British Journal of Anaesthesia **112** (4): 638–47 (2014)
Advance Access publication 19 January 2014 · doi:10.1093/bja/aet465

BJA

Intraoperative prophylactic and therapeutic non-invasive ventilation: a systematic review

L. Cabrini*, L. Nobile, V. P. Plumari, G. Landoni, G. Borghi, M. Mucchetti and A. Zangrillo

Department of Anesthesia and Intensive Care, San Raffaele Scientific Institute, Ospedale San Raffaele, Via Olgettina 60, Milano 20132, Italy

* Corresponding author. E-mail: cabrini.luca@hsr.it

Editor's key points

- This review has identified 30 papers which included 618 patients who underwent intraoperative non-invasive ventilation (NIV).
- In 92 patients, NIV was used to treat acute respiratory failure.
- In the majority of the patients, NIV was used during sedation.
- When tracheal intubation is best avoided, feasibility and usefulness of intraoperative NIV are confirmed.

Summary. Non-invasive ventilation (NIV) has been used to prevent or to treat perioperative acute respiratory failure (ARF). Intraoperative prophylactic and therapeutic use of NIV could be of interest to patients with anticipated difficulty in postoperative weaning from mechanical ventilation or to patients refusing tracheal intubation. Intraoperative NIV might also be useful when deep sedation is required, as this can cause respiratory depression. PubMed, Embase, Google Scholar, and Cochrane Library were searched for pertinent studies. Inclusion criteria were NIV use during surgery and adult patients; the exclusion criteria were NIV application only in the preoperative or postoperative periods, paediatric patients, NIV applied as negative pressure ventilation. Thirty papers including 618 patients were included for final analysis. Intraoperative therapeutic NIV to treat ARF was reported for 92 patients and in all those cases, including six Caesarean sections, surgery was completed uneventfully. Intraoperative prophylactic NIV to avoid ARF was described in 24 patients with severe respiratory limitation and in 502 healthy patients during deep sedation. Three patients could not be successfully ventilated due to upper airway obstruction, but no further complication was reported. Intraoperative NIV appears feasible, safe, and potentially useful, particularly when tracheal intubation is best avoided. However, high-quality, randomized studies are required.

Keywords: deep sedation; intraoperative care; intraoperative complications; non-invasive ventilation; respiratory insufficiency

Non-invasive ventilation (NIV) is widely used to treat chronic or acute respiratory failure (ARF) in selected cases, such as exacerbation of chronic obstructive pulmonary disease (COPD), cardiogenic pulmonary oedema, and ARF in immunocompromised patients.[1] NIV is also applied to prevent or to treat perioperative ARF: several reviews in fact suggest that patients at higher risk of postoperative ARF (obese or affected by lung diseases), and those undergoing surgeries at higher risk of postoperative respiratory complications (thoracic, cardiac, or upper abdominal surgery), would benefit mostly.[2–4]

To date, no review about the use of intraoperative NIV has been published as yet. By avoiding tracheal intubation, muscle relaxation, and general anaesthesia, NIV could be of particular interest for patients with labile respiratory function, a condition predisposing to difficult or impossible postoperative weaning from mechanical ventilation.[5 6] In daily practice, when postoperative weaning is deemed difficult, surgery poses an ethical dilemma and patients can choose not to undergo an otherwise recommended surgical procedure.[7] Moreover, intraoperative NIV might be useful when deep sedation, but not general anaesthesia, is required in patients with respiratory depression.[8–10]

Therefore, we performed a systematic review of all published studies reporting intraoperative application of NIV, whether prophylactic or therapeutic, in adult patients.

Methods

Search strategy

PubMed, Embase, Google Scholar, and Cochrane Library were searched for pertinent studies (updated October 1, 2012) by three investigators (L.C., L.N., V.P.P.). The full search strategy was performed as follows: [(NIV(tw) OR {[non-invasive(tw) OR noninvasive(tw)] AND [ventilation(tw)]} OR BiPAP(tw) OR CPAP(tw) OR NIPPV(tw) OR 'positive pressure'(tw)) AND ('surgical procedures, operative'(mh) OR intraoperative*(tw) OR intraoperative*(tw) OR perioperative*(tw) OR perioperative*(tw) OR theater(tw) OR surgery(tw) OR operation(tw) OR {operating(tw) NEAR [room(tw) OR theater(tw)]} OR {[care(tw) OR surgical(tw)] NEAR room(tw)})] AND 'anesthesia'(mh) NOT [animals(mh) NOT humans(mh)].

Further searches were focused on conference proceedings from pertinent congresses. The references of retrieved articles were carefully checked. No language restriction was enforced.

Study selection

References obtained from database and literature were first independently examined at the title/abstract level by the same three investigators, with divergences resolved by consensus and with supervision of two investigators (G.L., A.Z.) and

then, if potentially pertinent, retrieved as complete articles. The following inclusion criteria were used for potentially relevant studies: (i) NIV use during surgery; and (ii) study performed in adult patients. Exclusion criteria were as follows: (i) NIV application only in the preoperative or postoperative periods, (ii) paediatric patients, and (iii) NIV applied as negative pressure ventilation. Two investigators (L.C., L.N.) independently selected studies for the final analysis assessing their compliance with the selection criteria. Divergences were resolved by consensus.

Data abstraction and study characteristics

First author and year of publication, study design, country of the corresponding author, number and characteristics of patients, clinical setting, type and length of surgery, decubitus, device and technique used, preoperative use of NIV, intraoperative events, and follow-up were independently extracted by two investigators (G.B., M.M.).

Results

The search strategy retrieved 893 publications and a further 20 studies were found by cross-checking the references in bibliographies of the articles and manually searching other databases. After examination of the title, the abstract, and finally the full text, 31 papers, for a total of 618 patients, were included in the final analysis according to the inclusion and exclusion criteria.[7–37]

Six papers reported intraoperative therapeutic NIV application to treat an established ARF in 86 patients (Table 1).[11–16] Surgery was completed uneventfully in all cases. Another six papers reported intraoperative therapeutic NIV application in six pregnant women (five of which already on domiciliary NIV) undergoing Caesarean section and presenting with ARF (Table 2).[17–22] In all cases, the mothers and the newborns survived surgery. In one case, the mother developed pneumonia on day 7, was intubated the following day, and died on day 10 due to cardiac failure; post-mortem examination revealed completely non-aerated congestive lungs.[17] In all these 92 cases, tracheal intubation and general anaesthesia were refused or considered to be avoided.

Sixteen studies reported the prophylactic intraoperative use of NIV in a total of 24 patients with severe respiratory function limitation, seven of which already on domiciliary NIV (Table 3).[7 23–37] In these patients, the respiratory function was chronically limited. As weaning was expected to be difficult or impossible, tracheal intubation and general anaesthesia were considered unsafe or not appropriate, even though the preoperative labile respiratory status was not worse than the usual one. Surgery was completed in all cases without respiratory complications. No cases of intolerance to NIV or NIV-related complications were reported.

Finally, we identified four papers including a total of 502 patients with no pre-existing or intraoperative respiratory deficits who received prophylactic NIV to avoid hypoventilation during deep sedation (Table 4).[8–10 26] It is to be noted that all but one patient in this group came from the same centre and received deep sedation with propofol during spinal anaesthesia. Three out of 502 patients (0.6%) could not be successfully ventilated with NIV due to upper airway obstruction. One case was resolved by increasing end-expiratory pressure to 10 cm H_2O, the second one was resolved by inserting a nasal cannula, and the third was resolved by the insertion of a laryngeal mask. Furthermore, in one of the studies, a preliminary evaluation of 10 patients sedated with propofol, initially ventilated by nasal continuous positive airway pressure (CPAP) and then by nasal bilevel positive airway pressure (BiPAP), revealed that the patients showed insufficient ventilation with hypoxaemia and hypercapnia while on CPAP.[8] Ventilation was always adequate after crossing to BiPAP. The remaining patients did not present major complications.

Discussion

This is the first review of the use of intraoperative prophylactic or therapeutic NIV. NIV during surgery seems to be feasible, safe, and potentially useful, but only limited and low quality data are available. No randomized trial evaluated NIV efficacy and safety compared with other forms of mechanical ventilation or no mechanical ventilation. However, in all these very heterogeneous cases, NIV allowed the avoidance of tracheal intubation and general anaesthesia.

NIV has an established role in the treatment of chronic respiratory failure or ARF due to common causes like COPD or cardiogenic pulmonary oedema.[1] NIV is contraindicated in patients in respiratory arrest, unable to fit the mask, unable to manage the secretions, uncooperative, or with haemodynamic shock.[1] Several complications have been reported, such as intolerance, skin lesions, or excessive air leaks; moreover, failure rate can be as high as 50% in hypoxaemic patients.[1] Recently, NIV has been evaluated in the perioperative setting as a prophylactic or therapeutic tool. So far, the evidence available is still limited, but NIV seems especially promising when applied to prevent ARF, particularly in patients at higher risk of postoperative respiratory complications or after surgery at higher risk of postoperative ARF.[2–4]

In patients with ARF or at high risk of ARF, the supine position required in most surgeries can worsen the respiratory function; moreover, neuraxial anaesthesia has the potential to interfere with the intercostal muscle function.[22] In the above-mentioned conditions, NIV may improve ventilation reducing work of breathing, improving alveolar ventilation, reducing atelectasis, and reducing left ventricular afterload.[2] An improvement in diaphragmatic ventilatory excursion was observed by ultrasonography.[13]

Our systematic review showed that intraoperative NIV has been mainly used in two conditions:

(i) In a few cases, NIV was applied as a therapeutic tool while surgery was performed despite an ongoing severe ARF.[11–22] Interestingly, even if not fulfilling our inclusion criteria and therefore not further discussed in this paper, we identified five case reports on successful therapeutic NIV during labour and vaginal delivery in patients with ARF.[38–42]

Table 1 Reports on the use of therapeutic intraoperative NIV in patients with established ARF. BiPAP, bilevel positive airway pressure (Philips-Respironics); COPD, chronic obstructive pulmonary disease; CPAP, continuous positive airway pressure; NiPPV, non-invasive positive pressure ventilation; PCV, pressure control ventilation; PSV, pressure support ventilation

Study	Number of patients; surgical procedure; length	Decubitus	Anaesthesia	Patient's main morbidities	Preoperative NIV	Interface	NIV modality	Intraoperative events after starting NIV	Outcome
Nozaki-Taguchi and colleagues[11]	20; lower abdominal surgery; length not reported	Supine	Spinal anaesthesia and sedation (causing airway obstruction)	None	No	Nasal	CPAP	Uneventful	Not reported
Duque González and colleagues[12]	1; drainage of anal fistula; length not reported	Lateral	Sedation plus local anaesthesia	69-yr-old. Exacerbation of COPD in a patient on domiciliary oxygen therapy 18 h per day	No	Facemask	BiPAP	Uneventful	Not reported
Ferrandière and colleagues[13]	1; transurethral resection of the prostate; length not reported	Lithotomy position	Spinal anaesthesia	54-yr-old. Obesity, severe COPD	No	Full facemask	NIPPV	Uneventful; intraoperative improvement of P_{O_2} (P_{CO_2} unchanged)	NIV continued until anaesthesia wore off (overall: 150 min); discharged without complications
Thys and colleageus[14]	1; femoral fracture fixation (intramedullary nail); length: 75 min	Supine	Spinal anaesthesia	77-yr-old. Kyphoscoliosis, COPD, domiciliary oxygen 16 h per day, chronic cardiac failure, hypertension	NiPPV started 15 h before surgery	Not reported	NiPPV	Uneventful. Mild worsening of P_{CO_2}	Discharged from the ICU after 4 days and from the hospital on postoperative day 11
Bach and colleagues[15]	62; open gastrostomy; length not reported	Supine	Local anaesthesia and sedation (midazolam and ketamine)	44 with amyotrophic lateral sclerosis, 18 with other neuromuscular diseases	59 patients on domiciliary NIV	Facemask	PSV and PCV	Uneventful	Mean post-gastrostomy survival was 38.8 (6.2) months
Honda and colleagues[16]	1; thoracoplasty; length not reported	Not reported	Epidural anaesthesia	47-yr-old. Severe restrictive disorder, oxygen therapy	No	Nasal mask	NiPPV	Uneventful	Not reported

Table 2 Case reports on prophylactic NIV application for ARF during Caesarean section. BiPAP, bilevel positive airway pressure (Philips-Respironics); CPAP, continuous positive airway pressure; NiPPV, non-invasive positive pressure ventilation

Study	Decubitus	Anesthesia	Patient's main morbidities	Preoperative NIV	Interface	NIV modality	Intraoperative events	Maternal outcome	Newborn data and outcome
Bose and colleagues[17]	Semisitting and tilted to the left	Epidural anaesthesia plus ketamine	27-yr-old woman at 24 weeks of gestation; cystic fibrosis and pancreatitis, orthopnoea	Fully dependent on NiPPV by 24 weeks	Nasal mask	NiPPV	Sp_{O_2} gradually worsening despite increase in $F_{I_{O_2}}$ to 100%	On day 8, the mother developed pneumonia and required tracheal intubation. She died on the 10th day	Baby weighing 790 g; 7 weeks in ICU for respiratory distress, intraventricular haemorrhage and septicaemia. Transferred to another hospital on nasal oxygen and caffeine
Cameron and Skinner[18]	Supine left lateral tilt position	Combined spinal–epidural anaesthesia	21-yr-old at 29 weeks of gestation; cystic fibrosis with end-stage respiratory failure, domiciliary oxygen therapy 24/24 h, cor pulmonale, orthopnoea	From 24 weeks of gestation, nocturnal BiPAP, then fully dependent on BiPAP	Not reported	BiPAP	Uneventful	Ten days after the C-section, she was transferred to the respiratory for pneumonia. Discharged home on day 26 post-partum requiring BiPAP overnight	Baby weighing 1505 g. Apgar scores of 9 and 10 at 1 and 5 min, respectively. CPAP for one night; healthy 7-month-old child at the time of writing
Allen and Maguire[19]	Supine	Combined spinal–epidural anaesthesia	28-yr-old woman at 37 weeks of gestation; autosomal recessive limb-girdle muscular dystrophy, severe restrictive disease, and orthopnoea	Nocturnal NiPPV started at 34 weeks of gestation	Facemask	NiPPV	Uneventful	NiPPV for 1 h on day 1. Discharged home on day 8. Uneventful recovery at home with discontinuation of NiPPV after 6 weeks	Baby weighing 2435 g. Apgar scores of 9 and 10 at 1 and 5 min, respectively
Terblanche and colleagues[20]	Supine with left tilt	Spinal anaesthesia	28-yr-old woman, at 24 weeks gestation; myasthenia	Nocturnal by the age of 15. Gradual respiratory worsening	Not reported	BIPAP	Uncomplicated	Uncomplicated postoperative course. Discharged on day 12	Baby weighing 2270 g. Apgar scores of 8 and 9 at 1 and 5 min, respectively. CPAP for 12 h. Uncomplicated postoperative course
Yuan and colleageus[21]	Not reported	Epidural anaesthesia	22-yr-old woman at 33 weeks of gestation; mitochondrial thymidine kinase 2 deficiency and chronic respiratory failure, preeclampsia	NiPPV since 12 yr of age, 22 h per day pre-pregnancy and 24/24 h during pregnancy	Not reported	NiPPV	Not reported	Not reported	Baby weighing 1349 g. Apgar scores of 7 and 9 at 1 and 5 min, respectively. Discharged home on day 28
Erdogan and colleagues[22]	Semi-Fowler position	Spinal anaesthesia	28-yr-old morbidly obese at 34 weeks of gestation; asthma and severe preeclampsia with pulmonary oedema, orthopnoea	Immediately before C-section	Not reported	BiPAP	Uneventful	Intermittent BiPAP for 24 h after operation. Discharged home on day 4	Apgar scores of 5 and 8 at 1 and 5 min, respectively

Table 3 Reports on the use of prophylactic intraoperative NIV in patients without established ARF (all cases uneventful intraoperatively). BiPAP, bilevel positive airway pressure (Philips-Respironics); PAV, proportional assist ventilation; PCV, pressure control ventilation; PSV, pressure support ventilation; COPD, chronic obstructive pulmonary disease; CPAP, continuous positive airway pressure; OSA, obstructive sleep apnoea; CABG, coronary artery bypass grafting; NiPPV, non-invasive positive pressure ventilation; NIDDM, non-insulin-dependent diabetes mellitus; ICU, intensive care unit

Study	Number of patients; surgical procedure; length	Decubitus	Anaesthesia	Patient's main morbidities	Preoperative NIV	Interface	NIV modality	Outcome
Rubowitz and Assia[23]	1; phacoemulsification and intraocular lens implantation; length not reported	Supine	Local anaesthesia	40-yr-old. Myotonic dystrophy and severe orthopnoea	CPAP overnight, oxygen therapy during the day	Facemask	CPAP	Not reported
Iwama and Suzuki[24]	1; vasectomy; length: 1 h	Supine	Local anaesthesia and sedation	42-yr-old. Obesity, OSA	Domiciliary nocturnal CPAP	Nasal mask	BIPAP	Discharged home 2 h post-surgery without complications
Reber and Ursprung[25]	1; phacoemulsification; length not reported	Supine	Local anaesthesia and sedation	63-yr-old. OSA	Domiciliary nocturnal CPAP	Nasal mask	CPAP	CPAP continued for 1 h after the procedure
Yamamoto and colleagues[26]	1; awake craniotomy; length not reported	Supine	Sedation and local anaesthesia	Brain tumour, OSA	No	Nasal mask	PAV, turned to PCV during apnoea periods	Patient satisfied
Bapat and colleagues[27]	1; local resection of a carcinoma of the rectum; length: just over 1 h	Lithotomy position, head-down tilt	Spinal anaesthesia	74-yr-old. Severe COPD with restrictive/obstructive pattern, angina pectoris, alcoholic liver disease and orthopnoea	No	Facemask	CPAP	CPAP discontinued after surgery. Discharged home on the second postoperative day
Warren and Sharma[28]	1; dilation and curettage and bilateral tubal ligation; length: 60 min	Lithotomy position	Epidural anaesthesia	26-yr-old. 12-week pregnancy, myasthenia gravis with diaphragmatic paralysis, central sleep apnoea, chronic respiratory acidosis, orthopnoea	Domiciliary nocturnal BiPAP	Not reported	BiPAP with domiciliary setting	Discharged home on day 3 without complications
Huncke and colleagues[29]	1; awake craniotomy; length: longer than 90 min	Semilateral position	Conscious sedation and local anaesthesia	62-yr-old. Refractory seizures, COPD, OSA, morbid obesity, asthma, aortic stenosis, previous myocardial infarction	Domiciliary night-time CPAP	Not reported	CPAP	Not reported
Kinoshita and colleagues[30]	1; replacement of right femoral head; length not reported	Not reported	Spinal anaesthesia and sedation	69-yr-old. COPD	NIV prescribed by the pulmonologist just before surgery	Not reported	NiPPV	Not reported
Leech and colleagues[31]	1; insertion of a dynamic hip screw; length not reported	Supine with head-up tilt	Spinal anaesthesia	76-yr-old. Obesity, severe COPD, pulmonary hypertension, and cor-pulmonale	No	Not reported	BiPAP	BiPAP continued for 3 h after surgery. Discharged home on day 7 without complications

Guarracino and colleagues[32]	1; pleuropericardial window formation; length: 90 min	Lateral position	Sedation and epidural anaesthesia	72-yr-old. Breast cancer with thoracic vertebral metastases, dyspnoeic, accessory respiratory muscles recruitment	No	Facemask	NiPPV	NIV discontinued 5 h after surgery. Discharged from ICU to the ward on day 2
Kapala and colleagues[33]	1; sigmoidal resection; length: 4.5 h	Lithotomy position, upper body raised 30°	Spinal–epidural anaesthesia plus sedation	CABG 5 months earlier, NIDDM, COPD, paralysed left diaphragm, OSA, orthopnoea	Domiciliary night-time BiPAP	Not reported	BiPAP	BiPAP discontinued after surgery, and applied overnight. Discharged on day 5
Guarracino and colleagues[34]	3; transoesophageal echocardiography during percutaneous aortic valvuloplasty; length: 97 (5) min	Supine	Local anaesthesia and sedation	3 orthopnoeic patients with severe aortic stenosis	Not reported	Facemask with endoscopic port	BIPAP	NIV continued for 2 h after the procedure. All patients alive at 6 months
Guarracino and colleagues[35]	5; percutaneous aortic valvuloplasty; length: 100 (10) min	Supine	Local anaesthesia and sedation	Chronic respiratory failure and orthopnoea (4 pulmonary fibrosis and 1 silicosis)	No	Facemask with endoscopic port	PSV	NIV continued in the ICU for 2 h in 2 cases. All patients alive at 6 months
Guarracino and colleageus[36]	2; transaxillary percutaneous aortic valvuloplasty; length: 122 min	Supine	Local anaesthesia and sedation	Orthopnoeic	Not reported	Facemask with endoscopic port	BiPAP	NIV continued for 2 h after operation in the ICU. All patients alive 30 days after the procedure
Alonso-Iñigo and colleagues[37]	2; radical retropubic prostatectomy; length not reported	Supine	Epidural anaesthesia plus sedation	A: 66-yr-old. B: 63-yr-old. Both: obesity, hypertension, COPD	No	Facemask	BIPAP	Patients discharged home, respectively, on the fifth and seventh postoperative day
Dawson and colleagues[7]	1; total knee arthroplasty; length not reported	Supine	Continuous spinal anaesthesia	66-yr-old. Childhood poliomyelitis, partial paralysis and kyphoscoliosis, orthopnoea	Domiciliary nocturnal NIV	Not reported	BiPAP	Discharged home on day 11

Table 4 Intraoperative elective NIV during deep sedation in patients without respiratory limitation. BiPAP, bilevel positive airway pressure (Philips-Respironics); CPAP, continuous positive airway pressure

Study	Surgical procedure; length	Number of patients	Anaesthesia	Interface	NIV modality	Intraoperative events
Iwama[8]	Lower extremities or lower gynaecology surgery	213 elective ASA I–II patients	Epidural anaesthesia plus sedation with propofol 5 mg kg^{-1} h^{-1} or more	Nasal mask	BiPAP; a preliminary evaluation of CPAP in 10 patients revealed that CPAP did not allow a sufficient ventilation	All patients had stable respiratory parameters. No case of regurgitation, aspiration, or aerophagia. 55 patients required ephedrine for hypotension
Iwama and colleagues[9]	Lower extremities or lower abdominal gynaecology surgery	265 elective ASA I–II patients	Epidural anaesthesia plus sedation with propofol 5 mg kg^{-1} h^{-1}	Nasal mask	BiPAP	Three failure for obstruction of the upper airway: one resolved increasing end-expiratory pressure to 10 cm H_2O, one resolved by insertion of a nasal cannula, one resolved with the insertion of a laryngeal mask. All the remaining patients had stable respiratory patients. Six per cent of the patients complained of mild intranasal pain
Ohmizo and colleagues[10]	Repair of inguinal hernia	23 elective ASA I–II patients	Spinal anaesthesia plus sedation with propofol 5 mg kg^{-1} h^{-1}	Nasal mask	BiPAP	All patients had stable respiratory patients. No case of regurgitation, aspiration, or aerophagia. Eight patients required ephedrine for hypotension. One patient complained of mild intranasal pain
Yamamoto and colleagues[26]	Awake craniotomy	1 healthy supine patient	Sedation and local anaesthesia	Nasal mask	BIPAP	Uneventful

(ii) A limited but interesting number of case reports described prophylactic NIV in patients with chronic severe respiratory limitation due to different diseases undergoing surgery.[7 23–37] Most patients were orthopnoeic and unable to tolerate the required decubitus position; in some cases, sedation was required but considered unsafe due to the labile respiratory function. Seven of 24 (34%) patients were already on domiciliary treatment with oxygen or NIV; in most cases, the authors did not report how long the patients had been on domiciliary treatment.

In patients with very poor respiratory function, postoperative weaning can be difficult or impossible and pulmonary complications are common.[5 6] In such conditions, surgery can be denied by the healthcare staff or refused by the patient.[43] NIV could be a promising solution, but further studies are nevertheless required. Given that these cases are uncommon, multicentre studies by specialized hospitals (like centres specialized in cystic fibrosis) are likely to be needed.

Intraoperative NIV application in patients with ARF or at high risk for ARF requires a careful preoperative evaluation and an accurate planning: the staff must be fully trained, experienced, and equipped for NIV. Ethical aspects and patient wishes should be addressed and documented. An excellent teamwork and cooperation among all the surgical team are required. Strict monitoring (including at least pulse oximeter, non-invasive arterial pressure monitor, and electrocardiogram, with the constant presence of an anaesthetist) must be in place. When tracheal intubation is considered an option, the staff must be prepared to perform it immediately if needed.[44] The intraoperative prophylactic application of NIV should always be considered on top of all the other effective treatments like physiotherapy, smoking cessation, and preoperative optimization of medical care.

A third, different setting of intraoperative (prophylactic) NIV application is its use on deeply sedated healthy patients.[8–10 26] These four studies reported NIV use as a 'pneumatic splint' to keep the airway open and to support spontaneous ventilation, the majority of the cases coming from the same Japanese hospital.[8–10] Sedation is often administered during surgery and respiratory depression is a common event,[45] particularly in patients with predisposing factors like obesity.[5 6] NIV was almost always effective, and no complications were reported. However, so far, no randomized trial comparing NIV with mechanical ventilation or other types of ventilator support has been published. The minimal requirements mentioned above (adequate expertise, equipment and monitoring, with

alternative strategies planned) must also be present in this setting.

The main limitation of the present review is the low quality of the included studies: most of them are case reports, and no randomized trials were identified. Nevertheless, the analysed studies offer the best available data and could inspire future studies of better quality. We excluded the paediatric population: some studies were found during our search, and a review in the paediatric field could be performed.[46–49] We excluded from our review the studies performed using negative pressure as NIV, because such a technique at the moment is limited to a few centres; however, reports on intraoperative application of negative pressure ventilation have been published with positive results.[50–55] Finally, the heterogeneity of the analysed studies does not allow to assess reliably the role of NIV in specific diseases or kinds of surgery. However, our findings show that NIV is a promising tool that could be useful in a wide range of settings.

The best way to study this topic with a randomized trial would be to identify high risk, orthopnoeic patients (such as those with COPD) undergoing lower extremities, or lower abdominal surgery. The two groups of patients should receive: (i) local or neuraxial anaesthesia with deep sedation and intraoperative prophylactic NIV (NIV group); and (ii) general anaesthesia with tracheal intubation (control group). The primary endpoint of such a study could be a composite endpoint of the incidence of postoperative pulmonary complications (pneumonia, bronchial infection, bronchospasm, atelectasis, acute respiratory insufficiency, prolonged mechanical ventilation, or need for postoperative intubation/reintubation). The secondary endpoints could be the length of intensive care unit and hospital stay and 30 day and 1 yr mortality. In this case, to demonstrate a reduction in postoperative pulmonary complications from 30% to 20%, it would be necessary to enrol $\sim$315 patients per group (with sample size calculations based on a two-sided α-error of 0.05 and 80% power).[56]

In conclusion, intraoperative prophylactic or therapeutic NIV application has been reported in 618 cases, mainly in patients with severe respiratory limitation or in patients with respiratory depression after deep sedation. Only three failures were reported; no complication related to NIV and no intolerance to NIV were reported. NIV application seems feasible, safe, and potentially useful, particularly when tracheal intubation is best avoided. However, no randomized trial evaluated intraoperative NIV efficacy and safety compared with other forms of mechanical ventilation or no mechanical ventilation. Further studies of higher quality are required and a very cautious approach is to be taken, as data on its safety and efficacy are quite limited and of low quality.

Authors' contributions

All authors contributed to conception and design of the study, analysis and interpretation of data, and drafting of the article. Scientific database search and reference examination was performed by L.C., L.N., V.P.P.; data abstraction from selected papers was performed by G.B. and M.M.; article writing was collaboratively performed mainly by L.C., G.L., and A.Z.

Declaration of interest

None declared.

Funding

This work was supported by departmental funds only.

References

1 Nava S, Hill N. Non-invasive ventilation in acute respiratory failure. *Lancet* 2009; **374**: 250–9

2 Jaber S, Chanques G, Jung B. Postoperative noninvasive ventilation. *Anesthesiology* 2010; **112**: 453–61

3 Chiumello D, Chevallard G, Gregoretti C. Non-invasive ventilation in postoperative patients: a systematic review. *Intensive Care Med* 2011; **37**: 918–29

4 Landoni G, Zangrillo A, Cabrini L. Noninvasive ventilation after cardiac and thoracic surgery in adult patients: a review. *J Cardiothorac Vasc Anesth* 2012; **26**: 917–22

5 Barash PG, Cullen BF, Stoelting RK, eds. *Clinical Anesthesia*, 4th Edn. Philadelphia: Lippincott-Raven Publisher, 2001; 1385–92

6 Miller RD, ed. *Anesthesia*. New York, London: Churchill Livingstone, 1990; 2034–9

7 Dawson J, Jones M, Hirschauer N, O'Neill S. Continuous spinal anaesthesia and noninvasive ventilation for total knee replacement in a patient on home ventilation. *Br J Anaesth* 2012; **109**: 125–6

8 Iwama H. Application of nasal bi-level positive airway pressure to respiratory support during combined epidural–propofol anesthesia. *J Clin Anesth* 2002; **14**: 24–33

9 Iwama H, Obara S, Ozawa S, *et al.* A survey of combined epidural–propofol anesthesia with noninvasive positive pressure ventilation as a minimally invasive anesthetic protocol. *Med Sci Monit* 2003; **9**: 316–23

10 Ohmizo H, Morota T, Seki Y, Miki T, Iwama H. Combined spinal–propofol anesthesia with noninvasive positive-pressure ventilation. *J Anesth* 2005; **19**: 311–4

11 Nozaki-Taguchi N, Isono S, Nishino T, Numai T, Taguchi N. Upper airway obstruction during midazolam sedation: modification by nasal CPAP. *Can J Anaesth* 1995; **42**: 685–90

12 Duque González P, Ferrando A, Garutti I, Piñeiro P, García-Sancho J, Díaz-Regañón G. Noninvasive positive pressure ventilation during surgery in a patient with exacerbated chronic obstructive pulmonary disease. *Rev Esp Anestesiol Reanim* 2004; **51**: 290–1

13 Ferrandière M, Hazouard E, Ayoub J, *et al.* Noninvasive ventilation corrects alveolar hypoventilation during spinal anesthesia. *Can J Anaesth* 2006; **53**: 404–8

14 Thys F, Delvau N, Roeseler J, *et al.* Emergency orthopaedic surgery under noninvasive ventilation after refusal for general anaesthesia. *Eur J Emerg Med* 2007; **14**: 39–40

15 Bach JR, Gonzalez M, Sharma A, Swan K, Patel A. Open gastrostomy for noninvasive ventilation users with neuromuscular disease. *Am J Phys Med Rehabil* 2010; **89**: 1–6

16 Honda H, Honma T, Baba H. Epidural anesthesia with noninvasive positive pressure ventilation in a patient with compromised respiratory function. *Masui* 2010; **59**: 467–9

17 Bose D, Yentis SM, Fauvel NJ. Caesarean section in a parturient with respiratory failure caused by cystic fibrosis. *Anaesthesia* 1997; **52**: 578–82

18 Cameron AJ, Skinner TA. Management of a parturient with respiratory failure secondary to cystic fibrosis. *Anaesthesia* 2005; **60**: 77–80

19 Allen T, Maguire S. Anaesthetic management of a woman with autosomal recessive limb-girdle muscular dystrophy for emergency caesarean section. *Int J Obstet Anesth* 2007; **16**: 370–4

20 Terblanche N, Maxwell C, Keunen J, Carvalho JC. Obstetric and anesthetic management of severe congenital myasthenia syndrome. *Anesth Analg* 2005; **107**: 1313–5

21 Yuan N, El-Sayed YY, Ruoss SJ, Riley E, Enns GM, Robinson TE. Successful pregnancy and cesarean delivery via noninvasive ventilation in mitochondrial myopathy. *J Perinatol* 2009; **29**: 166–7

22 Erdogan G, Okyay DZ, Yurtlu S, *et al.* Non-invasive mechanical ventilation with spinal anesthesia for cesarean delivery. *Int J Obstet Anesth* 2010; **19**: 438–40

23 Rubowitz A, Assia E. Cataract surgery performed with continuous positive airway pressure (CPAP) ventilation. *Am J Ophthalmol* 2001; **131**: 128–9

24 Iwama H, Suzuki M. Combined local–propofol anesthesia with noninvasive positive pressure ventilation in a vasectomy patient with sleep apnea syndrome. *J Clin Anesth* 2003; **15**: 375–7

25 Reber A, Ursprung T. Cataract surgery in a patient with severe obstructive sleep apnea syndrome. *Anaesthesist* 2003; **52**: 1027–30

26 Yamamoto F, Kato R, Sato J, Nishino T. Anaesthesia for awake craniotomy with noninvasive positive pressure ventilation. *Br J Anaesth* 2003; **90**: 382–5

27 Bapat PP, Anderson JA, Bapat S, Sule A. Use of continuous positive airway pressure during spinal anaesthesia in a patient with severe chronic obstructive pulmonary disease. *Anaesthesia* 2006; **61**: 1001–3

28 Warren J, Sharma SK. Ventilatory support using bilevel positive airway pressure during neuraxial blockade in a patient with severe respiratory compromise. *Anesth Analg* 2006; **102**: 910–1

29 Huncke T, Chan J, Doyle W, Kim J, Bekker A. The use of continuous positive airway pressure during an awake craniotomy in a patient with obstructive sleep apnea. *J Clin Anesth* 2008; **20**: 297–9

30 Kinoshita H, Matsuda N, Hatano Y. The use of capnography for apnea monitoring during non-invasive positive pressure ventilation during spinal anesthesia. *Can J Anaesth* 2007; **54**: 850

31 Leech CJ, Baba R, Dhar M. Spinal anaesthesia and non-invasive positive pressure ventilation for hip surgery in an obese patient with advanced chronic obstructive pulmonary disease. *Br J Anaesth* 2007; **98**: 763–5

32 Guarracino F, Gemignani R, Pratesi G, Melfi F, Ambrosino N. Awake palliative thoracic surgery in a high-risk patient: one-lung, noninvasive ventilation combined with epidural blockade. *Anaesthesia* 2008; **63**: 761–3

33 Kapala M, Meterissian S, Schricker T. Neuraxial anesthesia and intraoperative bilevel positive airway pressure in a patient with severe chronic obstructive pulmonary disease and obstructive sleep apnea undergoing elective sigmoid resection. *Reg Anesth Pain Med* 2009; **34**: 69–71

34 Guarracino F, Cabrini L, Baldassarri R, *et al.* Non-invasive ventilation-aided transoesophageal echocardiography in high-risk patients: a pilot study. *Eur J Echocardiogr* 2010; **11**: 554–6

35 Guarracino F, Cabrini L, Baldassarri R, *et al.* Noninvasive ventilation for awake percutaneous aortic valve implantation in high-risk respiratory patients: a case series. *J Cardiothorac Vasc Anesth* 2011; **25**: 1109–12

36 Guarracino F, Covello RD, Landoni G, *et al.* Anesthetic management of transcatheter aortic valve implantation with transaxillary approach. *J Cardiothorac Vasc Anesth* 2011; **25**: 437–43

37 Alonso-Iñigo JM, Herranz-Gordo A, Fas MJ, Giner R, Llopis JE. Epidural anesthesia and non-invasive ventilation for radical retropubic prostatectomy in two obese patients with chronic obstructive pulmonary disease. *Rev Esp Anestesiol Reanim* 2012; **59**: 573–6

38 Allen TK, George RB, Peterson-Layne C, Habib AS. Management of a parturient with an acute exacerbation of idiopathic pulmonary haemosiderosis and posterior spinal instrumentation. *Br J Anaesth* 2008; **100**: 235–9

39 Perbet S, Constantin JM, Bolandard F, *et al.* Non-invasive ventilation for pulmonary edema associated with tocolytic agents during labour for a twin pregnancy. *Can J Anaesth* 2008; **55**: 769–73

40 Banga A, Khilnani GC. Use of non-invasive ventilation in a pregnant woman with acute respiratory distress syndrome due to pneumonia. *Indian J Chest Dis Allied Sci* 2009; **51**: 115–7

41 Frassanito L, Draisci G, Pinto R, Maviglia R, Maggiore SM. Successful application of helmet non-invasive ventilation in a parturient with acute respiratory distress syndrome. *Minerva Anestesiol* 2011; **77**: 1121–3

42 von Breunig F, Goetz AE, Heckel K. Severe muscular dystrophy and pregnancy: interdisciplinary challenge. *Anaesthesist* 2012; **61**: 52–5

43 Iung B, Cachier A, Baron G, *et al.* Decision-making in elderly patients with severe aortic stenosis: why are so many denied surgery? *Eur Heart J* 2005; **26**: 2714–20

44 The Association of Anaesthetists of Great Britain and Ireland. Recommendations for standards of monitoring during anesthesia and recovery. Available from http://www.aagbi.org/sites/default/files/monitoring00.pdf (accessed 25 March 2013)

45 Mathru M, Esch O, Lang J, *et al.* Magnetic resonance imaging of the upper airway. Effects of propofol anesthesia and nasal continuous positive airway pressure in humans. *Anesthesiology* 1996; **84**: 273–9

46 Palomero Rodríguez MA, Sanabria Carretero P, Laporta Báez Y, Sánchez Conde MP, Melo Villalba M, Barbero Reinoso F. Inhaled anesthesia through a device for noninvasive continuous positive airway pressure ventilation for upper digestive endoscopy in pediatric patients. *Rev Esp Anestesiol Reanim* 2010; **57**: 419–24

47 Bassanezi BS, Oliveira-Filho AG, Miranda ML, Soares L, Aguiar SS. Use of BiPAP for safe anesthesia in a child with a large anterior mediastinal mass. *Paediatr Anaesth* 2011; **21**: 985–7

48 Reber A, Geiduschek JM, Bobbià SA, Bruppacher HR, Frei FJ. Effect of continuous positive airway pressure on the measurement of thoracoabdominal asynchrony and minute ventilation in children anesthetized with sevoflurane and nitrous oxide. *Chest* 2002; **122**: 473–8

49 Horimoto Y, Ogawa N, Ban Y, *et al.* Case of spinal anesthesia for pyrolomyotomy in a former preterm infant with chronic lung disease. *Masui* 2011; **60**: 230–2

50 Broomhead CJ, Dilkes MG, Monks PS. Use of the Hayek Oscillator in a case of failed fibreoptic intubation. *Br J Anaesth* 1995; **74**: 720–1

51 Monks PS, Broomhead CJ, Dilkes MG, McKelvie P. The use of the Hayek Oscillator during microlaryngeal surgery. *Anaesthesia* 1995; **50**: 865–9

52 Dilkes MG, McNeill JM, Hill AC, Monks PS, McKelvie P, Hollamby RG. The Hayek Oscillator: a new method of ventilation in microlaryngeal surgery. *Ann Otol Rhinol Laryngol* 1993; **102**: 455–8

53 Natalini G, Cavaliere S, Seramondi V, *et al.* Negative pressure ventilation vs external high frequency oscillation during rigid bronchoscopy. *Chest* 2000; **118**: 18–23

54 Vitacca M, Natalini G, Cavaliere S, *et al.* Breathing pattern and arterial gases during Nd-YAG laser photoresection of endobronchial lesions under general anesthesia: use of negative pressure ventilation: a preliminary study. *Chest* 1997; **112**: 1466–73

55 Natalini G, Cavaliere S, Vitacca M, Amicucci G, Ambrosino N, Candiani A. Negative pressure ventilation vs. spontaneous assisted ventilation during rigid bronchoscopy. A controlled randomised trial. *Acta Anaesthesiol Scand* 1998; **42**: 1063–9

56 de Albuquerque Medeiros R, Faresin S, Jardim J. Postoperative lung complications and mortality in patients with mild-to-moderate COPD undergoing elective general surgery. *Arch Bronconeumol* 2001; **37**: 227–34

Handling editor: R. P. Mahajan