Metrološka procjena i post-tržišni nadzor respiratora: Komparativna analiza u regionu Balkana

Lemana Spahić, Sara Hodžić, Velid Dlakić, Nejra Merdović, Željka Stjepanović, Madžida Hundur, Amra Džuho, Delila Lekić, Lejla Gurbeta Pokvić

Ključne riječi: Metrologija, Respiratori, Post-tržišni nadzor, Komparativna analiza, Balkanski region.

KRATAK SADRŽAJ

Respiratori imaju ključnu ulogu u liječenju kod pacijenata s različitim bolestima pluća, infekcijama ili teškim akutnim respiratornim problemima. Njihova uloga postala je posebno očigledna tokom pandemije COVID-19. Važno je istaći da procjena i verifikacija respiratora uključuju više parametara, kao što su: inspiratorni protok i vrijeme, respiratornu frekvenciju, koncentraciju kisika, tidalni volumen, inspiratorni pritisak i pozitivni ekspiratorni pritisak. Osim toga, ovi uređaji mogu pokazati različite greške, poput neusklađenosti u ventilacijskom volumenu, problema s koncentracijom kisika, slomljenih komponenti i ozbiljnijih kvarova poput potpunih kvarova matične ploče.

Ova studija istražuje performanse respiratora koji se koriste u zdravstvenom sistemu u Bosni i Hercegovini i Republici Srbiji. Studija je obuhvatila uzorak verifikovanih respiratora u periodu od marta 2020. do septembra 2022. godine, odnosno od oktobra 2020. do septembra 2022. godine. Također, istraživanje se fokusiralo na identifikaciju broja i vrste grešaka primijećenih na neverificiranim respiratorima u ovim zemljama. Nakon temeljite analize, pronađene su različite volumetrijske greške u respiratorima koji su se koristili u Bosni i Hercegovini, što čini preko 50% svih pronađenih grešaka na neverificiranim uređajima.

Rad ima za cilj naglasiti potrebu za standardiziranim postupkom verifikacije koji bi trebali biti ojačani kako bi se osigurala sigurnost pacijenata te produženje stabilnosti i upotreba uređaja.

Metrological Assessment and Post-Market Surveillance of Mechanical Ventilators: A Comparative Study in the Balkan Region

Lemana Spahić, Sara Hodžić, Velid Dlakić, Nejra Merdović, Željka Stjepanović, Madžida Hundur, Amra Džuho, Delila Lekić, Lejla Gurbeta Pokvić

Keywords: Metrology, Mechanical Ventilators, Post-Market Surveillance, Comparative Analysis, Balkan Region.

ABSTRACT

Mechanical ventilators play a crucial role in the treatment of patients with various lung diseases, infections, or severe acute respiratory problems. Their role became particularly evident during the COVID-19 pandemic. It is important to note that the assessment and verification of mechanical ventilators includes multiple parameters, such as: inspiratory flow and time, respiratory rate, oxygen concentration, tidal volume, inspiratory pressure, and positive end-expiratory pressure. Additionally, these devices can show various errors, such as mismatches in ventilation volume, problems with oxygen concentration, broken components, and more serious failures like complete motherboard failures.

This study investigates the performance of mechanical ventilators used in healthcare institutions of Bosnia and Herzegovina and Republic of Serbia. The study covered a sample of inspected mechanical ventilators in the period from March 2020 to September 2022, and from October 2020 to September 2022 respectively. Also, the research focused on identifying the number and types of errors observed in non-compliant mechanical ventilators in these countries. After a thorough analysis, various volumetric errors were found in mechanical ventilators used in Bosnia and Herzegovina, accounting for over 50% of all errors found in non-compliant devices.

The paper aims to emphasize the need for a standardized conformity inspection procedure that should be strengthened to ensure patient safety and to extend the stability and usage of the devices.

BACKGROUND

Mechanical ventilators are normally used in all patients exhibiting severe respiratory issues such as severe pneumonia, lung conditions or infections including chronic obstructive pulmonary disease, acute respiratory distress syndrome, and even coma, stroke, anaphylaxis or in other case during surgery [1], [2]. During the COVID – 19 pandemic, officially announced on the 11th March of 2020 [3]. huge attention was drawn to these medical devices as a serious shortage has occurred in various countries. The situation was similar in Bosnia and Herzegovina and the Republic of Serbia. Not just the shortage of these critical medical devices was underpinned, but also huge attention was drawn to the performance issues. [2,4-6]. Even the World Health Organization developed a set of guidelines on minimum requirements that invasive and non-invasive ventilators must comply with to ensure quality, safety and effectiveness when used for the management of COVID-19. [7]

Being classified as electronic medical devices with highest risk to patients [8,9] the high mortality rate in treatment of patients with mechanical ventilators is not uncommon. A study done by Christophe de Terwangne, et al. [10] in 2021 shows that the mortality rate of critically ill patients requiring mechanical ventilation support was 55%, although all patients had at least one other disease that put them at a more severe risk. Auld et. al [11] also showed that the mortality rate of patients who required mechanical ventilation support was around 29.7% [11]. A correlation has been found in patients who required mechanical ventilators and their mortality rate. Unfortunately, in a high percentage of these cases it has been proven that the poor and unmonitored usage of ventilators caused severe damage to patients' lungs in either volutrauma or atelectrauma [12]. On the other hand situations in which the malfunction of the ventilator causes the death of patients mostly remain unrecorded. There is a limited number of sources confirming the flaws of mechanical ventilators. However, according to the FDA, in 2021 Philips had to recall numerous devices due to poor performance and release of toxic substances known as polyester-based polyurethane foam (PE-PUR) that was used for reducing sound and vibration [13,14]. In another source, it has been reported that Drager has technical issues regarding the ventilator compartment that cannot be properly closed. Therefore, such shortcoming has presented a problem with smaller objects that have been trapped in the compartment and caused the ventilator failure [15]. Therefore, it is very important to keep the mechanical ventilators in check and perform periodic monitoring to ensure the device is safe for usage.

Periodic monitoring of medical devices in healthcare institutions is still done differently from region to region, from institution to institution [16-18]. Distributors, service companies or internal clinical engineering / technical departments within healthcare institutions are usually the one providing the inspections / verifications. The maintenance and inspection / verification documentation is managed differently, usually not in a digital manner, therefore the historical information on device performance is usually lost. In Bosnia and Herzegovina and Republic of Serbia, this challenge has been overcome by introducing a set of electronic medical devices, including mechanical ventilators in the legal metrology framework [17,19]. According to the legal metrology framework, the mechanical ventilators used in healthcare institutions in these two countries are subject to periodical verification / inspection by an independent inspection body accredited by ISO 17020 international standard and appointed by relevant national authority. Every mechanical ventilator is inspected for significant parameters including, but not limited to: inspiratory flow and time, respiratory rate, oxygen concentration, tidal volume, PIP (peak inspiratory pressure), and PEEP (positive end-expiratory pressure) [20]. Standardized procedure implies using etalons with known traceability to determine the error of inspected parameters [21,22]. Only mechanical ventilators whose measurement error is within defined limits are found compliant and safe for usage. Both independent inspection bodies operate with software enabling data handling and performance tracking [23].

Having the same regulation in place in both countries, the aim of this study is to report the results of comparative analysis of mechanical ventilator inspections focusing on the inspections and mechanical ventilator performance during COVID-19 pandemics.

METHODS

1. Data acquisition

For conducting a study the data from Medical Device Inspection Laboratory Verlab, Bosnia and Herzegovina and Inspection body Inslab, Republic of Serbia was gathered. The inspection bodies inspect mechanical ventilators operating according to the inspection procedure described by Badnjevic et al., (2023) [9]. The mechanical ventilator performance data was collected with etalons IMT Medical PF-301 and Fluke biomedical VT900A Gas Flow Analyzer Ventilator Tester. For every mechanical ventilator, the following parameters were collected: (1) results of visual inspection of the device; (2) performance parameters: volume in 8 points in range of 100 ml to 900 ml; (3) results of verification / inspection.

The evaluation of device compliance was performed by inspection body authorized staff. The criteria for evaluation of the compliance were Rulebooks that are part of legal metrology framework in Bosnia and Herzegovina [24] and Republic of Serbia [25]. The metrological and technical requirements for the performance of mechanical ventilator is shown in the table below. If the results of visual inspection (Table 1) or any parameter of mechanical ventilator shown in the Table 2 is outside of the permissible limits, the device is marked as non-compliant.

Table 1. Visual inspection aspects accounted for during the inspection process

Technical requirement	Inspected requirements	Conformity assessment criteria
Prescribed labels and markings on the device under test	• Name and/or trademark of manufacturer • Production mark (basic type) • Year of production • Unique serial number • CE mark of appropriate administrative marking	Pass/Fail
Construction of the device	• The integrity of the device under test in respect to the manufacturer's specification	Pass/Fail
Performance of the device	• Measurement range • Measurement unit	Pass/Fail

With respect to the measurement range and permissible error margin for mechanical ventilator compliance assessment, the Rulebooks for metrological requirements of mechanical ventilators used in healthcare institutions are consistent in both Bosnia and Herzegovina and Serbia.

Table 2. Measurement range and permissible error margin for mechanical ventilator compliance assessment

Parameter	Range	Permissible error
Volume (L)	-1.00 - 4.00	± 10%
Flow (L/min)	-60 - 40 (low flow) -300 - 200 (high-flow)	±10%
Pressure (cmH2O)	- 60 - 140	± 5%
Concentration of oxygen		± 5%

The data included in this study was collected in the period March 2020 to September 2022 respectively. It should be noted that not all healthcare institutions were represented in this sample. The extracted data included only samples from public healthcare institutions representing mainly mechanical ventilators used in hospitals and clinical centers. Pediatric mechanical ventilators were not included in this dataset.

2. Data analysis

In order to assess and compare the success rate of the implemented legal metrology framework on performance of mechanical ventilators, comparative analysis relying on the main qualitative and quantitative indicators of mechanical ventilator failure was determined. The indicators included the type and severity of defects assessed by the range of deviation from the nominal values as well as the global outlook of the status of mechanical ventilators used in healthcare institutions in Bosnia and Herzegovina and Serbia respectively.

The devices were analyzed by compliance rate, but also for source of non-compliance. The "physical deficiency" referring to the devices encompasses several potential anomalies detected during visual inspection of the device with respect to the visual inspection aspects presented in Table 1, including:

1. Incomplete assembly of the device, lacking essential components initially provided by the manufacturer.
2. Absence of readable labels, leading to uncertainty in unequivocal identification of the device.
3. Non-functional status with apparent damage impacting its proper functionality.

The term "performance error" pertains to unadjusted volume, flow, pressure or oxygen concentration, denoting instances where one or multiple performance parameters deviate from referent values established by the legal metrology frameworks in both countries (Table 2.).

A comprehensive set of these indicators included the type of defects, severity of defects, assessed by the range of deviation from the nominal values as well as the global outlook of the status of mechanical ventilators used in healthcare institutions in Bosnia and Herzegovina and Serbia respectively.

RESULTS AND DISCUSSION

This section presents a systematic analysis of mechanical ventilator performance, focusing on the ones that have been used consistently during COVID – 19 in both Bosnia and Herzegovina and the Republic of Serbia. There is a significant difference in the number of samples collected in the same period from both inspection bodies. There are two reasons for this: (1) the inspection period in the Republic of Serbia is half the size of the one in Bosnia and Herzegovina and (2) there is a higher number of healthcare institutions in the Republic of Serbia. According to the data collected during regular performance inspections in Bosnia and Herzegovina and Serbia, Serbia has 8 times more mechanical ventilators installed in their healthcare institutions in comparison to Bosnia and Herzegovina.

According to the data obtained from performance-inspection repositories, there was a total of 541 541 inspected mechanical ventilator in Bosnia and Herzegovina, while there was a total of 4445 inspected devices in Serbia. Table below shows that given the larger dataset in the Republic of Serbia the rate of non-compliant devices was 8% higher than in Bosnia and Herzegovina. The analysis found out that in Bosnia and Herzegovina on every 32 mechanical ventilators there was one found non-compliant and in the Republic of Serbia that number was 1 on every 8 devices. This was expected since the similar incidence rate was found in previous research on samples from Bosnia and Herzegovina in early phases of legal metrology framework implementation [17]. Due to the significant discrepancy in terms of the number of inspected devices, data normalization was conducted by observing the indicators percentage-wise (Table 3).

Table 3. Compliance and non-compliance rate

	Bosnia and Herzegovina	Republic of Serbia
Compliance rate (%)	97	89
Non-compliance rate (%)	3	11

Figure 1 indicates the prevalence of cause for the mechanical ventilator to fail the inspection, i.e. the cause of non-compliance. In Bosnia and Herzegovina, the major cause of a device failing the inspection were technical deficiencies while in the Republic of Serbia, technical deficiencies attributed only to 37.6% of overall failures. The percentage of technical deficiencies is 1.6% higher in Bosnia and Herzegovina than in the Republic of Serbia while the percentage of physical deficiencies is 1.6% higher in the Republic of Serbia than in Bosnia and Herzegovina. The percentages of 1.6% indicate that, although the types of deficiencies are different, both countries face a similar overall challenge regarding quality and deficiency issues. This data suggests the need for periodic inspections of mechanical ventilators to address these problems regardless of a country.

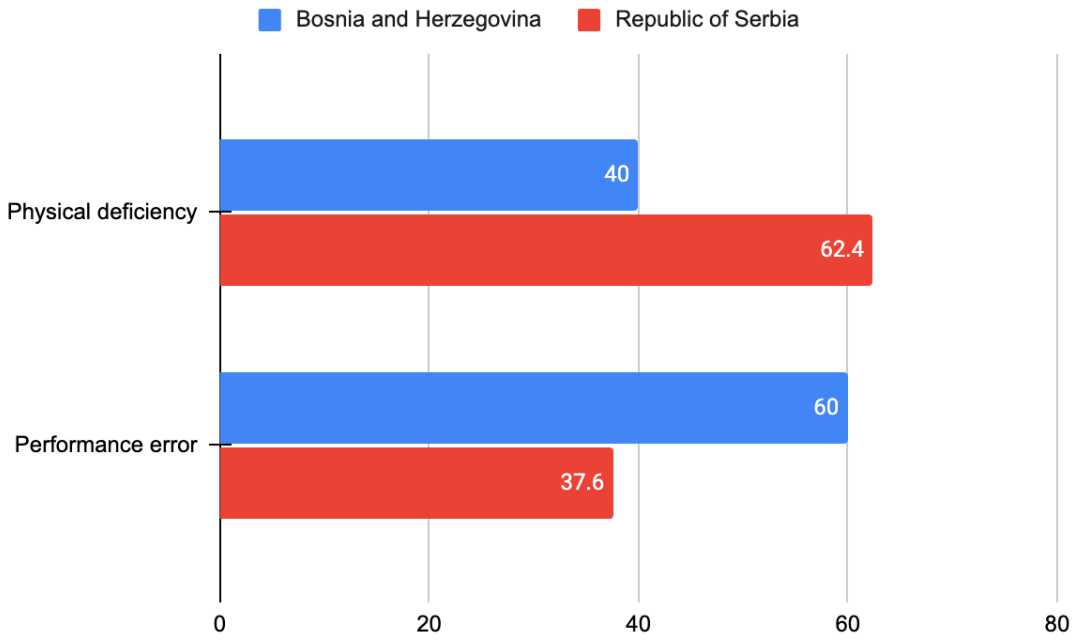

Figure 1. Prevalence of non-compliance found during inspection

In case of physical deficiency, in data from both countries, it can be concluded that only around 5% is related to power problems, while the majority (85%) is attributed to oxygen sensor malfunction. The rest of the

cases were physical damage on the device casing, display and switches. These devices were marked as non-compliant and sent for service, after which the inspection was undertaken again with positive outcome. The lower percentage of physical deficiencies was expected for Bosnia and Herzegovina. The main reason for that is because the legal metrology framework has been in place 4 years longer than in the Republic of Serbia. This proves that the awareness of healthcare staff has increased. During the yearly performance inspections in this country, physicians and staff became aware of the physical defects of mechanical ventilators that must be considered and they were more equipped for recognizing the problems on the device which can be detected by visual inspection.

In case of the inspections where performance error was outside of permissible limits, the average deviation above the maximum or minimum limit was 8%. It should be noted that the inspection / verification was done during devices regular usage in healthcare institutions. The major problem is that these deficiencies were not detected by medical professionals during the usage of the devices and patients were treated with these devices. The study didn't reveal any discrepancies in behavior of particular types of mechanical ventilators of particular manufacturers in both countries. A detailed insight into the deviations encountered during mechanical ventilator performance assessment with evaluation of the error rates is a future perspective of this study and will employ sophisticated statistical analysis methods to determine the most vulnerable points of mechanical ventilators used in the two countries.

CONCLUSION

This paper presented the results of comparative analysis of verification / inspection of mechanical ventilators according to the legal metrology framework in Bosnia and Herzegovina and the Republic of Serbia. The analysis highlighted several conclusions:

- healthcare institutions have similar challenges in terms of post-market surveillance of medical devices regardless of the country
- digital database of performance inspections of mechanical ventilators on a country level provides significant, evidence-based insight in post-market surveillance especially during the critical time of need
- verification / inspection framework conducted by independent inspection bodies provides higher reliability in performance and safety of mechanical ventilators including service and maintenance procedures
- verification / inspection framework conducted by independent inspection bodies contributes to raising awareness on medical device safety and reduces the probability of non-compliant devices to be used on patients

Introduction of a standardized inspection procedure for testing the safety and performance of mechanical ventilators produces traceable, accurate, complete, verified, unbiased and standardized data that can be used for downstream purposes that can bring upon preventive maintenance strategies that result in more cost-effective maintenance strategies. In the end, the implementation of a standardized inspection framework ensures consistency in the quality of mechanical ventilators, thereby enhancing patient safety and trust in medical devices across different regions.

Lemana Spahić, Research Institute Verlab for biomedical engineering, medical devices and artificial intelligence, Sarajevo Bosnia and Herzegovina; Research and development Center for Bioengineering, BioIRC, 34000 Kragujevac Serbia

Sara Hodžić, Verlab d.o.o, Sarajevo Bosnia and Herzegovina

Velid Dlakić, Verlab d.o.o, Sarajevo Bosnia and Herzegovina

Nejra Merdović, Research Institute Verlab for biomedical engineering, medical devices and artificial intelligence, Sarajevo Bosnia and Herzegovina

Lejla Gurbeta Pokvić, Research Institute Verlab for biomedical engineering, medical devices and artificial intelligence, Sarajevo Bosnia and Herzegovina

Željka Stjepanović, Kontrolno telo INSLAB d.o.o, Beograd Serbia

Madžida Hundur, Research Institute Verlab for biomedical engineering, medical devices and artificial intelligence, Sarajevo Bosnia and Herzegovina

Amra Džuho, Research Institute Verlab for biomedical engineering, medical devices and artificial intelligence, Sarajevo Bosnia and Herzegovina

Delila Lekić, International University of Sarajevo, Sarajevo Bosnia and Herzegovina

REFERENCES

1. "Mechanical Ventilation: Purpose, Types & Complications," Cleveland Clinic. Accessed: Feb. 23, 2024. [Online]. Available: https://my.clevelandclinic.org/health/treatments/15368-mechanical-ventilation
2. K. Iyengar, S. Bahl, Raju Vaishya, and A. Vaish, "Challenges and solutions in meeting up the urgent requirement of ventilators for COVID-19 patients," *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, vol. 14, no. 4, pp. 499–501, Jul. 2020, doi: 10.1016/j.dsx.2020.04.048.
3. According to the World Health Organization, the COVID – 19 pandemic was officially announced on the 11th March 2020
4. Badnjević, A., Pokvić, L.G., Džemić, Z. et al. Risks of emergency use authorizations for medical products during outbreak situations: a COVID-19 case study. BioMed Eng OnLine 19, 75 (2020). https://doi.org/10.1186/s12938-020-00820-0
5. S. Haribhai and S. K. Mahboobi, "Ventilator Complications," in *StatPearls*, Treasure Island (FL): StatPearls Publishing, 2024. Accessed: Feb. 23, 2024. [Online]. Available: http://www.ncbi.nlm.nih.gov/books/NBK560535/
6. Branson, R., Dichter, J. R., Feldman, H., Devereaux, A., Dries, D., Benditt, J., ... & Rubinson, L. (2021). The US strategic national stockpile ventilators in coronavirus disease 2019: a comparison of functionality and analysis regarding the emergency purchase of 200,000 devices. Chest, 159(2), 634-652.
7. World Health Organization (WHO) Accessed: Mar. 14, 2024. [Online]. Available: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/technical-guidance/covid-19-critical-items
8. Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC.
9. Food and Drug Administration (FDA) www.fda.gov
10. C. de Terwangne *et al.*, "Mortality Rate and Predictors Among Patients with COVID-19 Related Acute Respiratory Failure Requiring Mechanical Ventilation: a Retrospective Single Centre Study," *J Crit Care Med (Targu Mures)*, vol. 7, no. 1, pp. 21–27, Jan. 2021, doi: 10.2478/jccm-2020-0043.
11. S. C. Auld *et al.*, "ICU and ventilator mortality among critically ill adults with COVID-19," *medRxiv*, p. 2020.04.23.20076737, Apr. 2020, doi: 10.1101/2020.04.23.20076737.
12. L. Acho, A. N. Vargas, and G. Pujol-Vázquez, "Low-Cost, Open-Source Mechanical Ventilator with Pulmonary Monitoring for COVID-19 Patients," *Actuators*, vol. 9, no. 3, Art. no. 3, Sep. 2020, doi: 10.3390/act9030084.
13. C. for D. and R. Health, "Recalled Philips Ventilators, BiPAP Machines, and CPAP Machines," FDA. Accessed: Feb. 28, 2024. [Online]. Available: https://www.fda.gov/medical-devices/respiratory-devices/recalled-philips-ventilators-bipap-machines-and-cpap-machines
14. "Deaths reported with Philips ventilators, sleep apnea machines still climbing," MedTech Dive. Accessed: Feb. 28, 2024. [Online]. Available: https://www.medtechdive.com/news/PHG-Philips-recall-FDA-apnea-ventilators/651950/
15. R. A. Ortega, B. Vrooman, and R. Hito, "Another Cause for Ventilator Failure," *Anesthesiology*, vol. 104, no. 6, p. 1351, Jun. 2006, doi: 10.1097/00000542-200606000-00049.
16. Badnjević, A., Pokvić, L. G., Deumić, A., & Bećirović, L. S. (2022). Post-market surveillance of medical devices: A review. *Technology and Health Care*, *30*(6), 1315-1329.

17. Badnjevic A, Gurbeta L, Jimenez E.R., Iadanza E. „Testing of mechanical ventilators and infant incubators in healthcare institutions“ Technology and Health Care (2017) vol. 25, no. 2, pp. 237-250
18. Gurbeta, L., Dzemic, Z., Bego, T., Sejdic, E., Badnjevic, A. „Testing of Anesthesia Machines and Defibrillators in Healthcare Institutions“, J Med Syst (2017) 41: 133. https://doi.org/10.1007/s10916-017-0783-7
19. Badnjevic A, Gurbeta L, Boskovic D, Dzemic Z. „Measurement in medicine – Past, present, future“, Folia Medica Facultatis Medicinae Universitatis Saraeviensis Journal (2015) 50(1): 43-46
20. Badnjevic, A., Deumic, A., Trakic, A., & Pokvic, L. G. (2023). A novel method for conformity assessment testing of mechanical ventilators for post-market surveillance purposes. Technology and Health Care, 31(1), 367-376
21. Badnjević, A., Cifrek, M., Magjarević, R., & Džemić, Z. (2018). Inspection of medical devices. *Series in biomedical engineering. Springer, Singapore*.
22. Badnjević, A., Pokvić, L. G., & Spahić, L. (2020). Inspection of medical devices. In *Clinical Engineering Handbook* (pp. 491-497). Academic Press.
23. Gurbeta L, Badnjević A., „Inspection process of medical devices in healthcare institutions: software solution,“ Health Technol. (2017) Volume 7, Issue 1, pp 109–117, doi:10.1007/s12553-016-0154-2
24. Official Gazette of Serbia , No. 92/2020 PRAVILNIK O OVERAVANJU MERNIH UREĐAJA KOJI SU SASTAVNI DEO RESPIRATORA
25. Official Gazette of B&H (OG BH), No. 75/14. PRAVILNIK O MJERITELJSKIM I TEHNIČKIM ZAHTJEVIMA ZA RESPIRATORE I ANESTEZIOLOŠKE MAŠINE