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ORIGINAL ARTICLE

The Different Approaches of Single Lung Ventilation in Infants with Pulmonary Malformation

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Abstract

Since many years, feasibility and safety of thoracoscopic surgery in infants with pulmonary malformations has been confirmed. Nevertheless, infants present some problems caused by the anatomical and physiological peculiarities typical of the age and of the size of the structures. Several ways to overcome these difficulties have been proposed to assure efficacy and safety of mono-pulmonary ventilation. The knowledge of the infant's respiratory physiology is essential to prevent complications and eventually to treat them. In the same way the technical skill with all the available tools is mandatory for the airway management.

Keywords

One-lung ventilation, Pulmonary malformation, Video-assisted thoracoscopy, Infant

Introduction

Surgical treatment of infants with congenital lung malformations in the first months of their life is highly recommended because of their tendency towards recurrent respiratory infections and malignancy. Video-assisted thoracoscopic surgery (VATS) has for many years been the surgical option of choice because it offers better results than open thoracotomy: shoulder girdle weakness, chest wall deformity, and scoliosis are often the long-term results of thoracotomy in small children, even with the muscle-sparing surgical technique. On the other hand, benefits of thoracoscopy are well known: the minimal invasiveness implies decreased length of hospital stay, faster recovery, better cosmetic results, significant reduction of postoperative pain [1,2]. This surgical choice led anesthesiologists to change their usual anesthetic technique: indeed, a thoracotomy does not always require lung separation and collapse in infants [3].

Although one-lung ventilation (OLV) is not mandatory in thoracic endoscopic surgery [4,5], it is important for the success of the procedure, because it provides an optimal exposure of the surgical field; many authors found that a non-optimal exposure of the surgical field is a frequent cause of conversion to open surgery [4-7]. Moreover, it assures the protection from contamination of the healthy, dependent lung. OLV is more difficult in infants than in older children because of anatomical and physiological aspects typical of small children. Our aim is to explain the peculiar problems arising in these patients.

Anatomical Peculiarities of the Airway of Small Children

The small diameter of the infant's airway explains many of the problems that might occur during OLV: the narrow superior airway tract is the principal factor in the choice of the tracheal intubation technique; from this choice depends the quality of lung exclusion and the potential duration and success of thoracic endoscopic surgery. The tracheal and bronchial mucosa might suffer damage during intubation because of the decubitus of the blocker balloon [1]. A displacement of the tracheal tube or of the blocker can occur during the change of the decubitus position or during surgery, because the infant's airway is very short. The peripher-

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al airway might close in the dependent lung, because the functional residual capacity is closer to the residual volume and atelectasis ensues. A small lumen is easily obstructed by blood or secretions. Every manipulation of the tracheal tube, airway, and bronchial blocker has to be made very carefully.

The technical skills required for the management of OLV in infants are of great relevance and anesthetic management has a big impact on the successful performance of VATS [1,8].

Physiology of OLV and of lateral decubitus position in Infants

In adults and children in normal conditions the respiratory exchanges are optimal if ventilation (V) and perfusion (Q) are well matched. During OLV the ratio V/Q is increased, that is the intrapulmonary shunt is increased, with detrimental effects on oxygen exchanges. This effect is due to several factors: diaphragmatic pushing, lung compression by mediastinal structures, by abdominal viscera, and by rolls placed under the chest to obtain the right patient's position. Moreover, the decrease of residual functional capacity and of tidal volume, general anesthesia, surgical manoeuvers and mechanical ventilation are other factors promoting V/Q mismatch. There is a physiological mechanism which can decrease this negative effect, the hypoxic pulmonary vasoconstriction (HPV); the pulmonary vasoconstriction shifts the blood circulation away from lung areas where the ventilation is poor or absent to the well ventilated lung. When the lung is collapsed, a large share of the blood is diverted toward the dependent lung, but a small share remains in the non-ventilated lung and is not oxygenated. While these events occur in adults and children, the lateral decubitus position has negative effects on V/Q mismatch only in children. The adult patients in the lateral decubitus position do not experience serious difficulties because their rib cage is rigid, the hydrostatic pressure gradient between the lungs and the gravity pressure are higher than in small children. The diversion of the blood circulation from the diseased lung to the healthy, dependent lung is more difficult in children than in adults. Children have a soft rib cage and lungs: the dependent hemithorax is compressed by the lateral decubitus position and by the chest rolls placed to allow a better exposure of the surgical field, the lung compliance of the dependent, healthy, ventilated lung decreases and hypoxia ensues [9-11]. These events make small children prone to hypoxia; for this reason it is essential to maintain the possibility of ventilating both lungs during the whole procedure.

Techniques for OLV

The decreased airway size in infants excludes the choices of double-lumen endobronchial tubes and Univent tubes, which are too large for small children. Only two options are possible, namely selective main stem intubation and endobronchial blocker [1,5-7,12,13].

Selective Mainstream Intubation

The selective bronchial intubation with a single-lumen tracheal tube is the simplest and least expensive way to achieve OLV in infants. The tube must be a half size smaller than that one suitable for tracheal intubation. The right bronchial insertion is very easy and the auscultation of breath sounds is adequate to control the tube position. The blind left bronchial insertion is more difficult for anatomical reasons and some ways to solve the problem have been described [8,12]. But, in our opinion the blind left bronchus intubation is not advised. Instead, guidance of the tube and the control of its correct position with a fiber-optical bronchoscope (FOB) are recommended. A suitable FOB size in infants is 2.2 mm OD or less.

The tube can be cuffed or un-cuffed. A cuffed tube, when possible, assures good seal and satisfying lung collapse. In case of left lung surgery, the placement of the tube in the right main bronchus will cause the exclusion of the upper lobe bronchus with subsequent atelectasis of the upper right lobe and hypoxia. For this reason the right bronchial intubation is not recommended [14]. The problems occurring with selective bronchial intubation are poor lung isolation and difficulty in quickly re-establishing ventilation of both lungs if hypoxia should develop during surgery, since the tube manipulation under the surgical drapes is very dangerous. Moreover, if main bronchus intubation does not give a completely effective bronchus occlusion, it will be necessary to achieve the lung collapse with an intrapleural insufflation of carbon dioxide (CO_2). CO_2 is absorbed into the blood circulation, and this event can be responsible for the development of hypercapnia and acidosis [1,8,14].

Bronchial Blocker

In the seventies a Fogarty embolectomy catheter was used as bronchial blocker; a 2-3 French size Fogarty inserted outside the tracheal tube was considered suitable for OLV in infants. But the low-pressure low-volume high-pressure balloon can cause damage to bronchial mucosa. Moreover this catheter does not have an internal lumen [15]. The Arndt endobronchial blocker 5 French (Arndt Endobronchial Blocker, Cook, Bloomington, USA) represents an improvement in the research for a balloon-tipped catheter suitable for infants, with a high-volume low-pressure balloon, an internal lumen containing a flexible wire stylet with a loop at its end and a special adaptor (Arndt Multiport Airway Adapter) with three ports: one of them accommodating the bronchial blocker, the second one the FOB and the third one the connector for the ventilation circuit. This adaptor allows the prosecution of infant's ventilation during the whole procedure. In infants, whose trachea does not allow the insertion of a tracheal tube large enough to accommodate within it the blocker and the

FOB, the Arndt blocker 5Fr is inserted through its port in the adaptor before the tracheal tube, thus remaining outside of the tracheal tube. In this way, the extraluminal placement of the blocker leaves more room for ventilation. The FOB is then inserted through its port; the FOB tip must pass through the blocker loop and be advanced into the mainstem bronchus to be blocked. Now the balloon is slowly inflated under FOB direct vision with small volumes of air, depending on the size of the bronchial blocker. At this point the FOB may be removed. Lung auscultation will confirm the silence of breath on the blocked side.

It is suggested to check the correct position of the balloon in the bronchus after turning the child from supine to lateral position, to exclude the dislodgment of the blocker. Some authors suggest placing the blocker when the child is already in the lateral position [16].

After checking the correct position and inflation of the bronchial blocker balloon, the wire guide must be removed to leave the channel available for the lung deflation, for aspiration and for oxygen delivery.

The bronchial blocker allows effective collapse of the diseased lung and isolation of the healthy lung; moreover, it allows the fast switch from OLV to two-lung ventilation when necessary.

The insertion procedure must be made with extreme care to avoid complications such as dislodgment of the balloon into the trachea or airway injury.

Anesthetic Technique

Both inhalation and intravenous techniques are described for the anesthesia of infants undergoing VATS; it seems that inhalational agents might inhibit the HPV and be responsible for an intrapulmonary shunt increase and hypoxia, but a Cochrane database consultation does not indicate reviews or clinical randomized trials showing differences in outcome between intravenous and inhalational agents [17]. This conclusion has been confirmed by other authors [18,19].

A large bore intravenous access is mandatory, since the time necessary to stop bleeding from a large vessel is longer in VATS than in open surgery [19].

Several methods are available to support the infant's respiratory exchanges during OLV a tidal volume of 8-10 ml/Kg to the ventilated lung, intermittent or continuous positive airway pressure to the non-ventilated lung, intermittent insufflations to the non-ventilated lung or to both lungs can prevent atelectasis. If hypoxia still persists a higher oxygen fraction is recommended.

Electrocardiography, non-invasive blood pressure, pulse oxymetry, end-tidal CO_2 concentration and body temperature represent standard monitoring of infants undergoing VATS.

Infants and small children are prone to hypothermia during anesthesia and surgery; it is not clear yet if thoracoscopy is responsible for hypothermia or hyperthermia [8]. In any case, the temperature should be monitored as in all long-lasting surgical procedures performed in children and maintenance of body temperature assured with warming devices.

Some authors recommend the placement of an arterial line to check blood gas values [14,20]. Hypercarbia can occur during VATS due to hypoventilation, V/P mismatching and absorption of CO_2 insufflated into the chest when the seal of the bronchial tube is not reliable [14]; non-invasive monitoring cannot detect the real amount of arterial CO_2 value because of the discrepancy existing between end-tidal CO_2 ($EtCO_2$) and arterial CO_2: $EtCO_2$ underestimates the CO_2 arterial pressure. The difference is due to increased physiologic dead space. Nevertheless, $EtCO_2$ monitoring is very helpful for detecting ventilation problems. A moderate hypercarbia can be accepted, provided that oxygen saturation is adequate; when acidosis occurs ventilation must be adjusted [15,21].

Informed Consent

The anesthesiologist should be very clear and exhaustive in providing information. While some surgeons might minimize the procedure ("only three small holes"), parents must know that, along with the benefits, there are also some risks whose frequency and severity must be explained. Minimally invasive surgery does not mean minimal risk [19].

Postoperative Pain

Thoracoscopic surgery causes less postoperative pain than open surgery because it is less invasive; the injection of a topical anesthetic agent in the surgical incisions is an easy way to reduce pain. A paravertebral block or an epidural catheter with a continuous infusion of a local anesthetic agent guarantees pain prevention and treatment [22,23]. While thoracotomy requires a two-three days of analgesia, pain resulting from thoracoscopic surgery is of shorter duration and less relevant, probably due to the low invasiveness of the procedure and to the reduced need of the chest tube [24].

Conclusions

VATS is a safe alternative to open surgery in infants. OLV is feasible, but not mandatory: small children often do not tolerate it and VATS may be performed with conventional ventilation and comparable results [6]. Some benefits of VATS are undisputed, such as cosmetic, musculoskeletal benefits and reduction of postoperative pain; others are the subject of debate, such as length of hospital stay and rate of complications: some authors found no differences in hospital length of stay, chest tube duration and short-term complication rate between thoracoscopy and open access surgery [3,24]; recent meta-analysis shows that hospital stay and the persistence of the chest tube are of longer duration after the open approach [21], but the complication rate is similar between the two procedures.

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Conflict of Interest

Authors certify that they have no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangements, etc) that might pose a conflict of interest in connection with the submitted article.

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