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Science Letter

Flow-pressure characteristics of four adjustable pressure-limiting valves supplied with Mapleson C circuits

There is no consensus on the ideal characteristics of an adjustable pressure-limiting (APL) valve [1], but they are covered by the regulatory standard ISO 80601-2-13:2011. In 2017, we investigated the flow-pressure characteristics of an APL valve from an Intersurgical Mapleson C circuit [2]. Subsequently, a manufacturer approached us to ask if we would consider testing the APL valve from their system. In order to make the comparison broader, we conducted an internet search and contacted all manufacturers of Mapleson C circuits that we found, inviting them to send a sample circuit for testing. One further manufacturer responded.

We used an anaesthetic machine present at our new hospital, the Draeger Primus (Draeger Medical UK Ltd, Hemel Hempstead, UK). As fresh gas flows from this machine only increase to 18 l.min^{-1}, we subtly altered the apparatus to allow dual oxygen supplies to generate the required flows by combining the fresh gas outlet and auxiliary outlet. The APL valves were marked at 10% equi-angular intervals along their operational bevel rotation. The handheld manometer was four-point tested against the anaesthetic machine's internal manometer, agreeing to within 3 cmH_2O.

In our view, the simplest comparator for an APL valve's performance is against a hypothetical one that varies linearly with percentage working angular rotation, between nil and the maximal stated valve pressure (60 cmH_2O for all the adult circuits, 35 cmH_2O for the paediatric circuit). Mean airway pressures across all flow rates were compared with such a linearly performing valve by calculating the square of the Pearson correlation coefficient, R^2. We also calculated the standard deviation of the airway pressures, σ, from the mean airway pressures across different flow rates. Microsoft Excel was used for these calculations (Fig. 1).

Throughout the lower half of its operational bevel rotation, the Intersurgical APL valve had little effect on

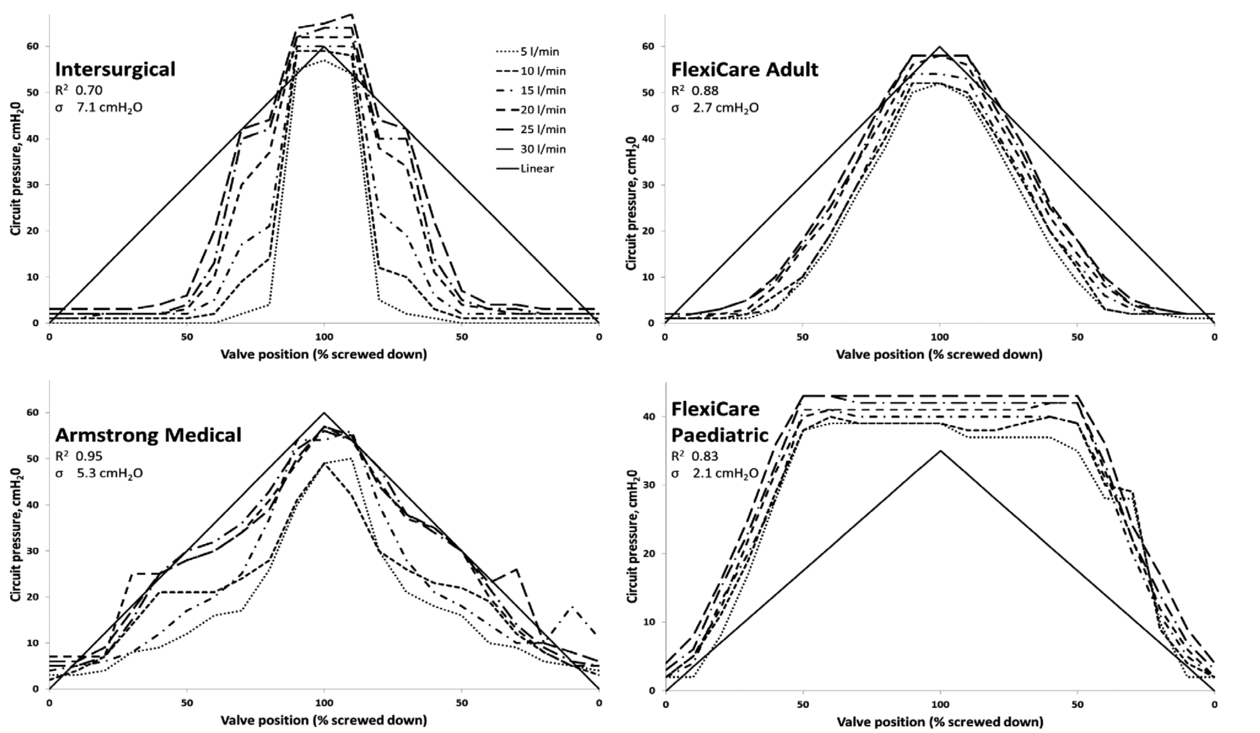

Figure 1 Flow-pressure characteristics of four Mapleson C APL valves. R^2, square of the Pearson correlation coefficient comparing a hypothetical linearly performing valve (solid black line) to the APL valve's mean pressures across all flow rates; σ, standard deviation of measured circuit pressures at different flow rates from mean pressures across all flow rates.

circuit pressure (essentially being a function of flow), followed by a steep rise in pressures over the remaining bevel rotation. It exhibited the most marked differences in performance with varying flow rates. These results are very similar to those of our previous study [2].

By the metric we used, the Armstrong Medical valve approximated a linearly performing valve most closely. After a slow initial rise through the lowest quarter of its operational range, the Flexicare adult APL valve performs remarkably linearly and with little variation across flow rates. The shape of the curve could be argued to be clinically more useful than a strict linear response, allowing titration of clinically-relevant levels of positive end-expiratory pressure throughout the initial segment of bevel rotation.

Pressures in the Flexicare paediatric APL valve rise steeply and quite lineally in the first half of its operational range, after which pressures plateau above the stated maximum of 35 cmH_2O, squandering a large proportion of the bevel's rotation. The highest measured pressure was 43 cmH_2O, which we think is clinically relevant, especially when ventilating the lungs of younger children. This pressure is more than 15% above the maximal quoted pressure, thus not conforming to the regulatory standard. It exhibited the least variation between different flow rates.

We did not observe any significant hysteresis from sticky valves or other sources of play in the system. In general, the adult APL valves behave more linearly with increasing flow rates. Therefore, as we previously observed [2], increasing flow beyond the maximum displayed value of 15 $l.min^{-1}$ from a typical ward-based oxygen rotameter is likely to give more linear valve performance in addition to reducing re-breathing.

Acknowledgements

Having read our previous work [2], Armstrong Medical's representative approached us to ask if we would consider analogous testing of the APL valve from their system. Armstrong Medical provided a sample for the purpose free of charge, which we received inside sealed original packaging. Flexicare provided their sealed sample circuits free of charge, following email invitation from us to do so. We already had access to Intersurgical Mapleson C circuits as they are stocked at our hospital. No other competing interests declared.

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