-Tee and the Neopuff TPRs for 30 s at a rate of 40–60 inflations per minute. The gas flow rate was set to 10 L/min. Variations in PEEP of 0.5 cmH_2O and PIP of 1 cmH_2O above or below the desired pressures were considered acceptable.

All data were analyzed using SPSS (SPSS for Windows, version 20.0). Data was analyzed using a paired Student's *t* test for parametric comparisons and continuous variables. Data was represented as mean (SD). Reported *p* values are two-sided, and a p value <0.05 was considered to indicate statistical significance.

Table 1 Minimal and maximal pressures (cmH_2O) measured when providing positive pressure ventilation when using the Neopuff and Neo-Tee TPRs at different gas flow rates (L/min)

Gas flow rate (L/min)		Neo-Tee device		Neopuff device	
		Minimal (cmH_2O)	Maximal (cmH_2O)	Minimal (cmH_2O)	Maximal (cmH_2O)
5	PIP	4.0	39.0	2.9	74.0
	PEEP	0.3	3.2	0.6	10.4
8	PIP	6.4	41.1	4.7	74.4
	PEEP	0.5	7.8	0.8	24.0
10	PIP	5.3	42.7	6.2	75.4
	PEEP	0.7	11.4	1.1	32.6
15	PIP	7.4	43.2	10.5	77.1
	PEEP	1.0	22.3	1.8	59.7

Results

The results of the measurements performed are as follows:

(A) When setting the pressures according to the manometer of the Neo-Tee to PIP 20, 25, 30, and 40 cmH_2O, a pressure of 20.9 (0.10), 25.8 (0.28), 30.7 (0.17), and 41.3 (0.47) cmH_2O was measured. When PEEP was set to 5, 6, 7, and 8 cmH_2O, pressures of 5.4 (0.66), 6.2 (0.80), 7.2 (0.73), and 8.6 (0.88) cmH_2O were measured.

(B) There were little differences in the maximum PIP when different gas flow rates were used. The minimum and maximum PIP that could be given by the Neo-Tee vs. the Neopuff device was 4.0–43.2 vs. 2.9–77.1 cmH_2O, respectively (Table 1). The minimal and maximal PEEP levels of the Neo-Tee compared to the Neopuff were 0.3–22.3 and 0.6–59.7 cmH_2O, respectively (for all minimal and maximal pressures at different gas flow rates, see Table 1). The maximum PEEP significantly increased when gas flow rate was increased using both devices (Neo-Tee less than Neopuff, Table 1). A PEEP pressure of 5 cmH_2O could not be reached with the Neo-Tee device when using a gas flow rate of 5 L/min. To reach 5 cmH_2O, a minimal gas flow rate of 8 L/min was necessary.

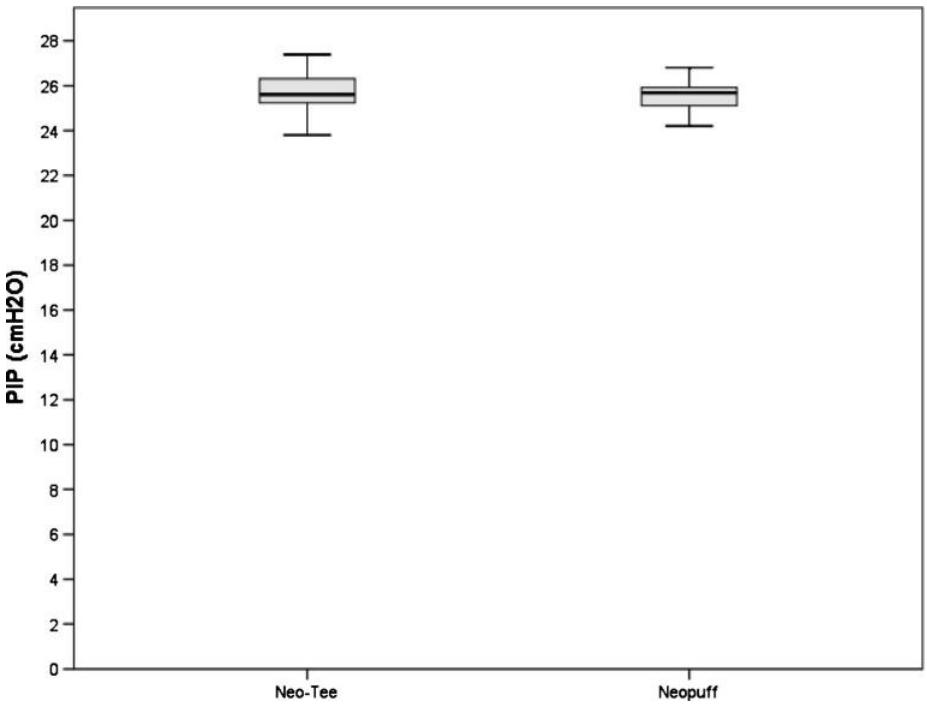

Fig. 2 PIP (cmH_2O) as set by 25 staff members of our NICU with both Neo-Tee and Neopuff TPR devices. *Box plots* show median values (*solid black bar*), inter-quartile range (*margins of box*), and range of data

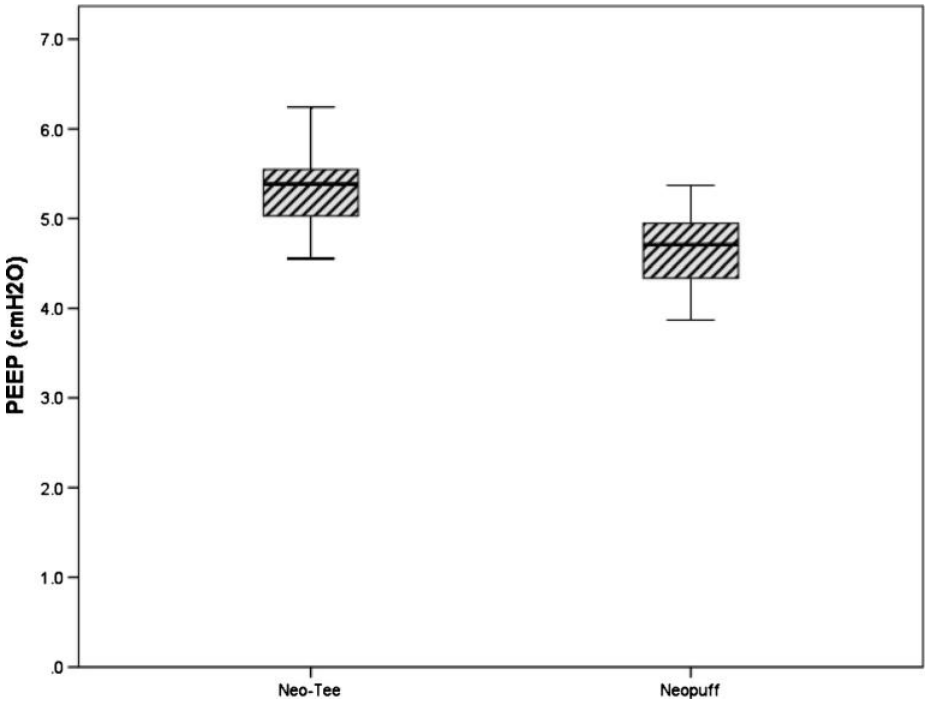

Fig. 3 PEEP (cmH_2O) as set by 25 staff members of our NICU with both Neo-Tee and Neopuff TPR devices. *Box plots* show median values (*solid black bar*), interquartile range (*margins of box*), and range of data

(C) We measured a median (IQR) PIP of 25.7 (25.1–26.0) cmH_2O when using the Neo-Tee vs. 25.6 (25.2–26.3) cmH_2O when using the Neopuff (ns). Variability (expressed in range) was 24.2–30.2 when using the Neo-Tee vs. 23.8–27.4 cmH_2O when using the Neopuff (ns). PIP was set within the acceptable range by 76 vs. 60 % of the participants (ns) (Fig. 2).

i. A PEEP of 4.7 (4.3–5.0) was measured using the Neopuff vs. 5.4 (5.0–5.5) cmH_2O when using the Neo-Tee ($p<0.001$) with a variability of 3.9–6.0 and 4.6–6.9 cmH_2O, respectively. PEEP was set within the acceptable range by 60 vs. 76 % of the participants (ns) (Fig. 3).

Table 2 Maximal PEEP levels (cmH_2O) for the Neo-Tee as claimed by the manufacturer vs. maximal PEEP levels measured at gas flow rates (L/min) specified by the manufacturer

Gas flow rate (L/min)	PEEP claimed (cmH_2O)	PEEP measured (cmH_2O)
5	2	3.2
8	6	7.8
10	9	11.4
15	15	22.3

Discussion

We observed that the built-in manometer of the Neo-Tee was accurate and the pressure-limiting mechanism prevented it giving pressures higher than 40–43 cmH_2O (depending on the gas flow rate given). Increasing the gas flow rate did not overrule the peak pressure-limiting mechanism. However, the maximum PEEP levels reached when using different flow settings were higher than claimed by the manufacturer (Table 2). Also, a minimal gas flow rate of 8 L/min was required to reach a PEEP of 5 cmH_2O. Also, we observed that caregivers could set pressures equally accurate when using the Neo-Tee or the Neopuff TPR. This implicates that the Neo-Tee can be a good alternative for the Neopuff. However, the manufacturer of the Neo-Tee should revise their claimed maximum PEEP levels at different gas flow rates, and a minimum gas flow rate of 8 L/min should be recommended when users aim for a PEEP level of 5 cmH_2O.

In contrast to the Neo-Tee, the accuracy, advantages, and disadvantages of the Neopuff have been well-established [6–8, 13, 14]. It has been shown that the Neopuff delivers more consistent pressures with less variability in comparison with the self-inflating bag and flow-inflating bag. However, increasing PIP using a TPR during resuscitation takes more time than using a self-inflating bag [1]. Also, a recent study demonstrated that there are small, potentially acceptable differences in pressures delivered between TPRs from different manufacturers [11]. Two recent studies [5, 16] confirm our

findings in experiment C where little differences in maximum PIPs were found when different gas flow rates were used and that the maximum PEEP level significantly increased when gas flow rate was increased using both TPR devices.

Increasing the gas flow rate during resuscitation could lead to unintended high pressures [5, 15, 16]. The PIP can be controlled by setting a maximum PIP level when using the Neopuff. However, high PEEP levels can occur when the PEEP-valve is not adjusted or the gas flow rate is inadequately high [15]. This could also occur when using a Neo-Tee TPR device. Although the highest PEEP level that can be achieved is much lower in the Neo-Tee than in the Neopuff, still the PEEP could rise to a dangerous level. To protect against unintended high PEEP, it has been recommended that gas flow rate should not be changed during resuscitation [15]. According to our data, this would also apply for the disposable TPR. Similar to the Neopuff, gas flow rate should be set at 8–10 L/min and this is not to be changed during resuscitation. With this gas flow rate, the commonly used PEEP levels (5–8 cmH_2O) can be achieved and a maximum PIP of 40 or 60 cmH_2O (depending which device is used) can be reached. When PIP or PEEP pressures are not reached, mask leak is the most probable cause and mask position, mask hold technique, and the infant's head position should be evaluated [4, 17].

A bench test is the proper approach to test the accuracy of a device, but this does not always reflect daily practice. However, we tested a wide set of variations of gas flow rate and pressures, as are commonly used by clinicians in daily practice. We also used the Neo-Tee device with a built-in manometer up to 40 cmH_2O, but the manufacturer also produces Neo-Tee devices with a built-in manometer which can reach pressures of up to 60 cmH_2O. However, we chose to test the devices with a manometer up to 40 cmH_2O, since this version contains a built-in manometer on which pressures are marked clearly. This device is made of less expensive components compared to non-disposables. Therefore, variance in administered pressures could exist. However, the three devices tested were randomly chosen and variability between the devices was small.

Conclusion

The accuracy of the Neo-Tee is comparable to that of the Neopuff device. However, the manufacturer should revise their claimed maximum PEEP levels and a minimum flow rate of 8 L/min should be recommended. If the set pressures are not met, mask position should be re-evaluated and gas flow rate should not be changed.

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Conflict of interest None.

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