EVALUATION OF A FIBEROPTIC SYSTEM FOR AIRWAY PRESSURE MONITORING

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ABSTRACT. Objective. Our objective was to evaluate the accuracy of a novel fiberoptic system for airway pressure measurement at the carinal end of the endotracheal tube in an in vitro pediatric lung model. **Methods.** A fiberoptic pressure measuring system was compared to the conventional method of measuring airway pressure with a pneumatic transducer using a test lung model. Pressure measurements were obtained using four endotracheal tubes of various internal diameters (ID) (3 to 6 mm) during simulated spontaneous and mechanical ventilation. Airway pressure was measured using both methods simultaneously and the results were compared by statistical analysis. **Results.** Airway pressure measured by the fiberoptic system was not significantly different from measurements obtained by the pneumatic transducer except when using the 3-mm and 4-mm ID endotracheal tubes during mechanical ventilation. **Conclusions.** We conclude that the fiberoptic system provides accurate and precise measurement of airway pressure during spontaneous and mechanical ventilation. Additionally, the statistically significant differences obtained for 3- and 4-mm tubes are not large enough to be clinically significant. The fiberoptic system offers advantages over the pneumatic system for measuring the airway pressure. These advantages include decreased chance of false pressure measurement secondary to occlusion with water or mucous, less chance of kinking, and, possibly, more rapid response to pressure changes due to the mechanical ventilator.

KEY WORDS. Equipment: tubes, endotracheal. Monitoring: ventilation. Ventilation: airway pressure.

RÉSUMÉ. Objectifs. Evaluer in vitro, à l'aide d'un modèle de poumon-test pédiatrique, l'exactitude d'un système innovant à fibre optique de la mesure de pressions des voles aériennes à l'extrémité distale d'une sonde endotrachéale. **Méthodes.** Une pression mesurée par un système à fibre optique a été comparée à la méthode conventionnelle de mesure des pressions des voies aériennes avec un capteur pneumatique, sur un modèle de poumon-test. Les mesures de pression ont été obtenues en utilisant 4 sondes endotrachéales d'un diamètre interne (DI) de 3 à 6 mm, pendant la simulation d'une ventilation spontanée et mécanique. La pression des voies aériennes a été mesurée en utilisant simultanément les 2 méthodes et les résultats ont été analysés statistiquement. **Résultats.** La pression des voies aériennes mesurée par le système à fibre optique n'a pas été significativement différente des mesures obtenues par le capteur pneumatique, sauf en ventilation mécanique lors de l'utilisation des sondes endotrachéales de DI de 3 et 4 mm. **Conclusions.** Nous concluons que pendant les ventilations spontanée et mécanique, le système à fibre optique donne des mesures exactes et précises des pressions des voies aériennes. De plus, les différences statistiquement significatives obtenues pour les sondes de DI de 3 et 4 mm ne sont pas assez grandes pour être cliniquement significatives. Le système à fibre optique offre des avantages par rapport au système pneumatique pour la mesure de pression des voies aériennes. Ces avantages comprennent: la diminution du risque d'avoir de fausses mesures secondaires à une occlusion par de l'eau ou du mucus, moins de risque de torsion et peut être une réponse plus rapide aux changements de pression dus à la ventilation mécanique.

ABSTRAKT. Fragestellung. Die Beurteilung der Genauigkeit eines neuen fiberoptischen Systems zur in-vitro-Messung des Atemwegsdruckes am kranialen Ende eines Endotrachealtubus anhand des Modells einer Kinderlunge. **Methodik.** Ein fiberoptisches Druckmessystems wurde mit der konventionellen Methode der Atemwegsdruckmessung mittels pneumatischem Transducer verglichen, wobei dazu eine Testlunge verwendet wurde. Die Druckmessung erfolgte mit 4 verschiedenen Endotrachealtuben unterschiedlichen Innendurchmessers (ID)(3–6 mm) während simulierter spontaner und mechanischer Ventilation. Der Atemwegsdruck wurde bei gleichzeitiger Anwendung beider Methoden gemessen und die Ergebnisse durch statistische Analysen verglichen. **Ergebnisse.** Der Atemwegsdruck, der mittels fiberoptischem System gemessen worden war, unterschied sich nicht signifikant von den Werten, die mit dem pneumatischen Transducer erhalten wurden, außer wenn man die 3 mm und 4 mm ID-Endotrachealtuben während der mechanischen Ventilation verwendete. **Schlußfolgerung.** Wir schließen daraus, daß das fiberoptische System genaue und präzise Werte des Atemwegsdrucks während spontaner und mechanischer Ventilation liefert. Zusätzlich allerdings sind die statistisch signifikanten Unterschiede zwischen 3 mm und 4 mm Tuben nicht so groß, um klinische Signifikanz zu erhalten. Das fiberoptische System bietet zur Atemwegsdruck-Messung einige Vorteile gegenüber dem pneumatischen System. Diese Vorteile beinhalten: vermindertes Risiko falscher Druckmessung sekundär zu Verschluß mit Wasser oder Schleim; geringeres Risiko von Knotenbildung und wahrscheinlich eine raschere Reaktion auf Druckänderungen, die durch das Beatmungsgerät verursacht sind.

RESUMEN. Objetivos. Evaluar la exactitud de un nuevo sistema fibrooptico para medir presión de vía aérea en el extremo carinal del tubo endotraqueal, en un modelo *in vitro* de pulmón pediatrico. **Métodos.** Un sistema fibrooptico para medir presión fue comparado con un transductor neumático, que es el método convencional usado para medir presión de vía aérea, o sea, mediante un modelo *in vitro* del pulmón. Las mediciones de presión fueron obtenidas usando cuatro tubos endotraqueales de diferentes diámetros internos (ID) (3- a 6-mm) durante ventilación simulada espontánea y mecánica. La presión de vía aérea se midió usando ambos métodos simultaneamente

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y los resultados se compararon mediante análisis estatístico. **Resultados.** La presión de vía aérea medida por el sistema fibrooptico no fue significativamente diferente de las mediciones obtenidas con el transductor neumático, excepto al usar los tubos endotraqueales 3-mm y 4-mm ID durante ventilación mecánica. **Conclusiones.** Concluimos que el sistema fibrooptico proporciona mediciones exactas y precisas de la presión de vía aérea durante ventilación mecánica y espontánea. Adicionalmente, las diferencias estatisticamente significativas obtenidas para los tubos de 3- y 4-mm no fueron suficientemente grandes como para alcanzar significación clínica. El sistema fibrooptico posée ventajas sobre el sistema neumático para medir presión de vía aérea. Estas ventajas incluyen: menor probabilidad de falsas mediciones secundarias a oclusión con agua o mucus, menos probabilidad de acodadura, y posiblemente respuesta más rápida a los cambios de presión debidos al ventilador mecánico.

Airway pressure measurement has become standard for patients receiving ventilatory support. Clinical decisions and assessments regarding triggering pressure (the pressure the patient must generate to initiate a breath), peak inflation pressure, positive end-expiratory pressure, and pressure limit depend upon accurate and rapid measurement of pressure in the airway. Multiple studies have demonstrated the benefit of measuring the pressure at the tracheal, or carinal, end of the endotracheal tube [1–5]. These methods depend on inserting a catheter into the endotracheal tube or using special endotracheal tubes with side tubes incorporated. The performance of air-filled catheters is, however, impaired by problems with mucous plugging, water accumulation, disconnection, and physical obstruction secondary to kinking of the small monitoring tube or catheter.

The present study evaluated the accuracy of a novel fiberoptic system for airway pressure measurement at the carinal end of the endotracheal tube in an in vitro pediatric lung model. This device has been evaluated and tested in both clinical and in vitro settings for intracranial and left atrial pressure measurements [6], but, to our knowledge, no other laboratory studies have validated the accuracy and precision of this device for airway pressure measurement. One study evaluated the use of this catheter in patients, but made no effort to validate the device [7]. That study did, however, find an excellent correlation between the airway pressures measured by pneumatics and those measured by the fiberoptic system in the adult patient.

METHODS AND MATERIALS

The airway pressure was simulated using a tracheal model (Imatrach, Mallinckrodt, Argyle, NY), which was attached to a test lung (Model TTL, Michigan Instruments, Grand Rapids, MI). Pressures were measured simultaneously at approximately 1 cm past the carinal end of the endotracheal tube using a standard pressure transducer (Model P23, Gould-Statham, Oxnard, CA) through a side port in the tracheal model. The fiberoptic pressure measuring probe (Camino Laboratories, San Diego, CA) was inserted and positioned at the carinal end of the endotracheal tube. Cuffed endotracheal tubes (3-, 4-, 5-, and 6-mm ID) (NCC, Mallinckrodt, Argyle, NY) were alternately inserted into the tracheal model. Cuffed endotracheal tubes were used to ensure minimal leakage between the tracheal model and the endotracheal tube (Fig 1). To simulate both positive and negative deflections, pressures were measured during both mechanical ventilation and simulated spontaneous ventilation. Mechanical ventilation was achieved using a ventilator (Model 7200, Puritan-Bennett Corp., Overland Park, KS) to actively inflate the aforementioned test lung with tidal volumes ranging from 50 to 200 ml, flow rates of 15 to 20 L/min, and a respiratory rate of approximately 20 breaths/min. Spontaneous ventilation was simulated using the same ventilator to deliver a sinusoidal inspiratory flow waveform to one compartment of the test lung (see Fig 1). The two compartments of the test lung are connected by a lifting bar so that when one compartment is actively inflated by the ventilator, the contralateral compartment that simulates a lung is displaced by the same volume. When the ventilator cycles "off," the lifting bar disengages and the contralateral simulated lung exhales passively (compliance of the lung was set at 0.05 L/cm H_2O) [3] (see Fig 1). With this model, spontaneous ventilation can be simulated by measuring pressure in the passively moving compartment of the test lung.

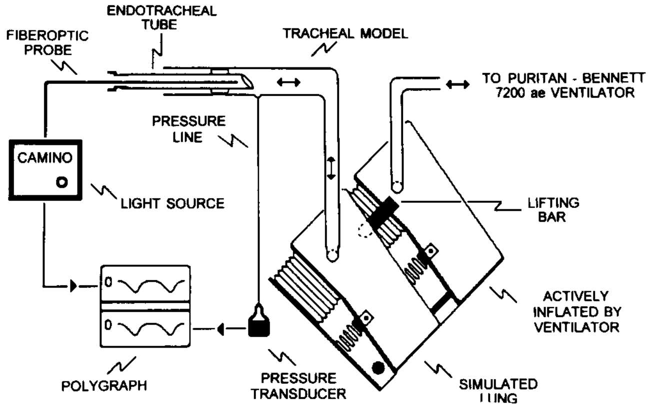

Fig 1. Model used to simulate spontaneous ventilation and measure airway pressure. Pressure was measured with a fiberoptic probe system and a standard pressure transducer connected to the tracheal model. Both pressure signals were directed to a polygraph recorder. Mechanical ventilation was simulated by attaching a ventilator directly to the endotracheal tube.

Pressures were measured at a simulated spontaneous peak inspiratory flow rate demand of 15 to 20 L/min, tidal volumes of 50 to 200 mL, a respiratory rate of approximately 20 breaths/min, and an I:E ratio of 1:2. Airway pressures measured with the pressure transducer and the fiberoptic probe were recorded on a polygraph recorder system (Model 7B, Grass Medical Instruments, Quincy, MA). A minimum of 10 recordings were made at each setting and endotracheal tube size. No humidification system was used in the breathing circuit.

Statistical Analysis

Data were analyzed using a Mann-Whitney *U*-test to compare simultaneous measurements from the fiberoptic and pneumatic transducers. Alpha was set at 0.05 for statistical significance.

RESULTS

There was no significant difference between pressure measurements obtained with the standard pressure transducer and with the fiberoptic probe system under most conditions tested. The peak inflation pressures measured by the fiberoptic probe under conditions of mechanical ventilation using 3- and 4-mm ID endotracheal tubes were significantly higher than the pneumatic measurements, with a maximum difference of 2 cm H_2O for the 3-mm tube (Fig 2). The decrease in airway pressure during spontaneous ventilation was not significantly different at any endotracheal tube size, regardless of the measurement technique. These data reveal a high degree of agreement between the two pressure-measuring techniques.

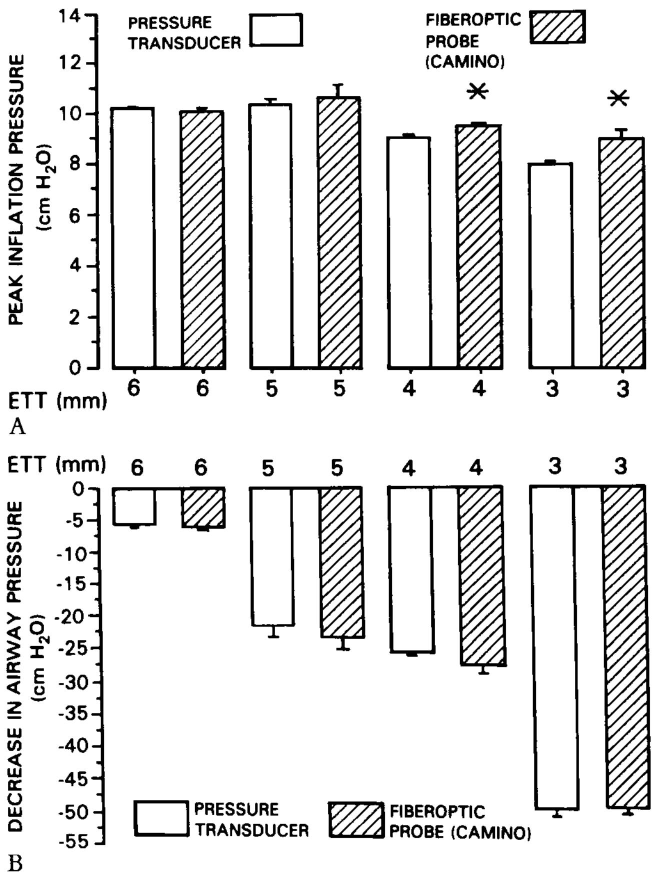

Fig 2. (A) Peak inflation pressure (PIP) measured with a pressure transducer and the fiberoptic probe system with different internal diameter endotracheal tubes (ETT) during mechanical ventilation (= $p < 0.05$, compared to pressure transducer with the same size ETT). (B) Decrease in airway pressure measured with a pressure transducer and the fiberoptic probe system with different internal diameter endotracheal tubes (ETT) during spontaneous ventilation. Data are mean ± SD.*

DISCUSSION

Our data demonstrate that the fiberoptic probe system is as accurate and precise in measuring the changes in airway pressure as the pneumatic transducer system. Although statistically significant differences were noted for measurements using 3- and 4-mm ID endotracheal tubes during mechanical ventilation, the actual difference is not clinically significant. This difference may simply represent a Venturi effect, which occurs because the entrance line attached to the pressure transducer is perpendicular to the endotracheal tube. As gas flows across the entrance, a slight decrease in pressure may be generated. This might explain the 0.5-cm H_2O difference observed with the 4-mm ID endotracheal tube and the 1.0-cm H_2O difference observed with the 3-mm ID endotracheal tube. More study is needed to determine with certainty the cause of these differences.

The fiberoptic probe system has several advantages over a conventional air-filled catheter or a pressure-measuring line that is incorporated into an endotracheal tube and attached to a pressure transducer. First, the fiberoptic probe is unlikely to occlude from moisture, mucous plugs, or kinking. These probes are currently used clinically implanted in brain tissue as intracranial pressure monitors or on the heart as left atrial pressure monitors. Significant clinical experience with these probes has demonstrated excellent pressure monitoring without occlusion or kinking. Second, the fiberoptic catheter has a narrow outside diameter of approximately 1 mm, and will not compromise the internal diameter of the endotracheal tube. A third potential advantage of the fiberoptic probe system is the response time. While we did not measure the response time of the system, the manufacturer reports a response time of 1 millisecond from pressure incurred to electronic output. A rapid response time could be useful if a fiberoptic probe system were used to transmit pressure data to a microprocessor-controlled ventilator. For example, the exhalation valve might be opened more rapidly at the onset of a cough to prevent excessive airway pressure. This more rapid system could also be incorporated to improve the response time of demand-flow systems and, thus, patient comfort. Clinical studies are needed to evaluate whether an airway pressure monitor with a rapid response time can, indeed, improve ventilator function.

We conclude that the fiberoptic catheter system described here is as accurate and precise as conventional pressure transducer systems for measuring changes in airway pressure during mechanical and spontaneous ventilation under the conditions studied.

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