

# Non-invasive ventilation during surgery under neuraxial anaesthesia: a pathophysiological perspective on application and benefits and a systematic literature review

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## Abstract

Unlike general anaesthesia, neuraxial anaesthesia (NA) reduces the burden and risk of respiratory adverse events in the post-operative period. However, both patients affected by chronic obstructive pulmonary disease (COPD) and chest wall disorders and/or neuromuscular diseases may experience the development or the worsening of respiratory failure, even during surgery performed under NA; this latter negatively affects the function of accessory respiratory muscles, resulting in a blunted central response to hypercapnia and possibly in an exacerbation of cardiac dysfunction (NA-induced relative hypovolemia). According to European Respiratory Society (ERS) and American Thoracic Society (ATS) guidelines, non-invasive ventilation (NIV) is effective in the post-operative period for the treatment of both impaired pulmonary gas exchange and ventilation, while the intra-operative use of NIV in association with NA is just anecdotally reported in the literature. Whilst NIV does not assure a protected patent airway and requires the patient's cooperation, it is a handy tool during surgery under NA: NIV is reported to be successful for treatment of acute respiratory failure; it may be delivered through the patient's home ventilator, may reverse hypoventilation induced by sedatives or inadvertent spread of anaesthetic up to cervical dermatomes, and allow the avoidance of intubation in patients affected by chronic respiratory failure, prolonging the time of non-invasiveness of respiratory support (i.e., neuromuscular patients needing surgery). All these advantages could make NIV preferable to oxygen in carefully selected patients.

**Key words:** neuraxial anaesthesia, non-invasive ventilation, intra-operative respiratory failure.

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Nowadays, all surgical interventions are performed under some form of anaesthesia. When compared to general anaesthesia (GA), regardless of whether respiratory drive is temporarily abolished or preserved, neuraxial anaesthesia (NA) exerts minor effects on pulmonary function. According to European Respiratory Society (ERS) and American Thoracic Society (ATS) guidelines on the application of non-invasive ventilation (NIV) in acute respiratory failure, NIV is effective in the post-operative period for the treatment of both impaired pulmonary ventilation and gas exchange [1], but its intra-operative use is still poorly investigated, mostly anecdotally reported and no randomized trials exist. NIV does not assure a patent and protected airway and is burdened with risk of patient-ventilator asynchronies, gastric distension, hemodynamic effects and discomfort (i.e., mask unsuited to the patient's facial shape, head and skin pain due to tight straps, air leaks, noise, eye irritation, anxiety); however, NIV, by requiring an intact respiratory drive, may optimize the pulmonary ventilation to perfusion match, even better than in intubated patients, in whom the non-dependent lung area is preferentially ventilated, favoring the normalization of blood gas tension during the surgery but with avoidance of intubation-related complications (i.e., baro- and volutrauma, biotrauma, airways mechanical irritation, infections) [2]. Patients at risk of postoperative pulmonary complications (PPCs), as defined in 2015 guidelines for peri-operative clinical outcome (European Perioperative Clinical Outcome, EPCO) by a European joint taskforce [3], could particularly be benefited by a combined NIV-NA approach. The purpose of this review is to discuss the physiopathological rationale and the current scientific evidence of using NIV during surgery performed under neuraxial anaesthesia.

### GENERAL ANAESTHESIA AND NEURAXIAL ANAESTHESIA: EFFECTS ON LUNG FUNCTION

GA exerts a deep influence on the respiratory system. Hedenstierna *et al.* [4, 5] have shown that all general anaesthetic agents, except ketamine, cause a loss of static muscle tone, with a reduction in chest wall outward recoil to counteract the inward elastic recoil of the lung. As consequence, FRC (i.e., the resting capacity of the respiratory system) is reduced by 0.4 to 0.5 L under GA [6]. The detrimental reduction of FRC toward the closing volume promotes atelectasis formation in dependent lung areas, with lowering of the ventilation to perfusion ratio ( $V_A/Q$ ); in particular, as reported by Froese and Bryan [7], the cranial displacement of the diaphragm is the major cause of FRC drop during GA (regardless of the route of general anaesthetics), with a minor contribution by a decrease of the transverse area of

the thorax. However, other authors suggest that the role of the diaphragmatic-abdominal compartment is minor compared to the role of the ribcage muscles (primarily intercostal muscles) in the lowering of FRC during GA: Spens *et al.* [8] compared the effects of three intra-venous induction agents on ribcage and abdominal dimensions of 76 patients without respiratory diseases scheduled for elective surgery; although abdominal volumes remained unchanged, ribcage volumes decreased (median value 136 mL).

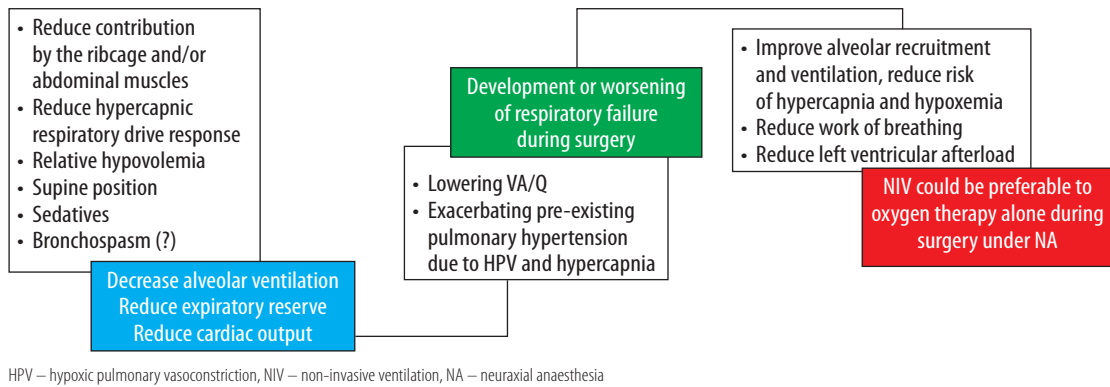
Controlled mechanical ventilation (CMV), with a passive and flaccid diaphragm, may exert both "macroscopic" (due to the preferential distribution of the ventilation in non-dependent lung area with  $V_A/Q$  mismatch [7, 9]) and "microscopic" adverse effects (such as the time-dependent overexpression of muscle atrophy genes, leading to early myofibrillar disarray [10]); in contrast, under NA, the diaphragmatic function is preserved until the sensory blockade of low cervical dermatomes [11, 12]. NA includes spinal, epidural and combined spinal-epidural technique; in principle, spinal anaesthesia (SA) produces a higher and faster motor block than epidural anaesthesia (EA), because the anaesthetics spread more easily in the cerebrospinal fluid. In 1967, Freund *et al.* [13] described the different magnitude of the effect of EA and SA on inspiratory capacity (IC) and expiratory reserve volume (ERV) in eighteen healthy subjects, at different levels of motor block, from T12 to T1. The authors found a decrease in IC by 8% with SA and by 3% with EA, while ERV fell by 48% with SA and by 21% with EA. Interestingly, IC decreased only 19% under total spinal thoracic motor block, due to the preponderant role of the diaphragm in generating the transpulmonary pressure during inspiration. In contrast, the mean percent reduction of ERV reached 100% under total spinal thoracic motor block, due to the crucial contribution of expiratory ribcage muscles and abdominal muscles to active expiration. Paskin *et al.* [14] performed a study focusing on the effects of SA on lung function in nine patients with chronic obstructive pulmonary disease (COPD), undergoing transurethral prostatectomy, in which the sensory block was at the mid-thoracic level. The authors reported a fall in peak expiratory flow and vital capacity values; however, alveolar ventilation, blood gas tensions and respiratory gas exchange were not impaired, suggesting that SA with a block to or above the seventh thoracic dermatome could be relatively safe in COPD patients. In these latter, preserving the function of expiratory muscles is crucial, active expiration being an adaptive mechanism to compensate for the insufficient lung emptying due to the reduced elastic recoil. Furthermore, a whole active expiration is necessary for cough (by defini-

tion, a forced effort against the closed glottis, due to the contraction of expiratory muscles), because the mucus dislodgement from trachea-bronchial tree by the high expiratory flow prevents micro-atelectasis and, in turn, respiratory failure and pulmonary infections [15]. Other studies in the literature also appear to support Paskins's results. Hausman *et al.* [16] performed a study to quantify the benefit of avoiding GA in COPD patients. For this purpose, 2644 "regional" COPD patients (i.e., surgery performed under spinal, epidural or peripheral nerve block anaesthetic techniques) were propensity-score matched to COPD patients who underwent GA and invasive mechanical ventilation. There was a significant reduction in the incidence of pulmonary infection, ventilator dependence and unplanned intubation in the former group of patients even though the 30-day mortality rates were similar between the two groups. Nonetheless, the presence of COPD was defined clinically (degree of dyspnea) and not by pulmonary function test, limiting the validity of these results. As NIV is mostly applied in COPD with a severe degree of airway obstruction ( $FEV_1 < 30\%$  of predicted value), the benefits of NA during the intra-operative period as a way to lower the incidence of peri-operative pulmonary complications could not be sufficient in these patients, remaining scientifically unproven. Undoubtedly, unlike GA, NA preserves the diaphragmatic function. Pansard *et al.* [17] investigated the effect of thoracic extra-dural block (TEA) on diaphragm activity in 14 patients undergoing abdominal aortic surgery. The intramuscular electrodes were placed on the costal and crural parts of the diaphragm, then the electromyographic signals of the muscle before and after TEA were recorded. The authors reported that TEA induced an increase in diaphragmatic activity, possibly because the abdominal visceral deafferentation interrupted the inhibitory effect of the nervous sensory pathways on phrenic activity, via a negative reflex spinal arch. Theoretically, preganglionic sympathetic block due to a high thoracic EA with unopposed parasympathetic tone should result in an increase of airway resistance. In fact, high thoracic EA does not worsen airway resistance or attenuate the response to an inhalation provocation test in patients with bronchial hyper-reactivity [18]. Indeed,  $\beta_2$  bronchiolar adrenoceptors, exposed to circulating catecholamines, outnumber  $\beta_1$  bronchiolar adrenoceptors, innervated sympathetically by three- to fourfold [19]. Because EA does not depress the adrenal release of catecholamines in the systemic circulation, the bronchodilator action of  $\beta_2$  adrenoceptors should remain unaffected by any pulmonary sympathetic blockade [20]. However, even though it is not very common, cases of bronchospasm trig-

gered by spinal anaesthesia in COPD and asthmatic patients are reported [21]. Similar to patients with COPD, patients with chest wall and/or neuromuscular disorders (NMD) also have a significantly increased risk of PPCs. Hypoventilation due to respiratory muscles weakness and/or to increased chest wall elastance, along with the impaired coughing effort, and possibly with the reduced cardiac reserve (damage of cardiac muscle fibers in certain dystrophinopathies), delay the time of weaning from the ventilator and promote micro-atelectasis formation, responsible for hypoxemia. In patients with NMD, GA may also induce life-threatening complications, including malignant hyperthermia, rhabdomyolysis and hyperkalemic cardiac arrest, because of striated muscles' denervation hypersensitivity to some anaesthetic agents [22–24]. Hence, in patients with reduced pulmonary function, NA should be preferable based on both physiological perspectives and preliminary clinical reports.

#### **NON-INVASIVE VENTILATION TO SUPPORT LUNG FUNCTION DURING NEURAXIAL ANAESTHESIA. AN EXPANDED PATHOPHYSIOLOGICAL RATIONALE**

Because NIV is effective in patients with increased work of breathing and/or an exhausted respiratory pump, its intra-operative application can theoretically reduce the risk of any potential adverse effects of NA on respiratory function. During surgery, the simple shift of the patient's position from upright to supine induces a decrease in FRC ranging from 0.8 to 1 L [6], and a decrease in vital capacity (VC) and  $FEV_1$  between 7% and 23% [25, 26]; in particular, when lying down, slowly emptying alveoli become poorly ventilated even in subjects without lung disease and it would furnish a quote of venous admixture to the arterial blood [25]. Therefore, both COPD and chest wall disorder/NMD patients could be suffering from the reduction of expiratory reserve by the simple assumption of the supine position: the aeration of poorly ventilated alveoli (i.e., increased airway resistance, inadequate inspiratory lung expansion) could further deteriorate up to the development of intra-operative respiratory failure. However, the protective activation of hypoxic pulmonary vasoconstriction (HPV) in poorly ventilated alveoli could still maintain a normal or near-normal arterial oxygen pressure ( $PaO_2$ ), but at the expense of exacerbating pre-existing pulmonary hypertension in patients with respiratory disease [27]. Another concern arises about the influence of thoracic extradural anaesthesia (TEA) on the respiratory response to variations of arterial blood gases. Kochi *et al.* [28] performed a study on six healthy male subjects undergoing high TEA; the authors found a significant reduction of ventilatory response to



**FIGURE 1.** Detrimental effects of neuraxial anaesthesia on respiratory system and the potential benefits of noninvasive ventilation

hypercapnia induced through carbon dioxide re-breathing: probably, the mechanical impairment of the ribcage muscles by TEA can significantly influence the breathing pattern (that is, decrease the hypercapnic ventilatory response) in healthy human volunteers. Indeed, as reported in an elegant study by Remmers [29], the rhythmic activation of the fusimotor/spindle afferent system synchronous with intercostal muscle contraction directly affects the reflex control of breathing, suggesting a wider role of ribcage muscles in the regulation of breathing pattern. Often, during awake thoracic surgery, the simple administration of oxygen prevents hypoxemia but induces hypercapnia, particularly in COPD patients [30]; also if an increased arterial carbon dioxide level in the perioperative period is rarely a life-threatening condition (concept of permissive hypercapnia), it could impair the state of vigilance and blunt the airway protective reflexes, with risk of aspiration. From a purely mechanical perspective, the blockage of ribcage muscles by TEA is detrimental, with COPD patients using these muscles to generate a sufficient flow. Because NA interferes with these complex mechanisms, it should be used cautiously in patients with respiratory muscles' wasting and dysfunction, as it may precipitate respiratory failure [31, 32]. Depending on the level of spinal segment deafferentation, NA is associated with a cardio-depressant effect due to arterial and venous dilatation, with relative hypovolemia. If increased sympathetic activity above the block is an important homeostatic mechanism to maintain blood pressure, COPD patients with right and/or left ventricular dysfunction may tolerate NA and any associated therapeutic measure such as fluid administration very poorly [33, 34]. The adverse effects of NA on respiratory function may be listed as follows:

- loss of contribution of accessory muscles of respiration,
- blunted ventilatory response to variation of blood gas tensions,

- reduced chest wall expansion due to supine positioning,
- relative hypovolemia.

These effects could negate the potential benefits of avoiding intraoperative endotracheal intubation and mechanical ventilation [16]. Since NIV can (1) partially compensate for the affected respiratory function by unloading the respiratory muscles and reducing the work of breathing, (2) improve alveolar recruitment with preservation of lung volumes, resulting in better gas exchange, (3) reduce right ventricular preload and left ventricular afterload, and (4) avoid complications of invasive mechanical ventilation [35–40], the intraoperative use of NIV along with NA may be, at least in theory, justifiable in some patients with COPD or chest wall and NMDs (Figure 1).

## METHODS

We performed an online search in PubMed, Cochrane Library, and Google Scholar databases for any publication (including case report, case series, reviews, trials, etc.) fully written in English or at least with the abstract written in English, without date restriction. Articles focusing on patients < 18 years old and/or on NIV used in the pre-operative and/or post-operative period only were excluded. We searched for publications with the following key words: "noninvasive ventilation" OR "non-invasive ventilation" OR "NIV" OR "BIPAP" OR "noninvasive positive pressure ventilation" OR "intra-operative noninvasive ventilation OR non-invasive ventilation OR NIV", "neuraxial anaesthesia" OR "neuraxial blockade" OR "spinal anaesthesia" OR "epidural anaesthesia" OR "regional anaesthesia", "COPD" OR "chronic obstructive pulmonary disease", "neuromuscular diseases", "Duchenne muscular dystrophy" OR "Duchenne dystrophy", "scoliosis", "chest wall disorders", "amyotrophic lateral sclerosis" OR "ALS". The articles retrieved were analyzed and then tabulated in an Excel spreadsheet with a link to the abstracts; repeated publications were removed from

the list. Publications not suitable for the purpose of this review were deleted too; in particular, articles reporting the use of continuous positive airway pressure (CPAP) or NIV + local anaesthesia were excluded. The remaining articles were analyzed and their references were screened for any possible missed important references. Figure 2 shows the flowchart used for study selection.

## RESULTS

### Abdominal, pelvic and lower extremity surgery

Yurtlu *et al.* [41] reported the successful application of NIV together with epidural anaesthesia for upper abdominal surgery (emergency open cholecystectomy) in a COPD patient with severe airflow obstruction (pre-operative FEV<sub>1</sub> value was 0.7 L – 21.3% predicted) and hypercapnic respiratory failure, on home ventilation; the patient's own NIV device was used, set in biphasic intermittent positive airway pressure (BIPAP). The arterial blood gas values improved both in the intra-operative and in the post-operative setting. Alonso-Inigo *et al.* [42] reported two cases of obese-COPD patients with hypercapnic respiratory failure scheduled for radical retro-pubic prostatectomy under epidural anaesthesia plus continuous intravenous sedation with remifentanyl; the authors did not specify if they were on home oxygen/ventilation or any other long-term inhalation therapy. The pre-operative spirometry was available only in one case and it documented a moderate degree of obstruction (FEV<sub>1</sub> 1.77 L – 57% predicted). The intra-operative respiratory course was uneventful in both cases. In 2002, Iwama [43] in a prospective consecutive case series of 213 patients with a good health status (ASA I-II) who underwent lower extremity/gynecological surgery, reported that NIV, delivered through a nasal mask, was effective in sustaining ventilatory function and gas exchange during combined propofol-epidural anaesthesia. Iwama *et al.* [44] subsequently described a minimally invasive anaesthetic protocol with NIV plus combined epidural-propofol anaesthesia in 265 patients; unfortunately, the proportion of patients with lung diseases was not reported and no comparison was made with patients receiving combined epidural-propofol anaesthesia and supplemental oxygen alone. The use of NA in conjunction with intravenous anaesthetic agent has also been reported by Kapala *et al.* [45], in a patient who underwent surgery for sigmoid cancer. The patient, already on home ventilation plus oxygen, was affected by hypercapnic respiratory failure due to multiple morbid conditions including COPD, severe obstructive sleep apnea syndrome (apnea/hypopnea index of 146, derived from polysomnography) and left diaphragmatic paralysis.

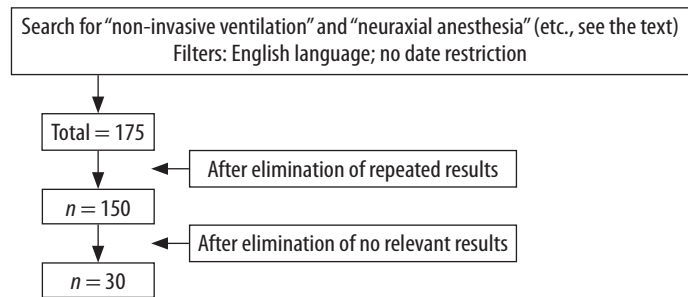


FIGURE 2. Flowchart for systematic review study selection

NIV was successful in maintaining satisfactory alveolar ventilation along the entire course of surgery. Similarly, good outcomes after using NIV with NA were described in three high risk patients with poor respiratory reserve due to severe COPD scheduled for inguinal hernia repair, laparoscopic cholecystectomy and hysterectomy in a case series by Jadon *et al.* [46]. Satisfactory results were also reported by Ohmizo *et al.* [47] in a prospective observational study on 32 patients scheduled for inguinal hernia repair, using NIV to reverse the hypoventilation induced by the concomitant propofol infusion. Various case reports describe the feasibility and safety of NIV plus NA for orthopedic surgery in patients affected by obstructive sleep apnea syndrome and/or severe COPD [48–53].

### Thoracic surgery

Guarracino *et al.* [54] described a terminal cancer patient with recurrent pleuro-pericardial effusion who had uneventful video-assisted thoracoscopic surgery under epidural anaesthesia and with NIV delivered via a facemask. This report opens an interesting scenario: in a terminal patient with a do-not-resuscitate order, NIV may facilitate the need to relieve symptoms due to recurrence of malignant pleural effusion without using endotracheal intubation which may require post-operative ventilation. Honda *et al.* [55] reported the successful reversal of hypoxemia – occurring within 10 minutes of epidural anaesthesia – by NIV in a patient who had severe restrictive respiratory disorder during a right thoracoplasty. The application of NIV “on demand” (not planned) to reverse hypoxemia encountered during the surgery has also been reported by Ferrendier *et al.* [56] in an obese COPD patient.

### Labor and delivery

During normal pregnancy there is a 20–50% increase in resting minute ventilation primarily through an increase (around 2 cm) in downward excursion of the diaphragm with an increase in tidal volume. Therefore, an intact diaphragmatic function is essential during labor; however, some conditions such as obesity, amyotrophic lateral sclerosis, and



scoliosis cause detrimental changes in the respiratory mechanics, increasing the risk of respiratory failure. Polin *et al.* [57] described the management of three parturients with super-morbid obesity (body mass index greater than 50 kg m<sup>-2</sup>) undergoing labor, with a double neuraxial catheter technique (thoracic epidural + lumbar spinal). In one case – a woman affected by asthma and obstructive sleep apnea syndrome on home bi-level ventilation – the intra-operative use of NIV was needed to maintain satisfactory gas exchange. In a 34-year-old woman affected by congenital severe kyphoscoliosis, progressive deterioration in respiratory function was observed from the second trimester of pregnancy due to a reduction in excursion and cranial displacement of the diaphragm by the enlarging uterus in the abdomen. NIV was started to correct nocturnal hypoventilation and fatigue and it was delivered during the labor, performed under NA, preventing respiratory failure and then invasive ventilation [58]. Kock-Cordeiro *et al.* [59] reported the case of a 25-year-old patient at 32 weeks of gestation with motor neuron disease in whom NIV was used to treat hypercapnic respiratory failure precipitated by a viral respiratory infection. After improving her respiratory distress and hypercapnia, NIV was continued during the cesarean section under NA, with a good outcome for both mother and baby. Fujita *et al.* [60] described a case of acute pulmonary edema in a 32-year-old woman who needed an emergency cesarean; after the beginning of NA, NIV was able to relieve her dyspnea and reverse the severe initial desaturation (SpO<sub>2</sub> 84% with supplemental oxygen 15 L min<sup>-1</sup>). In another patient who had pulmonary edema after tocolytic treatment, Perbet *et al.* [61] reported the successful use of NIV to improve the respiratory function. The successful use of NIV to prevent respiratory failure during cesarean section under NA was also reported in a case of inadvertent total spinal anaesthesia following EA [62] and in two parturients affected by limb-girdle muscular dystrophy with a moderate restrictive pattern [63, 64]. A 22-year-old Hispanic woman with mitochondrial thymidine kinase 2 deficiency and chronic respiratory failure due to severe neuromuscular weakness requiring NIV since 12 years of age was also successfully managed by NIV without intubation during the cesarean section operation performed under NA [65]. Other cases of cesarean or tube ligation under NA+NIV are also reported in patients affected by cystic fibrosis, myasthenic syndrome and mitochondrial myopathy [66–70].

### Neuromuscular disorders

Arai *et al.* [71] described the successful management of a patient affected by amyotrophic lateral

sclerosis (ALS) undergoing an emergency laparotomy with NA and NIV. Anaesthetic management of ALS is burdened by a number of serious concerns including hyperkalemia from succinylcholine administration, making the use of non-depolarizing neuromuscular blocking agents mandatory, at the price of probable prolonged paralysis. The presence of advanced bulbar symptoms may further delay extubation, increasing the risk of pneumonia and aspiration. NIV may thus, at least in theory, be useful to allow some of these patients to undergo surgery with NA instead of using invasive ventilation under GA.

### DISCUSSION

In some forms of respiratory failure, noninvasive ventilation has proved to be as effective as endotracheal intubation to deliver tidal volume and improve gas exchange. Despite the conditional recommendation provided by ERS/ATS guidelines for NIV application to treat post-operative respiratory failure, the intra-operative use of NIV combined with NA has been reported mostly in the form of case reports or case series. Without a comprehensive list of patients' characteristics, it is difficult to decide when NIV with NA would be preferable to invasive ventilation with GA or to oxygen delivered via nasal cannulas or a face mask plus NA. Furthermore, case reports are prone to publication bias, making any benefits hard to interpret. From a pathophysiological perspective, NIV *per se* has been used to reach a number of goals during surgery under NA including: 1) to reverse alveolar hypoventilation due to general anaesthetic agents or inadvertent spread of anaesthetic up to cervical dermatomes in patients without respiratory impairment; 2) to prevent or to treat acute respiratory failure in patients who are deemed to be "at risk" of respiratory deteriorations due to NA (COPD or chest wall disorders and/or NMDs); 3) to prevent the worsening of gas exchange in patients who are affected by chronic respiratory failure before surgery (i.e., home oxygen therapy and/or mechanical ventilation); 4) to allow palliative surgical procedures in end-of life patients with do-not-resuscitate and intubate orders. Unlike GA, lumbar and low thoracic NA produces negligible repercussions for pulmonary function, while high thoracic anaesthesia causes a reduction in vital capacity and FEV<sub>1</sub> up to 20%. As observed by Groeben [72], these consequences are so small that the beneficial reduction of PPCs observed with NA makes this latter preferable to GA. However, we could argue that the same effects are enough to disrupt the delicate balance between ventilatory demand and respiratory capabilities/reserve in patients affected by pulmonary diseases. NIV, used commonly in patients with acute and chronic respiratory disorders,

proves to be a handy and effective respiratory support to restore that balance, avoiding the risk of intubation and preserving a more physiologic, “noisy” breathing pattern. NIV improves the matching of ventilation to perfusion in the dependent lung areas and reduces respiratory muscles’ workload. These benefits are especially desirable in patients affected by restrictive or obstructive lung diseases undergoing surgery under NA. NA mostly impairs the expiratory lung reserve, increasing the risk of atelectasis in restrictive diseases and of worsening of hypoventilation in alveoli supplied by obstructed airways. Recently, an interesting review by Cabrini *et al.* [73] analyzed the use of NIV in different types of surgery performed under epidural anaesthesia: sixteen studies reported the intra-operative use of NIV on a total of 24 patients with or at risk for respiratory failure with severe respiratory dysfunction; surgery was completed in all cases without respiratory complications. In these patients at high risk of weaning failure, NIV was used even though the pre-operative labile respiratory status was not worse than the usual one. The authors concluded that intra-operative NIV appears feasible, safe and potentially beneficial, particularly when tracheal intubation is best avoided. However, in many articles reported in Cabrini’s review the patients are assisted during the surgery with CPAP and not with NIV, while in others NIV or CPAP was used in association with local anaesthesia. Conversely, in this review, we focused only on surgery performed under NA with the respiratory support of intermittent positive pressure ventilation. To optimize the patient’s adaptation to NIV and then to maximize the benefits and success of NIV use during NA, NIV should be ideally started in a planned manner at the beginning of NA, before the titration of anaesthetic agents; from this perspective, the administration of ketamine could favor the patient’s adaptation to NIV through good pain control, counteracting the hypotension induced by the sympathetic blockade of NA, without depressing respiratory drive. Furthermore, in patients on home ventilation, a significant advantage of using

NIV during NA lies in the fact that it may be delivered via the domiciliary ventilator, resulting both in a resource-sparing strategy and in a psychologically comfortable choice for the patient. As appears from the above, NIV seems to be handy and successful also for use “on demand”, that is management of acute respiratory failure due to intravenous administration of sedatives or inadvertent cervical block during NA. NIV could be an appealing option also in do-not-intubate patients needing surgery with labile respiratory compensation: the avoidance of invasive ventilation and then of the risk of weaning failure could have a positive impact on the qualitative dimension of dying and death. However, before choosing NIV with NA, the limitations of NIV should be carefully evaluated, including the worsening of NA-induced relative hypovolemia, the inability to clear respiratory secretions, the poor tolerance to a nasal or face mask, the altered consciousness (both hyperactive and hypoactive states), the risk of gastric distension, vomiting and aspiration pneumonia and the presence of a difficult airway (i.e., the immediate availability of a fiberoptic bronchoscope to quickly convert NIV into invasive mechanical ventilation should be mandatory) (Figure 3). An adequately powered randomized controlled trial is needed to confirm whether elective use of NIV with NA is superior to using supplemental oxygen with NA in improving patient-centered outcomes in patients with and without acute and chronic respiratory diseases. Until the results of this trial is available, NIV should only be used judiciously with NA after careful consideration of the patient’s underlying medical condition when the pathophysiological benefits of NIV outweigh its possible risks.

## CONCLUSIONS

NIV appears to be a handy tool to counteract the negative effects of NA on the respiratory system in selected patients undergoing surgery under NA, possibly being more beneficial than oxygen alone. NIV could theoretically reduce the incidence of PPCs, improving the post-surgical respiratory outcome of

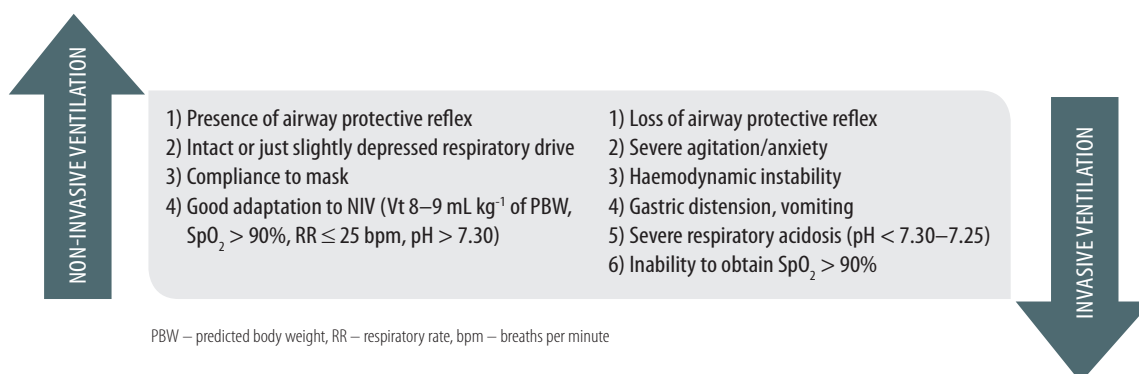


FIGURE 3. Factors to check for the choice of noninvasive ventilation or invasive ventilation during surgery



**FIGURE 4.** Non-invasive ventilation positioning through oro-nasal mask during the preparation of surgical field for femoral osteosynthesis in an elderly obese chronic obstructive pulmonary disease patient (courtesy of Dr. Giuseppe Fiorentino)



**FIGURE 5.** The same case of previous figure at the beginning of surgery (courtesy of Dr. Giuseppe Fiorentino)

at-risk, compromised patients, and resulting in resource sparing compared to GA. However, the limitations and the adverse events of a non-invasive respiratory approach during surgery under NA should be carefully considered, together with the possibility to quickly convert NIV to invasive ventilation.

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