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ORIGINAL RESEARCH

Thorpe tube and oxygen flow restrictor: what's flow accuracy?

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Abstract

Oxygen gas flowmeters (OGF) are used to regulate the oxygen flow in acute and chronic care. In hospitals, Thorpe tubes (TT) are the classical systems most used for delivering oxygen. In recent years, the oxygen flow restrictor (OFR) has appeared. These devices use a series of calibrated openings in a disk that can be adjusted to deliver different flow rates. These devices have a reputation for delivering more accurate oxygen flow rates compared to classical OGFs. However, to our knowledge, few study has examined this supposition. This study aimed to compare and evaluate the accuracy and precision of the ready-to-use TTs and OFRs. OGFs were selected from hospitals in Belgium and France. Before performing the flow measurements, the inlet pressure was checked. The accuracy of the OGF was analyzed with a calibrated thermal mass flowmeter (RED Y COMPACT™ GCM—0 to 20 L/min—VÖGTLIN Instruments). Different flows (2, 4, 6, 9 or 12 L/min) were evaluated. Linear regression analysis, bias (with confidence interval) and lower and upper limit of the agreement were calculated for TTs and OFRs. All measurements are expressed in absolute values. Four-hundred-seventy-six TTs and 96 OFRs were analyzed. The intra-class correlation coefficient calculated for the calibrated thermal mass flowmeter was >0.99 and reflected the excellent reliability of our measurements. For TTs, the bias value was − 0.24 L/min (± 0.88), and the limits of agreement were − 1.97 to 1.48 L/min. For OFRs, the bias value was − 0.30 L/min (± 0.54), and the limits of agreement were − 1.36 to 0.77 L/min. As the flow increased, the accuracy of all analyzed OGFs decreased. With the increasing flow, some data fell outside the limits of agreement, and the trend increased with the elevated oxygen flow. TTs were less accurate compared to OFRs due to the increased flow variability. However, for TTs and OFRs, as the required flow is elevated, the dispersion of values increases on both sides of the actual flow.

Keywords Oxygen therapy · Thorpe tube · Oxygen flow restrictor · Hypoxia · Hypoxemia

1 Introduction

Oxygen therapy is commonly used in both acute and chronic care [1]. Oxygen gas flowmeters (OGFs) are used to regulate the oxygen flow. In hospitals, oxygen flow is often delivered through a wall-mounted Thorpe tube (TT) [2]. In recent years, a new generation of OGFs has appeared: the oxygen flow restrictor (OFR). These devices use a series of calibrated openings in a disk that can be adjusted to deliver many flows [2]. At a given inlet pressure, only so much flow can pass through a restricted orifice. A large orifice produces a high flow, and a small orifice generates a low flow. These devices have a reputation for delivering more accurate oxygen flow rates compared to classical OGFs.

Recently, studies have examined the accuracy of oxygen flowmeters [3–5]. These studies concluded there is large variability in delivery flow among the measurements from different OGFs. This variation could lead to over- or

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under-oxygenation, a phenomenon that can be potentially deleterious [6, 7]. To our knowledge, few studies have examined the accuracy of OFRs. This study aimed to evaluate the accuracy and precision of the ready-to-use Debson TM2™ OGF with flow restrictors and compare it with the accuracy of TTs.

2 Methods

Delivered flows were evaluated on different ready-to-use OGFs: TT and OFR. OGFs were studied in units for adults where oxygen is frequently delivered (intensive care, emergency unit, respiratory unit, cardiology and surgery). The evaluated OGFs were those used routinely in these services and allocated to the next patient who required oxygen therapy. Only the OGF devices available on site on these days were analyzed. Each analyzed OFR was identified either by location on site or serial number to avoid repeating the same measurement on the same device twice.

2.1 Measurements

Before performing the flow measurements, the inlet pressure was checked by direct reading on the manometer upon entry to the hospital unit.

Flows are expressed in absolute value and in standard units (L/min). The accuracy of each OGF was analyzed with a calibrated thermal oxygen mass flowmeter (OMF; RED Y COMPACT™ GCM—0 to 20 L/min—VÖGTLIN Instruments, Switzerland; accuracy 1% of full scale or ± 0.2 L/min). Flow measurements with the OMF were independent of temperature and atmospheric pressure. For both OGF types, different flows (2, 4, 6, 9 or 12 L/min) were evaluated in a random order (using the random function of an Excel spreadsheet). The delivered flow was quantified after 5 s at a steady state. The measurements were performed twice at each flow, and the mean value was recorded.

TT data are based on the calculations and plots available in studies published 2014 [3]. To avoid parallax error, the oxygen flow reading for TTs was done by strictly horizontal sight.

2.2 Statistical analysis

Statistical analyses were performed with Sigma Stat™ (version 12.0, Systat Software Inc., London, UK) and Statistical Analysis System (version 9.4, SAS Institute, United States). Mean values are expressed with their standard deviation (SD) for parametric data and median values with interquartile ranges for non-parametric data.

We used a modified Bland–Altman method (MBAM) to assess the agreement between the required and actual oxygen flows [8, 9]. We used this method to avoid an overly optimistic reflection of the bias (and thus accuracy) of the OGFs. Indeed, we considered the OMF to be the accurate "gold standard" value. Thus, bias and accuracy were calculated relative to this standard gold standard and not to the average value: (OFR + OMF)/2.

We calculated the bias between the differences and estimated the agreement interval of the differences of the required oxygen flow compared to the actual oxygen flow (± 1.96 times the SD of the differences). To assess the relationship between bias and the magnitude of measurements, we performed a linear regression study. To quantify the goodness of linear regression, we calculated a coefficient of determination (R^2). An intraclass correlation coefficient (test–retest reliability), according to the method described by Shrout and Fleiss [10], was calculated to verify the repeatability of three random measurements of oxygen flows (2, 4, 6, 9 or 12 L/min) of six OFRs, which was performed during the precision experiment phase. An intraclass correlation coefficient greater than 0.75 was considered to reflect excellent repeatability of measurements.

3 Results

Four hundred seventy-six TTs were analyzed in eight general Belgian and French hospitals [Floval™, Caudalimeter™, DKD™, Drager™, Heyer™, Puritan Bennet™, RTM1™, RTM2™, RTM3™, Timeter™ and Taema™ (0–15 L/min). Ninety-six Debson TM2™ (0–15 L/min); Technologie Médicale, Noisy-le-Sec, L/min France] OFRs were analyzed in two general Belgian and French hospitals (Table 1).

3.1 Inlet pressure

For TTs, the maximum, median and minimum inlet pressures were 6.3, 5.4 and 4 Bar, respectively. For the OFRs, the maximum, median and minimum inlet pressures were 6.9, 6 and 4 Bar, respectively.

3.2 The flow of the flowmeters

The intraclass correlation coefficient was equal to 0.999. This value reflected the excellent reliability of the measurements performed by OMF. Linear regression analysis showed an R^2 of 0.94 for TTs and 0.98 for OFRs (Fig. 1). For TTs, the bias value was − 0.24 L/min (± 0.88), and the limits of agreement were − 1.97 to 1.48 L/min. For OFRs, the bias value was − 0.30 L/min (± 0.54), and the limits of agreement were − 1.36 to 0.77 L/min (Table 2). At 2 and 4 L/min, TT values scattered out of the limits of agreement. At the same flow, OFR values remained within the

Table 1 Brand distribution of the analyzed oxygen gas flowmeters (Thorpe tubes and oxygen flow restrictors) from 10 Belgian and French hospitals

	Thorpe tube	France (n = 205)	Belgium (n = 367)	Total
Air Liquide	Floval rotameter 0–15 France	4	3	7
Caudalimeter™	Ferno, UNIBODY Thorpe Tube 0–15, Wilmington, USA	–	47	47
DKD™	OHIO 7700-1260-931 England	7	0	7
Drager™	TT 0–15, Drägerwerk, Lübeck, Deutchland	–	4	4
Heyer™	660–0100 HEYER Medical AG, Bad Ems, Deutschland	–	10	10
Puritan bennet™	SLA—Slim Line Aluminum Body FME 901 Indian Creek Parkway USA	–	12	12
RTM1™, RTM2™, RTM3™	Technologie médicale, Noisy La Sec, France	74	246	320
Timeter™	Chemetron 32.15002 O3T Allied Healthcare Products USA	–	26	26
Taema™	oxygen flowmeter 0–15 LPM HW050803 Belgium	43	–	43
		128	348	476
	Oxygen flow restrictor			
Debson TM2	Technologie Médicale—Noisy Le Sec France	77	19	96
		General	572	

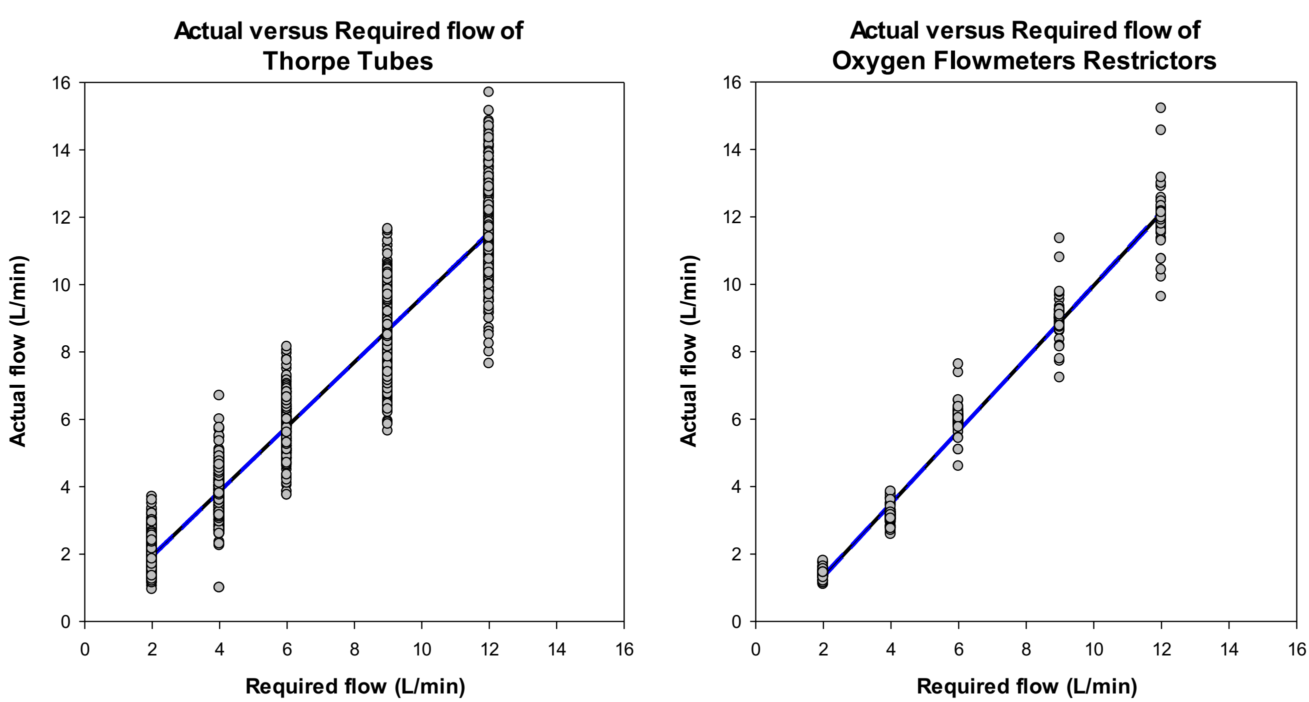

Fig. 1 Linear regression analysis and scatter plot distribution between required flow and the actual flow of Thorpe tubes (n = 476) and oxygen flow restrictors (n = 96) at 2, 4, 6, 9 or 12 L/min oxygen flow rates

limits of agreement. At 6 L/min and above, the number of values that were out of the limits of agreement increased approximately linearly for TTs and OFRs. However, the dispersion of the measurements was more prominent for the TTs compared to the OFRs (Fig. 2).

4 Discussion

This study evaluated the accuracy and precision of two OGF types, namely TTs and OFRs, using a calibrated thermal OMF. The linear regression analysis showed a strong

Table 2 Bias, standard deviation, limits of agreement and confidence interval (CI) for bias and lower and upper limit of agreement for Thorpe tubes and oxygen flow restrictors at 2, 4, 6, 9 or 12 L/min oxygen flow

	Thorpe tubes (n = 476)	Oxygen flow restrictors (n = 96)
Bias	− 0.24	− 0.30
Standard deviation	± 0.88	± 0.54
Limits of agreement	− 1.97 to 1.48	− 1.36 to 0.77
Bias CI 95%	− 0.28 to − 0.21	− 0.35 to − 0.25
Lower limit of agreement CI	− 2.03 to − 1.90	− 1.45 to − 1.28
Upper limit of agreement CI	1.42 to 1.54	0.68 to 0.85

Values are presented as L/min

association between the required and actual oxygen flow. The intraclass coefficient correlation demonstrated the excellent reliability of measurements performed by the OMF. The bias was slightly under the required flow for TTs and OFRs, but there were differences between the apparatuses. These data indicated accuracy variations in oxygen flow between the TTs and OFRs. Variances in the SD of the bias between TTs and OFRs showed that flow variability was higher for TTs compared to OFRs. These differences were observed at both low and high flow. At 2 and 4 L/min, TTs demonstrated a limited accuracy because some values scattered out of the limits of agreement. At the same flows, OFRs showed better accuracy because the values remained within the limits of agreement. From 6 L/min and higher, the number of values that were out of the limits of agreement increased approximately linearly for TTs and OFRs. However, the dispersion of the measurements was more prominent for TTs compared to OFRS.

In 2012, Davidson et al. analyzed TTs from a tertiary hospital using a calibrated flow analyzer [5]. The authors concluded that there was large variability among the measurements, mainly at low flow (1 and 3 L/min). Moreover, above 5 L/min, the actual flow was well above the required flow. Our study confirms these previous results and highlights that OFRs have better accuracy than TTs at low flow. Thereby, patients who are oxygenated successively with different OGFs are unlikely to have a stable oxygenation level because the accuracy of these devices is different.

TTs are fragile devices. Their accuracy can be altered when exposed to static electricity or a magnetic field, secondary to a mechanical shock or a lack of verticality. Additionally, wear over time and changes in atmospheric pressure or room temperature (depending on the model) can alter performance. Mechanically, OFRs are much simpler compared to TTs. In theory, the holes through which the oxygen flows guarantee the sustainability of the flow accuracy. However, they accuracy is dependent on the inlet pressure. This factor may explain the accuracy differences between the two systems. Whatever the utilized system, there is always some inaccuracy in oxygen flow delivery. At high flow, the inaccuracy is higher both TTs and OFRs compared to low flow. In this case, practitioners who use prediction formulae to

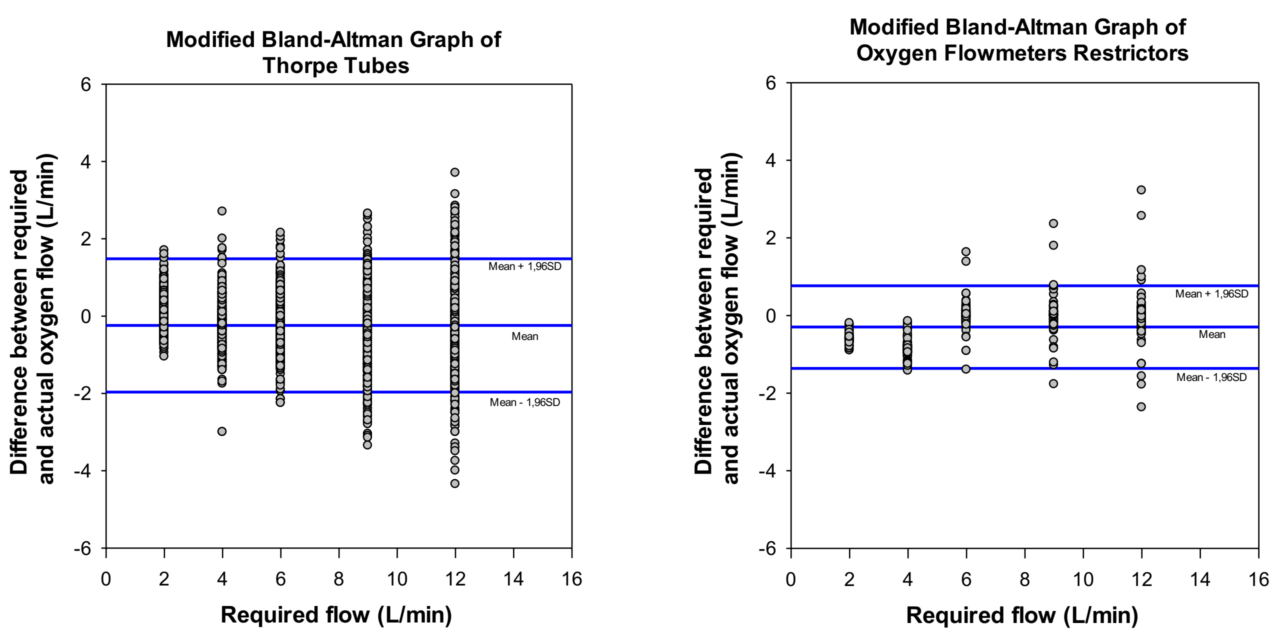

Fig. 2 Modified Bland Altman analysis of the agreement between required flow and the actual flow for Thorpe tubes (n = 476) and oxygen flow restrictors (n = 96) at 2, 4, 6, 9 or 12 L/min oxygen flow

determining FiO_2 could over- or underestimate the health status of their patients [11–13]. On the one hand, in paediatric care, the inaccuracies at low flow can lead to over or under oxygenation. Indeed, in this case, low flow variability may have a major impact on the FiO_2 of babies due to their low inspiratory flow [12, 14–16]. On the other hand, some patients with chronic obstructive pulmonary disorder (COPD) or obesity hypoventilation syndrome can develop a hypercapnic decompensation with respiratory acidosis when an excessive oxygen flow is delivered [17]. In this case, low oxygen flow inaccuracies can also affect these patients. At low flow, TTs show more variability compared to OFRs, and thus the risk of developing hypercapnia concomitant with oxygen therapy is more probable with TTs than OFRs.

To avoid over or under oxygenation, it is necessary to check the peripheral oxygen saturation (SpO_2), or blood gas analysis, as soon as a new or another OGF is used. Recent guidelines recommend a SpO_2 target of 88 to 92% in COPD patients, pending the blood gas results are adjusted to 94 to 98% if the $PaCO_2$ is normal [18, 19].

4.1 Limitations

There are weaknesses in this study, as only one OFR brand was studied. In Belgium and France, this device is relatively new, as it has been on the market for less than 10 years. This factor explains why we found only one OFR brand available for our study. Further studies should be examine different OFR brands and also consider time effect on flow accuracy to confirm these results.

5 Conclusion

This study showed that oxygen flows delivered by OFRs were more accurate than TTs. Moreover, below 6 L/min, the OFR data were in the limits of the agreement. Above 4 L/min, some data began to fall outside the limits of agreement, and the trend increased with the elevation in flow. However, this variability was lower than the oxygen flow delivered by TTs. Changing oxygenation systems is risky and can lead to under- or over-oxygenation, particularly at high flow but also at low flow in paediatric patients. After any OGF change, SpO_2 measurements should be performed more frequently to ensure the level of oxygenation is always appropriate.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical Approval This article is a bench study, there are no human people involved.

References

1. Pavlov N, Haynes AG, Stucki A, Jüni P, Ott SR. Long-term oxygen therapy in COPD patients: population-based cohort study on mortality. Int J Chron Obstruct Pulmon Dis. 2018;13:979–88.
2. Cairo J, Pilbeam S. Mosby's respiratory care equipment. Amsteram: Elsevier; 2018.
3. Duprez F. Accuracy of medical oxygen flow meters: a multicentric field study. Health. 6(15):1978–83; 2014
4. Duprez F, Michotte JB, Cuvelier G, Legrand A, Mashayekhi S, Reychler G. Accuracy of oxygen flow delivered by compressed-gas cylinders in hospital and prehospital emergency care. Respir Care. 2018;63(3):332–8.
5. Davidson J, Gazzeta C, Torres LC, Jardim JR, Nascimento OA. Precision and accuracy of oxygen flow meters used at hospital settings. Respir Care. 2012;57(7):1071–5.
6. Stub D, Smith K, Bernard S, Bray JE, Stephenson M, Cameron P, et al. A randomized controlled trial of oxygen therapy in acute myocardial infarction air verses oxygen in myocardial infarction study (AVOID study). Am Heart J. 2012;163(3):339.e1–45.e1.
7. Hafner S, Beloncle F, Koch A, Radermacher P, Asfar P. Hyperoxia in intensive care, emergency, and peri-operative medicine: Dr. Jekyll or Mr. Hyde? A 2015 update. Ann Intensive Care. 2015;5(1):42.
8. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. Lancet Lond Engl. 1986;1(8476):307–10.
9. Bland JM, Altman DG. Measuring agreement in method comparison studies. Stat Methods Med Res. 1999;8(2):135–60.
10. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155–63.
11. Lamb K, Piper D. Southmedic OxyMaskTM compared with the Hudson RCI® non-rebreather MaskTM: safety and performance comparison. Can J Respir Ther CJRT, Rev Can Thér Respir RCTR. 2016;52(1):13–5.
12. Benaron DA, Benitz WE. Maximizing the stability of oxygen delivered via nasal cannula. Arch Pediatr Adolesc Med. 1994;148(3):294–300.
13. Frat J-P, Thille AW, Mercat A, Girault C, Ragot S, Perbet S, et al. High-flow oxygen through nasal cannula in acute hypoxemic respiratory failure. N Engl J Med. 2015;372(23):2185–96.
14. Duprez F, Mashayekhi S, Cuvelier G, Legrand A, Reychler G. A New formula for predicting the fraction of delivered oxygen during low-flow oxygen therapy. Respir Care. 2018;63(12):1528–34.
15. Walsh M, Engle W, Laptook A, Kazzi SNJ, Buchter S, Rasmussen M, et al. Oxygen delivery through nasal cannulae to preterm infants: can practice be improved? Pediatrics. 2005;116(4):857–61.
16. Finer NN, Bates R, Tomat P. Low flow oxygen delivery via nasal cannula to neonates. Pediatr Pulmonol. 1996;21(1):48–51.
17. Susanto C, Thomas PS. Assessing the use of initial oxygen therapy in chronic obstructive pulmonary disease patients: a retrospective audit of pre-hospital and hospital emergency management. Intern Med J. 2015;45(5):510–6.
18. Jubran A. Pulse oximetry. Crit Care Lond Engl. 2015;19:272.
19. O'Driscoll BR, Howard LS, Bucknall C, Welham SA, Davison AG, British Thoracic Society. British Thoracic Society emergency oxygen audits. Thorax. 66(8):734–5; 2011