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Technical Note

A novel method for conformity assessment testing of infusion and perfusion pumps for post-market surveillance purposes

Almir Badnjevic[a,b,c,d], Amar Deumic[a,b], Merima Smajlhodzic-Deljo[a] and Lejla Gurbeta Pokvic[a,*]
[a]*Verlab Research Institute for Biomedical Engineering, Medical Devices and Artificial Intelligence, Sarajevo, Bosnia and Herzegovina*
[b]*Medical Device Inspection Laboratory, Verlab Ltd., Sarajevo, Bosnia and Herzegovina*
[c]*Faculty of Pharmacy, University of Sarajevo, Sarajevo, Bosnia and Herzegovina*
[d]*International Federation of Medical and Biological Engineering (IFMBE), Sarajevo, Bosnia and Herzegovina*

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Abstract.
BACKGROUND: Introduction of fluids, medicaments and nutrients into the human body during hospitalization is fundamental for treatment and healing of patients. Fluids are introduced by means of infusion pumps while nutrients and medicaments are introduced by perfusion pumps. It is of vital importance for these devices to deliver exact amounts of the aforementioned substances as significant deviations can result in severe patient harm. Therefore it is important to effectively monitor their performance and prevent failures.
OBJECTIVE: This paper proposes a novel method for conformity assessment testing of infusion and perfusion pumps for post-market surveillance purposes.
METHOD: The method was developed on the basis of metrology characteristics of the devices. In addition to the evaluation of essential safety and visual integrity of infusion and perfusion pumps, their performance in terms of delivered volumes was assessed and monitored.
RESULTS: The developed method was validated between 2018 and 2021 in healthcare institutions of all levels. The results obtained during validation suggest that conformity assessment testing of infusion and perfusion pumps as a method used during PMS contributes to significant improvement in devices' accuracy and reliability.
CONCLUSION: A standardized approach in conformity assessment testing of infusion and perfusion pumps during PMS, besides increasing reliability of the devices, is the first step in digital transformation of management of these devices in healthcare institutions opening possibility for use of artificial intelligence.

Keywords: Medical device, performance, infusion pumps, perfusion pumps, testing, standardisation, post-market surveillance

*Corresponding author: Lejla Gurbeta Pokvic, Verlab Research Institute for Biomedical Engineering, Medical Devices and Artificial Intelligence, Sarajevo, Bosnia and Herzegovina. E-mail: lejla@verlabinstitute.com.

1. Introduction

According to the Food and Drug Administration (FDA) [1] an infusion and perfusion pump is a medical device that delivers fluids, such as nutrients and drugs, into the patient's body in controlled amounts. According to the MDR [2], infusion and perfusion pumps belong to three distinct medical device classes, namely class IIa, class IIb, and class III. These devices' construction and the type of fluid they provide to patients' bodies serve as the primary criteria for grouping them into the three different categories. This classification determines regulatory scrutiny to which devices are subjected to before placing on the market. Generally, Class II determines a medical device with a moderate to high risk that requires special controls. Class III determines a medical device with high risk that requires premarket approval. Class III are therapeutic devices whose intended ity is dependent to a significant degree on an integrated or incorporated diagnostic function.

Infusion/perfusion pumps can be referred to as medical devices with a measuring function (MDMF) since they are used to both monitor and deliver flow, volume, and pressure in relation to the fluid given to the patient's body [3]. The ity of the measuring instruments and sensors within the infusion and perfusion pumps directly affects the overall quality of care and reliability of these devices.

Regardless of the discrepancies in classification and premarket requirements, infusion and perfusion pumps perform the same function, which is the delivery of fluids, such as nutrients and drugs, into the patient's body. Therefore, the end user is only affected by the level of the delivered liquid. Irregularities in the delivery of the specified liquids within the specified values can lead to serious adverse events. These events are documented in European database on medical devices (EUDAMED) as well as Manufacturer and User Facility Device Experience (MAUDE) databases [4,5]. Both of these databases serve the purpose of documenting any adverse events arising from the usage of medical devices in general. Even though both of them provide significant insight into the performance of the devices on the market they lack standardization in reporting. This leads to a gap in post-market surveillance of medical devices, including infusion and perfusion pumps that must be bridged in order to ensure the best possible quality of healthcare to all patients.

A profound set of standards is used to demonstrate conformity with essential safety and performance requirements of infusion and perfusion pumps [6] prior to their market placement. These standards can be grouped into three categories, general quality standards, electrical safety standards, particular infusion and perfusion pumps standards. However, the post-market surveillance is significantly disharmonized and there are no international standards nor proposed methodologies on how to effectively evaluate the performance of infusion and perfusion pumps used in healthcare institutions.

This paper lays out a technical description of the methodology that can be implemented for post-market surveillance of infusion and perfusion pumps taking into account their metrological characteristics. Along with the methodology the paper presents the results of validation of the methodology during a four year period at healthcare institutions of all levels.

2. Method

To present the novel methodology, the accepted concept of OIML guidelines for other medical devices with measuring functions such as thermometers or sphygmomanometer was followed [7]. The method, developed under OIML recommendations, is reported as a coherent structure, through the following parts:

1. Definition of technical requirements for infusion and perfusion pumps

2. Definition of metrological requirements for infusion and perfusion pumps
3. Description of method for visual inspection
4. Description of method for electrical safety inspection
5. Description of method for performance inspection
6. Summary and expression of test results

During method validation, the performance assessment testing of infusion and perfusion pumps was done by using two etalons, Fluke Biomedical ESA 620 electrical safety analyser [8] and Fluke Biomedical IDA-5 Infusion Pump Analyzer and Tester [9]. Both of these devices were periodically calibrated in EN ISO 17025 accredited laboratories [8]. The novel method was validated during the 2018–2021 time period. The presented data was analysed using a statistical approach.

3. Results and discussion

The results are presented in two parts. The first part consists of reporting the novel methodology for conformity assessment testing of infusion and perfusion pumps and the second part consists of the validation report of this methodology done in real-time by inspection bodies in Bosnia and Herzegovina and Republic of Serbia.

3.1. Novel method for conformity assessment of infusion and perfusion pumps

The method for conformity assessment defines technical and metrological requirements for the device and methods to test these requirements in the environment where the device is used.

3.1.1. Technical and metrological requirements of infusion and perfusion pumps

Technical and metrological requirements are defined based on the regulatory requirements stated in directives/regulation, manufacturers' technical specifications and international standards defining safety and performance of medical devices.

3.1.1.1. Technical requirements

In order to ensure safety and reliability of infusion and perfusion pumps once they enter the market and once they are used in clinical settings the periodical inspection of their technical requirements is very important. In order to ensure traceability of the devices, labels and markings shall be visible, legible and indelible, and it is not possible to remove them without permanent damage. In case of the infusion and perfusion pumps, the technical requirements are formalised in the following manner:

- Label and marking
  - Name and/or trademark of manufacturer
  - Production mark (basic type)
  - Year of fabrication
  - Unique serial number
  - CE mark of appropriate administrative marking
- Construction of the device that guarantees security against any interference to metrological characteristics.
- The display shall be designed and arranged so that the information including measuring values can be read and easily recognized.

- Power supply: 220–240 V AC, 50/60 Hz; Battery supply.
  - Charging time < 10 h
  - Working time on battery on maximum flow is 3 hours
- Compliance with IEC 60601-2-24 Medical electrical equipment – Part 2–24: Particular requirements for the basic safety and essential performance of infusion pumps and controllers [11].

For inspection of all above mentioned requirements, a testing method needs to be adopted. As per OIML recommendations, the testing of these types of the requirements is to be carried out by visual inspection and by electrical safety inspection in accordance with IEC 60601 [11].

3.1.1.2. Metrological requirements

Reliability of medical devices can be proven with its compliance with metrological requirements. Metrological parameters such as error, accuracy and uncertainty are quantitative parameters specific for every device that serve as an evidence of device reliability. For every measurement device specific parameters are defined by its manufacturer such as measurement unit, range and division and accuracy. Following the OIML guideline, in case of the infusion and perfusion, the metrological requirements are formalised in the following manner:

- Measurement unit
  - Flow of volume is set and measured in millilitres per hour [ml/h].

Millilitre per hour is a derived unit of volume flow in the International System of Units (SI) (NIST 2019). It is defined as the volume in ml divided by the duration in hours.

- Measuring range and division
  - Flow of volume range:
    - Infusion pumps (0.1–999.99) [ml/h]
    - Perfusion pumps (0.1–99.9) [ml/h]
  - Outside this working range no energy reading and no measurement result shall be displayed.
  - Division: Measurement points are defined and distributed evenly on the whole measurement range.
  - Performance accuracy stated by the manufacturer in the technical specification.

For inspection of all above mentioned requirements, a testing method needs to be adopted. As per OIML recommendations, the testing of these types of the requirements is to be carried out by performance inspection presented in Section 3.2. of the results. A test report shall be prepared according to part 3.2. of the results. With a performance inspection method the metrological conformity assessment testing is done. The metrological conformity assessment testing requirement can be formulated as per OIML recommendations as follows:

- For any set of conditions within the ambient temperature range of 21°C to 26°C in the maximum permissible error for the flow measurements is as follows:
  - Infusion pumps: $\pm$ 5%,
  - Perfusion pumps: $\pm$ 2%.

3.1.2. Method of test

3.1.2.1. Visual inspection

a) Equipment

The prerequisites for performing visual inspection are:

- Device under test/infusion and perfusion pumps
- Manufacturers specification

Table 1
Technical requirements and pass/fail criteria

No.	Technical requirements	Result	Conformity assessment testing
1.	Prescribed labels and markings on the device under test	– Name and/or trademark of manufacturer – Production mark (basic type) – Year of fabrication – Unique serial number – CE mark of appropriate administrative marking	Pass/Fail
2.	Construction of the device	– The integrity of the device under test in respect to the manufacturer's specification – The ity of the device under test in respect to the manufacturer's specification	Pass/Fail
3.	Construction of the device	– Measurement range – Measurement unit	Pass/Fail

b) Procedure

The procedure for visual inspection for a device under test consists of checking label/marking and construction integrity. The device must comply with the manufacturers' specification in terms of ity and accompanying parts.

c) Summary and expression of test results.

The results are expressed as Pass/Fail answers to the tested criteria (Table 1).

3.1.2.2. Electrical safety inspection

a) Equipment

The prerequisites for electrical safety inspection are:

– Device under test/infusion and perfusion pump
– Reference electrical safety testing equipment/analyser

b) Procedure

The procedure starts with connecting the infusion and perfusion pump to electrical safety testing equipment. Test of the electrical safety of a device under test is performed according to the requirements of IEC 60601-1:2005 – Medical electrical equipment – Part 1: General requirements for basic safety and essential performance [11]. This test includes measurement of: mains voltage (live to neutral, neutral to earth, live to earth), protective earth resistance, insulation resistance (normal condition, mains to protective earth) earth leakage current (applied parts and normal condition, open neutral, normal condition – reversed mains, open neutral – reversed mains), enclosure leakage current (applied parts, normal condition, open neutral, normal condition – reversed mains, normal condition – reversed mains, open earth – reversed mains), patient applied parts leakage current.

c) Summary and expression of test results

The results are expressed in terms of requirements of IEC 60601-1:2005 – Medical electrical equipment – Part 1: General requirements for basic safety and essential performance [11]. An example of an electrical safety test is depicted in Table 2.

3.1.3. Performance inspection

a) Equipment

The prerequisites for performance inspection are:

Table 2
Example of electrical safety test report

Column 1	Column 2	Column 3
No.	Criteria	Conformity assessment testing **Pass/Fail**
1.	Are the requirements of the electrical safety regulations fulfilled?	

Table 3
Example of performance evaluation for infusion pumps in range 20–900 [ml/h]

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
No.	Set flow Xs [ml/h]	Reading flow Xm [ml/h]	Deviation ΔX [%]	Maximum deviation [%]	Conformity assessment testing Pass/Fail
1.	**20**	19.89	0.55	$\pm$5%	Pass
2.	**200**	198.43	0.78	$\pm$ 5%	Pass
3.	**300**	285.56	4.81	$\pm$ 5%	Pass
4.	**500**	464.68	7.06	$\pm$ 5%	Fail
5.	**700**	670.91	4.16	$\pm$ 5%	Pass
6.	**900**	851.34	5.41	$\pm$ 5%	Fail

Column 1 = Measuring point; Column 2 = Values set on the device under test; Column 3 = Values measured by calibrated testing equipment; Column 4 = Deviation expressed as relative error; Column 5 = Maximum deviation; Column 6 = Conformity assessment testing statement.

- Device under test/infusion and perfusion pump
- Reference testing equipment/analyser

b) Procedure

Based on device measuring range select measuring points to cover the entire measuring range. Test the flow in every measuring point. To test the flow in every measuring point, on a device, select the desired values that are expressed in *ml/h*. Connect the infusion of perfusion pump to calibrated reference testing equipment. When the device is connected, initiate the start of the flow on the DUT. Performance inspection of perfusion and infusion pump is performed in a similar manner with the only difference being the fact that perfusion pumps use syringe and do not allow the flow to exceed 100 ml/h, whereas the infusion pumps consist of an infusion pack and the achieved flow can be up to 1000 ml/h. All measurements were evaluated for their performance by measuring the delivered flow at the same point multiple times in order to check for consistency in the delivered value.

c) Summary and expression of test results

The decision of conformity assessment testing is obtained after the analysis of the results of the conducted tests. The OIML recommends a summary of the results in the form of tables. As it could be seen, visual inspection is reported in the form of qualitative analysis. Simple YES/NO answers to the criteria states the conformity assessment testing. For the performance inspection, the results are expressed using terms of error. In metrology error can be expressed using absolute error or relative error. In case of infusion and perfusion pumps, the performance inspection result can be reported as the relative error between the set values of the device under test and the corresponding readings of the calibrated reference testing equipment.

Relative error calculation:

$$\Delta X = X_{set} - X_{measured}/X_{set} * 100[\%] \quad (1)$$

The conformity assessment testing in performance inspection is determined by the value of this error.

Table 4
Example of performance evaluation for perfusion pumps in range 20–900 [ml/h]

Column 1	Column 2	Column 3	Column 4	Column 5	Column 6
No.	Set flow Xs [ml/h]	Reading flow Xm [ml/h]	Deviation ΔX [%]	Maximum deviation [%]	Conformity assessment testing Pass/Fail
1.	**5**	5.04	0.80	$\pm$ 2%	Pass
2.	**10**	10.11	1.10	$\pm$ 2%	Pass
3.	**30**	30.21	0.70	$\pm$ 2%	Pass
4.	**50**	50.36	0.72	$\pm$ 2%	Pass
5.	**70**	70.28	0.40	$\pm$ 2%	Pass
6.	**90**	90.44	0.49	$\pm$ 2%	Pass

Column 1 = Measuring point; Column 2 = Values set on the device under test; Column 3 = Values measured by calibrated testing equipment; Column 4 = Deviation expressed as relative error; Column 5 = Maximum deviation; Column 6 = Conformity assessment testing statement.

The allowed performance error is presented in Tables 3 and 4 (above). It was formulated based on the international standards followed during the production of the infusion and perfusion pump. Based on this requirement the conformity error is formulated as follows:

– If the error is less than the greatest allowed limit, then the device is compliant with metrological requirements.

In addition to quantitative testing, as proposed in this methodology, all infusion and perfusion pumps in this study were inspected for following qualitative features that influence their performance such as chassis integrity (technical requirements) in terms of: strain reliefs, connectors, switches, displays, alarms, battery. Moreover, accuracy of instruments and control, charging time, internal electrical power source, device operation after battery alarm and batteries were tested.

3.2. Method validation

Method validation was done by inspection bodies appointed by the national metrological institutes in Bosnia and Herzegovina and Republic of Serbia. Both of the inspection bodies are accredited by ISO 17020 standard for testing and inspection.

During method validation, in both countries, devices were inspected in both private and public healthcare institutions. The best indicator of the effectiveness of the developed method is the decrease in the percentage of non-compliant infusion and perfusion pumps over the years the method was validated. The largest difference in the percentage of non-compliant infusion and perfusion pumps occurred between the first two years of method implementation in practice. The decreasing trend persists throughout the years, but is less intensive.

This strengthens the conclusion that the medical device inspection method according to OIML metrological standards is the most effective way of preventing non-compliant infusion and perfusion pumps being used in medical practice. If there was no performance inspection, most of the non-compliant infusion and perfusion pumps would persist in usage as healthcare professionals would remain unaware of the non-compliance of the output values of the measured volume flow.

All of the aforementioned results confirm the necessity of independent periodical inspection of technical and metrological requirements for the infusion and perfusion pumps in use, as the performance test revealed the performance variations that were not detected during usage or periodical preventive and corrective maintenance. Moreover, all the data collected during the inspection of the devices was standard, traceable, accurate and it was immediately transferred into the digital database specially developed for this purpose.

4. Conclusion

Access to health is fundamental human right. However, various adverse event involving medical devices pose a risk to patients safety and well-being. The importance of safe and compliant medical devices has been especially demonstrated during COVID-19 pandemics [12]. Lately, regulators have been working in improving post-market surveillance of medical devices to ensure that number of incidents and adverse events including medical devices is lowered. Specifically, in the European Union, Medical Device Regulation (MDR) introduces the EUDAMED database [13,14] containing all information regarding the adverse events associated with medical devices and reported by the end users that may be physicians, medical technicians or patients themselves. However, current databases collect information for each database from both voluntary sources and mandatory reports. Judging by the number of reported incidents involving medical devices it can be concluded that the limitations of the databases are that the data submitted include "incomplete, inaccurate, untimely, unverified, or biased data." In addition, many use errors stay underreported and data format unknown. Moreover, current databases are limited to administrative data only including manufacturers and distributor data, vigilance and clinical studies data, hence the surveillance is not taking its full capacity. Also, baseline evidence for medical device safety and performance cannot be established due to lack of traceable data.

This paper lays out a novel methodology for conformity assessment testing of infusion and perfusor pumps for post-market surveillance purposes. The novel methodology was developed based on OIML guidelines for technical and metrological characteristics and performance evaluation. Developed methodology has been validated by the work of two inspection bodies for medical devices working under the legal metrology framework which has been adopted for medical devices in Bosnia and Herzegovina and Republic of Serbia [15,16]. The introduction of standardized conformity assessment method for testing of safety and performance of infusion and perfusor pumps produced traceable, accurate, complete, verified, nonbiased and standardized data. All data resulting from the inspection carried out by independent appointed inspection bodies has been entered in database specially developed for this purpose – eLab [17]. This practice showed that significant cost-effectiveness can be achieved in management of maintenance in healthcare institutions because standardized data showed certain patterns for healthcare institutions.

The work demonstrated how standardized method for conformity assessment testing produces complete, accurate, verified, traceable and unbiased data. Following the trend of digital transformation and application of artificial intelligence, the researchers investigated application of artificial intelligence on this database [18–23]. The hypothesis of predictive management of maintenance of medical devices has been set up. Indeed, as medicine is shifting toward personalized medicine clinical engineering should follow the path of predictive approach.

Conflict of interest

None to report.

References

[1] Food and Drug Administration (FDA) www.fda.gov.
[2] Medical Devices Regulation (MDR): 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.

[3] European Union. 2017. The European Union Medical Device Regulation – Regulation (EU) 2017/745 (EU/MDR). Accessed December 20, 2021. https://eumdr.com/.
[4] European Medical Device Database (EUDAMED), https://ec.europa.eu/tools/eudamed/#/screen/home.
[5] Manufacturer and User Facility Device Experience (MAUDE) database, https://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfmaude/search.cfm.
[6] EU Medical Device Directives: Directive 98/79/EC of the European Parliament and of the Council of 27 October 1998 on *in vitro* diagnostic medical devices, Official Journal of the European Communities, L 331, 2000.
[7] Organisation Internationale de Métrologie Légale (OIML). 2015. National metrology systems – Developing the institutional and legislative framework. Accessed December 15, 2021. https://www.oiml.org/en/files/pdf_d/d001-e20.pdf.
[8] Fluke ESA620 Electrical Safety Analyzer, 2022 [online], available at: www.flukebiomedical.com.
[9] Fluke IDA-5 Infusion Pump Analyzer and Tester, 2022 [online], available at: www.flukebiomedical.com.
[10] ISO/IEC 17025:2017 – General requirements for the competence of testing and calibration laboratories, International Organisation for Standardisation, Geneva, Switzerland, ISO standard, 2017.
[11] IEC 60601. Medical electrical equipment – all parts, International Electrotechnical Commission, Geneva, Switzerland, IEC standard, 2021.
[12] Badnjević A, Pokvić LG, Džemić Z, et al. Risks of emergency use authorizations for medical products during outbreak situations: A COVID-19 case study. BioMed Eng OnLine. 2020; 75: 19. doi: 10.1186/s12938-020-00820-0.
[13] 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.
[14] Regulation (EU) 2017/746 of the European Parliament and of the Council of 5 April 2017 on *in vitro* diagnostic medical devices and repealing Directive 98/79/EC and Commission Decision 2010/227/EU.
[15] Badnjević A, et al. Post-market surveillance of medical devices: A revie. Technology and Health Care. 2022; 30(6): 1315–1329.
[16] Badnjević A, Cifrek M, Magjarević R, žemić Z. (eds). Inspection of Medical Devices. Series in Biomedical Engineering. 2018. Springer, Singapore.
[17] Gurbeta L, Badnjević A. Inspection process of medical devices in healthcare institutions: software solution. Health Technol. 2017; 7(Issue 1): 109–117. doi: 10.1007/s12553-016-0154-2.
[18] Badnjević A, Pokvić LG, Hasičić M, Bandić L, Mašetić Z, Kovačević Ž, Kevrić J, Pecchia L. Evidence-based clinical engineering: Machine learning algorithms for prediction of defibrillator performance. Biomedical Signal Processing and Control. September 2019; 54: 101629.
[19] Kovačević Ž, Gurbeta Pokvić L, Spahić L, Badnjevic A. Prediction of medical device performance using machine learning techniques: infant incubator case study. Health Technol. 2019. doi: 10.1007/s12553-019-00386-5.
[20] Badnjević A, Avdihodžić H, Gurbeta Pokvić L. Artificial intelligence in medical devices: Past, present and future. Psychiatria Danubina. 2021; 33(suppl 3): 101–106.
[21] Spahić L, Kurta E, Cordic S, Becirovic M, Gurbeta L, Kovacevic Z, Izetbegovic S, Badnjevic A. Machine Learning Techniques for Performance Prediction of Medical Devices: Infant Incubators. In: Badnjevic A, Škrbić R, Gurbeta Pokvić L. (eds) CMBEBIH 2019. CMBEBIH 2019. IFMBE Proceedings, vol 73. Springer, Cham. 2020.
[22] Hrvat F, Spahic L, Gurbeta Pokvic L, Badnjevic A. Artificial Neural Networks for prediction of medical device performance based on conformity assessment data: Infusion and perfusor pumps case study. IEEE 9th Mediterranean Conference on Embedded Computing (MECO), Budva, Montenegro. 08–11 June 2020.
[23] Gurbeta Pokvic L, Deumic A, Lutovac B, Badnjevic A. Possibility of Managing Medical device Post-market Surveillance using Artificial Intelligence and Standardized Methodology. IEEE 10th Mediterranean Conference on Embedded Computing (MECO), Budva, Montenegro. 07–10 June 2021.