Protective Ventilation in the OR

Intraoperative recruitment maneuvers

For many anesthetists, alveolar recruitment maneuvers (RMs) are a routine procedure in general anesthesia, even though they are not generally recommended in existing guidelines. Recommendations from literature are scarce and strong evidence is unavailable. This paper sheds some light on the current state of discussion.

Intraoperative recruitment maneuvers: Latest scientific findings and recommendation

For many anesthetists, alveolar recruitment maneuvers (RMs) are a routine procedure in general anesthesia, even though they are not generally recommended in existing guidelines. At many locations, they are a common procedure and have an established place in everyday clinical routine. In fact, some patient groups (e.g. in thorax surgery) depend on intraoperative RM procedures. Despite this, it is often not clearly known what exactly evidence-based medicine has to say about recruitment maneuvers and what the current thinking among experts is regarding their use. In particular in connection with the use of lung-protective ventilation in the operating room, the significance of RMs still seems to be unclear. Although there is no generally accepted consensus regarding the use of intraoperative recruitment maneuvers, it is possible to identify a number of well-recognized basic principles and points of orientation.[1]

In this paper we will take a look at the currently available data and recommendations of experts and will provide you with an overview of the present state of knowledge and opinion regarding intraoperative alveolar recruitment.

Medical-scientific classification

Intraoperative recruitment maneuvers (RMs) serve to open atelectatic regions of the lungs, thus resulting in an increase in oxygenation and ventilation during anesthesia. Parameters such as compliance and functional residual capacity (FRC) also improve. Concurrently, respiratory effort and pulmonary right-to-left shunt decrease.[1,3] Atelectasis is found in up to 90 percent of all patients during general anesthesia and thus occurs very frequently.[28] Atelectasis is also among the postoperative pulmonary complications which cumulatively have a highly relevant effect on morbidity and mortality.[6] According to a study from 2010, five percent of all surgical patients suffer from postoperative pulmonary complications. Other studies specify figures ranging from 2 to 19 percent. In the 2010 study, 1 in 5 of the included patients died within the first 30 postoperative days.[7,8]

Recruitment maneuvers: Important, but not without risks

For certain patients, RMs represent an important intervention. As with all forms of treatment, however, RMs can also be accompanied by adverse effects. For example, increased intrathoracic pressure has a depressive effect on circulation through a reduced venous return. Arterial pressure declines as does the cardiac output with a resultant negative effect on oxygen transport capacity. For this reason, pronounced hypovolemia is judged to be a contraindication for RMs.[2,9] Cardiac arrhythmia is also a possible adverse effect of recruitment maneuvers.[2] It has also been shown that RMs involve some risk for pulmonary barotrauma which is attributable to excessive regional stretching of the sensitive lung parenchyma. This can result in structural damage with alveolar hemorrhaging; in addition, ventilation-induced damage to lung tissue can cause a pneumothorax.[10]

Furthermore, mechanical organ stress can release inflammatory mediators (e.g. IL-8 and TNF-α), which may have damaging effects on the lungs themselves as well as on other organs via the blood circulation (biotrauma hypothesis).[11,12] Cellular apoptosis can also be caused in the kidneys and intestine. Researchers speculate that this is caused by an interaction of inflammatory mediators and proapototic factors.[13] In patients with risk factors for the development of postoperative complications, particularly when such patients are subject to a high degree of surgical trauma, the application of lung-protective ventilation parameters, including the use of RMs in the event of a corresponding indication, appears to make sense.

Indications for recruitment maneuvers

The principal indication for intraoperative RMs is atelectasis resulting in hypoxemia and an impairment of ventilation as well as of lung compliance. Even if atelectasis can be found in up to 90 percent of patients receiving general anesthesia, not all of these patients require RMs.[5] Resorption atelectasis is a frequent indication, which usually appears a few minutes after the induction of anesthesia. This occurs when the gas exchange between alveoli and capillaries exceeds the fresh gas supply. Resorption atelectasis can be favored by preoxygenation with a high level of FiO_2 and the redistribution of ventilation resulting from muscle relaxation in a supine position.[14] The latter two factors can also induce compression atelectasis. This results in an increase of pleural pressure. When the pleural pressure exceeds the alveolar pressure, this leads to the collapse of the affected lung region which typically is close to the diaphragm and dorsally located.[15,16]

Generally speaking, obese patients are particularly subject to intraoperative atelectasis because the abdominal mass and the resultant pleural pressure can be extremely high. In comparison to patients of normal weight, there is already a preoperative reduction of FRC of up to 20 percent. This effect is aggravated by anesthesia. An average decrease in FRC of 50 percent following induction has been found. Further indications for RMs include endotracheal suction and disconnection, intraoperative ventilation with very high doses of oxygen, and ARDS.[9] Some experts are of the opinion that patients of normal weight and healthy pulmonary function only require RMs in the event of persistent hypoxemia when a preceding increase of FiO_2 and PEEP have not met with success.[5,17] But this opinion is a matter of controversy.

Contraindications for recruitment maneuvers

Contraindications include:

- Pulmonary emphysema: Emphysematous blebs can rupture as a result of the ventilation pressure[9]
- Circulatory instability: In particular pronounced hypovolemia[9]
- Right-sided heart failure: Risk of a full failure of the right heart[9]
- Elevated cerebral pressure: Recruitment maneuvers can increase the cerebral pressure through a reduction of flow in the jugular veins[9,18]

Alveolar recruitment: Yes, but how?

The classic inflation maneuver via the manual ventilation bag is a very widely used form of RM. This procedure continues to be practiced in many hospitals. Although it is definitely effective and can be quickly applied, the high peak pressure levels cannot be viewed uncritically. They involve a risk of hemodynamic and pulmonary adverse effects. Recruitment success as well as various complications can be detected using respective monitoring (e.g. pulse oximetry, capnography and hemodynamic monitoring).[19]

According to a publication by Güldner and Gama de Abreu, however, an even lower degree of hemodynamic load can be achieved through stepwise, incremental increase of the inspiratory pressure during the RM. With this approach there is an incremental increase in the PEEP, whereby the pressure differential between inspiratory pressure and PEEP should optimally be kept constant.[5] With an RM conducted in this incremental manner it is important that the maneuver consists of an incremental and a decremental part. The stepwise increase of PEEP and inspiratory pressure serves to open the atelectatic region of the lungs; therefore the maximum pressure level must at least reach the level necessary for alveolar opening. In the decremental part of the maneuver, the pressure is decreased in a similar manner. Through appropriate monitoring, the patient-specific PEEP for maintaining the recruited status of the lungs can be identified.[37] In this regard, studies document a lower release of inflammatory mediators such as IL-8 (- 41%) and TNF-α (- 20%) with increased compliance and oxygenation.[12] In addition, new studies confirm the improved toleration of a stepwise recruitment with lower pressure parameters accompanied by fewer alveolar lesions and less endothelial cell damage.[20]

For the intraoperative application of RMs, these lower pressure levels must, however, be evaluated in connection with the surgical procedure that is being undertaken. The adverse hemodynamic effects of slowly applied RMs have also been found to be less pronounced.[21] Due to the relative simplicity with which it can be applied, the inflation maneuver via the manual ventilation bag continues to be used widely and can definitely be seen as an effective technique. Therefore, this procedure also has its place as a viable technique. But various experts are recommending more and more an incremental recruitment approach.[5,17] This approach, however, does take longer and requires more operating steps.

A very pragmatic approach was presented by the Australian anesthetist Dr. Chris Thompson in 2015 at the annual meeting of the Australian and New Zealand College of Anesthetists [see presentation of Dr. Chris Thompson, ANZCA 2015]. It showed a shift of the VT/PEEP curve in the decremental phase of the RM. The tidal volumes are increased at lower pressure values in comparison to the incremental phase and an individual patient PEEP can be identified. In addition to individually adjusted ventilation monitoring, hemodynamic monitoring is also essential when recruitment is being conducted in a stepwise manner.

The probability of success differs

Although recruitment maneuvers sometimes have great clinical significance, their effect is not always the same. If the atelectasis has only been present for a short time, for example in connection with anesthesia (following induction of anesthesia or in laparoscopic procedures), the collapsed areas of the lung can be opened with sufficient pressure. For patients with acute lung failure that has a primarily extrapulmonary cause (e.g. in peritonitis, concomitant obesity, disorders with increased abdominal pressure), the probability of success for RMs is high.[14] When intrapulmonary factors are involved (e.g. pneumonia), RMs are typically less effective according to several studies, and the probability of success is only five to ten percent. The latter, however, is found more frequently in intensive care settings and less often in the operating room.

In intensive care, the negative effects of RMs can outweigh the benefits as the patients in the ICU are generally in worse condition and more often have pre-existing pulmonary conditions than those undergoing normal surgery. Pneumonia, for example, can be aggravated through recruitment and ventilation as a result of the mechanical pressure on the lung parenchyma.[22,24] Other studies show an effectiveness rate of 50 to 90 percent for RMs also with intrapulmonary causes of acute lung failure, however with use of very high pressure levels.[23]

Regardless of which approach is taken, RMs are only effective with atelectasis and not with pulmonary consolidation when the alveoli are filled with secretion, liquid or foreign tissue.[24] For these reasons, there are responders and nonresponders with the use of RMs. The optimal level of recruitment pressure varies from patient to patient and the most effective duration and frequency for administering RMs have yet to be finally determined.[22] This is particularly the case when the PEEP is not raised following the RM to prevent a subsequent derecruitment from occurring. Large differences are to be found among patients. These differences must in some cases be handled through the use of differing recruitment procedures and technical solutions.

Success monitoring as a fundamental component

While it is certainly necessary to be aware of potentially harmful effects of an RM, it must also be emphasized that use of an RM can help achieve significantly better oxygenation and compliance in many patients. Improvement of compliance is important because this ensures adequate tidal volume at lung-protective pressure levels (inspiratory pressure, driving pressure). Therefore it is important to assess the success of an RM on the basis of both these factors.
An improvement in oxygenation can be quickly and simply detected via pulse oximetry. Monitoring of improvements in compliance, however, requires corresponding functionality at the anesthesia work station. In conducting this monitoring, it is important to see how compliance develops over time so that any improvement or deterioration can be quickly detected. In particular, a merged trend comparison of PEEP and compliance can provide valuable information for the individual adjustment of PEEP for each patient and thus help to keep the lungs open following a recruitment procedure.

Recruitment maneuvers as part of lung-protective ventilation

According to current practice and data, perioperative lung-protective ventilation consists of a low tidal volume, moderate PEEP and recruitment maneuvers, whereby the recruitment is not necessarily part of standard procedure.[25] In surgical patients with medium and high risk profiles this approach facilitates a reduction in the occurrence of postoperative pulmonary complications. In ARDS patients, this approach has now become part of routine procedure in several centers, although it is not directly corroborated by guidelines.[26]

The practice of administering continuous airway pressure of 35 to 40 cmH_2O for 40 seconds (sustained inflation), which has been standard practice for a long time, has proved to be effective. However, it may be associated with an increased risk of adverse hemodynamic effects and does not provide better results even for ARDS patients. These facts have been confirmed in studies by Futier et al.[26] In addition to the peak inspiratory pressure, the driving pressure also has an important influence on the risk of postoperative pulmonary complications. Driving pressure is the difference between the peak inspiratory pressure and PEEP.

If an RM with subsequent PEEP optimization results in improved compliance, then the same Vt can be applied with a lower driving pressure. A driving pressure below 13 cmH_2O seems to be associated with a lower rate of risk for postoperative pulmonary complications in comparison to higher values.[27] For further risk reduction, Ladha et al. recommend the use of a PEEP of 5 cmH_2O and a peak inspiratory pressure of 16 cmH_2O or less with continuing mechanical ventilation as protective ventilation setting.[28] This, however, will most likely not completely prevent the occurrence of atelectasis in many patients.[14] A general recommendation regarding concrete PEEP values must therefore be viewed critically from a physiological standpoint.

Experts are of the opinion that an individual patient-based adjustment of PEEP following a recruitment maneuver may have better chances of success.[14] This individual patient-based PEEP can be identified in the part of the decremental phase of a RM with PEEP-titration in which the tidal volume or the compliance is highest (see presentation of Dr. Chris Thompson, ANZCA 2015). To date, however, there are no data that show the possible advantages of an individual patient-based PEEP setting for the relevant perioperative outcome parameters.

What recommendations can be made?

A clear, evidence-based recommendation for one or another recruitment procedure or regarding the indications when alveolar recruitment should be conducted cannot be made on the basis of currently available data. With the aim of having fewer hemodynamic, inflammatory and barotraumatic complications, some experts recommend incremental recruitment.

The necessary pressure level for opening collapsed lung sections resulting from atelectasis – cited in the literature as 40 cmH_2O in patients of normal weight and 50 cmH_2O in obese patients – may be achieved with less strain using incremental RMs.[5,14,29,30,31,14] An incremental RM does not necessarily need to be completely executed if sufficient oxygenation can already be restored before the maneuver has been finished. The use of a PEEP alone in most cases does not result in the recruitment of collapsed alveoli. Some experts see full recruitment as not being necessary in every instance, a stance which is expressed in the concept of permissive atelectasis.[5,32]

In operative procedures of short duration, limited surgical trauma and low patient-related risk factors for the development of perioperative complications, the ventilation strategy does not appear to place a critical role.[7,14] When feasible with regards to oxygenation, atelectasis can be accepted to a certain extend in order to improve tolerance of ventilation (less mechanical stress and fewer hemodynamic effects).[5,33] Implementing this approach as a matter of principle has, however, generated strong criticism.

In accordance with the approach of tolerating some atelectasis, ventilation for patients of normal weight with healthy lungs undergoing abdominal surgery should in the opinion of some experts have a low PEEP of 2–5 cmH_20 to limit extensive formation of atelectasis. In accordance with this view, the benefit of hemodynamic stability outweighs a possible improvement in oxygenation, particularly because in most patients oxygenation is sufficient in any case.[5] If perioperative hypoxemia should occur, then an initial attempt to counteract this should be made with an increase of FiO_2 to 0.6 and an adjustment of the PEEP. If this condition persists, then a recruitment maneuver is indicated.[5,17] This approach is based, however, on the not universally accepted assumption that atelectasis can be accepted when the oxygenation level permits.

Whether recruitment is undertaken immediately or rather in a more restrained manner, the following applies for all patients: The PEEP following a RM must be high enough to prevent recurrent atelectasis formation and thus atelectrauma with the release of cytokines. The exact level of PEEP continues to be a subject of discussion and has not been established clearly in the literature. As already described, in the application of an incremental recruitment approach indicators for a patient-adapted PEEP may be detected in the decremental portion of the procedure. (see presentation of Dr. Chris Thompson, ANZCA 2015).

In obese patients, intraoperative recruitment maneuvers followed by a PEEP of 10–18 cmH_2O (depending on examination results) provide advantages compared with a PEEP of 5 cmH_2O or a recruitment maneuver without PEEP. These advantages consist of improved oxygenation and a reduction of atelectasis.[34,35,38] For the use of a PEEP in obese patients there is still no general consensus, but there is some evidence that due to the higher pleural pressure (exterior pressure) a higher PEEP is required in such patients to prevent compression atelectasis. Caution is called for in all patients who have already suffered a so-called first hit (e.g. injury, infection, etc.).[36] Advocates of the "second hit theory" argue that ventilation-induced complications first occur through an interaction of barotrauma and a previous injury.[14] Patients at hemodynamic risk with hypovolemia should – assuming there is no contraindication – receive a preoperative fluid substitution or a treatment with vasopressors.[14]

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