Revista Contexto & Saúde
Editora Unijuí
Programa de Pós-Graduação em Atenção Integral à Saúde
ISSN 2176-7114 – v. 25, n. 50, 2025

http://dx.doi.org/10.21527/2176-7114.2025.50.15193
HOW TO CITE:
Diniz RM, Pfrimer IAH. Georeferencing and Real-Time Temperature Monitoring During the Transport of Human Biological Materials. Rev. Contexto & Saúde, 2025;25(50):e15193.

ORIGINAL ARTICLE

GEOREFERENCING AND REAL-TIME TEMPERATURE MONITORING DURING THE TRANSPORT OF HUMAN BIOLOGICAL MATERIALS

Rogério Martins Diniz[1], Irmtraut Araci Hoffmann Pfrimer[2]

Highlights:
(1) Importante of Temperature Monitoring in the Transport of Biological Samples.
(2) Efficiency of Active Electrical Packaging in the Tansport of Biological Materials.
(3) Economic Impact and Sustainability in the Transport of Biological Materials.

ABSTRACT

Objective: To evaluate and compare the average temperature between active electric packaging and passive thermal packaging with artificial ice packs during the transport of human biological materials. *Methods*: The temperatures (in °C) of the transported biological samples were assessed over 6 consecutive days, using two different biological material transport boxes: (1) passive thermal box cooled with artificial ice packs, and (2) active electric box with a long-lasting lithium battery, cooled by a closed-circuit system using a compressor and coil. A total of 2,247.1 km was traveled, and 10,606 biological samples were collected across 11 different clinical analysis laboratories. Temperature monitoring was carried out through sensors installed in both boxes, allowing real-time online tracking and temperature monitoring. *Results*: On all analyzed days, the active box proved more efficient than the passive box, maintaining the average temperature within the established requirements (2 to 8°C) throughout the journey until final delivery. Environmental temperature variation did not directly affect the internal temperature of either packaging used in this type of transport. *Conclusion*: Active electric packaging is more efficient when compared to passive packaging cooled with artificial ice packs, as it maintained the correct temperature throughout the entire biological material transport process.

Keywords: biocompatible materials; biological monitoring; contaminant transport.

[1] Pontifical Catholic University of Goiás- PUC Goiás. Goiânia/GO, Brasil. https://orcid.org/0009-0008-5273-9276
[2] Pontifical Catholic University of Goiás- PUC Goiás. Goiânia/GO, Brasil. https://orcid.org/0000-0002-3737-0027

INTRODUCTION

Human biological material can be used for various purposes, such as research, diagnosis, and/or teaching. With the expansion of large research and diagnostic networks, the transportation of biological samples to central laboratories for processing has increased, requiring that the temperature remain within the required range[1].

According to the World Health Organization (WHO), many biological samples deteriorate before reaching their final destination due to storage and transportation methods. Temperature and processing time directly affect the variability of the final result obtained after processing. Therefore, the need for more specific guidelines regarding the transportation of biological materials is growing[2].

Most biological materials must be transported within a temperature range of 2°C to 8°C or 15°C to 30°C to maintain the integrity and stability of analytes. The allowable variation within these ranges is approximately ±1.5°C. Regulations established by the National Health Surveillance Agency (Anvisa) in Brazil stipulate that any temperature excursion outside this range may compromise sample quality[3]. Therefore, it is essential that transportation systems are capable of strictly maintaining these conditions throughout the entire logistics process.

A large-scale laboratory receives an average of 20,000 biological samples per day[3]. For the laboratory to provide reliable results, it is not enough for techniques to be correctly performed and by trained personnel. It is essential to use a properly preserved biological sample. Thus, temperature is one of the most critical factors during the transportation and storage of biological material[4]. During transport, most biological materials must be kept between 2°C and 8°C or even frozen to preserve the biological and chemical properties of their analytes.

In the clinical analysis laboratory, the methodology is divided into three phases: pre-analytical, analytical, and post-analytical[5]. The transportation of biological material is included in the pre-analytical phase, during which most laboratory test errors occur[6].

If a biological sample arrives deteriorated at the clinical laboratory for analysis, it can lead to significant errors with undesirable consequences for the patient, such as delays in diagnosis and treatment, increased healthcare costs, incorrect diagnoses, and, consequently, inadequate treatments that may put the patient's life at risk.

Due to the centralization of processing units, the time and distance traveled between collection units and processing centers have increased, requiring greater care with storage conditions and transport quality when dealing with human biological materials. As a result, the packaging used for such transport has undergone modifications over time[7].

Transport packaging can directly affect the temperature and viability of human biological samples, potentially leading to a loss of sensitivity in detecting microorganisms[8]. Studies have already shown that temperature can impact the viability of immune system cells when stored at different temperatures[9,10]. Moreover, it is essential to consider the impact of temperature and the stability of bioanalytes throughout the entire transport process[1].

Human biological material to be transported must be packaged in a way that preserves its integrity and stability during transport[2]. For this purpose, artificial ice packs, used in passive cooling systems, must undergo a freezing process for at least 12 hours. On the other hand, electrically powered packaging with active cooling systems has been increasingly adopted, eliminating the need for artificial ice packs[11].

It is important to emphasize proper packaging to match transport conditions and ensure the safety of users and other people involved in the process, such as cargo handlers. In addition to protecting the environment, it is necessary to follow parameters and regulations for handling and transporting biological samples established by regulatory authorities[3].

Biological samples often degrade over time when not stored and transported at the recommended temperature[2]. Improvements in equipment for transporting human biological materials, combined with better infrastructure and temperature monitoring and logistics systems, following best practices, have evolved[7] resulting in enhanced stability of analytes to be measured in various types of laboratories[8].

There is a gap in the literature regarding the comparative efficacy of passive thermal packaging versus active refrigeration systems for transporting these materials. This study aims to fill that gap by directly comparing the two packaging options, evaluating their effectiveness in maintaining the appropriate temperature throughout transport.

In this context, the objective of this study was to evaluate and compare the average temperature between active electric packaging and passive thermal packaging with artificial ice packs during the transport of human biological materials.

METHODS

This is a type of study in which exposure to a factor or cause is observed simultaneously with its effect. In this type of research, a situation or phenomenon is described at a specific point in time, and an analysis is conducted to verify the presence or absence of exposure and the presence or absence of the effect[12].

The present study evaluated the temperature (in °C) of two boxes during the transport of biological material: (1) a passive box and (2) an active electric box. Temperatures were measured at the departure and arrival of the boxes at the collection units (11 units).

The study took place on March 8th, 9th, 10th, 14th, 15th, and 16th, 2023, in the state of Goiás. A total distance of 2,247.10 km was covered, and 10,606 samples were collected. In addition to the temperature of the boxes, the following variables were recorded: arrival and departure times at the units, distance traveled (in km) per day, and the total number of samples collected.

The materials used in the research were: a) Passive boxes: 30-liter thermal boxes (Coleman brand) for transporting biological materials, cooled with artificial ice packs: 9 medium-sized ice packs (21.5 x 14.5 x 2.5 cm) positioned around the box; b) Active electric boxes: 30-liter Hagelab® boxes with long-lasting lithium batteries, featuring a closed-circuit cooling system with a compressor, coil, condenser, evaporator, and R134 gas; c) Temperature and GPS Hagelab® sensors, properly calibrated and thermally qualified, capable of providing real-time temperature and geolocation data through the Hagelab® monitoring software; d) Validated software for real-time online temperature monitoring and geolocation, with alert notifications.

Statistical analysis included both descriptive and inferential statistics. For descriptive statistics, categorical variables were presented as absolute frequencies (n) and relative percentages [f (%)], while continuous variables were described using mean (central tendency measure), standard deviation (SD), and minimum and maximum values.

For inferential statistics, normality was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk tests, showing non-parametric behavior for all continuous variables ($p < 0.05$). Bootstrapping procedures (1,000 resamplings) were performed to improve result reliability, correct normality deviations, and account for differences in group sizes. Additionally, the following tests were conducted: Student's t-test for dependent samples (comparing the same box: active box exit temperature vs. arrival temperature and passive box exit temperature vs. arrival temperature). For independent samples (comparing box types: active vs. passive boxes).

Two Pearson correlation tests were applied. (1) between the variables: temperature variation modulus of the active boxes, temperature variation modulus in passive boxes, distance traveled (in km), time (in minutes); and (2) between the variables: ambient temperature variation (maximum ambient temperature minus minimum ambient temperature recorded during transport), temperature variation modulus in the active box (modular value of the result of the initial exit temperature of the active box minus the final arrival temperature of the active box), temperature variation modulus in the passive box (modular value of the result of the initial exit temperature of the passive box minus the final arrival temperature of the passive box) and average ambient temperature (half of the sum of the lowest and highest temperatures recorded during the transport of the biological material), all temperature values in Celsius (°C).

For statistical calculations, tables and figure generation (graphs), the following software was used: Hagelab®, Microsoft® Excel® 365, BioEstat® 5.3, IBM®, SPSS® (Statistical Package for the Social Sciences). The significance level was set at 5%.

RESULTS

During the study period, a total distance of 2,247.1 km was covered, and 10,606 biological samples were transported. The day with the highest number of collected samples and the longest distance traveled was March 16, while the largest variation in external ambient temperature occurred on March 8, 2023, with a fluctuation of 10°C and this variation had no significant impact on the internal temperature of the boxes (Table 1).

Throughout the entire transport route, the temperatures of the active electric box and the passive box were monitored, specifically at the departure and arrival points of each collection unit. Table 1 shows the average daily temperature of each box at the departure and arrival of each unit. On all study days, no significant temperature variation was observed in either box, except on March 15, 2023, when the passive box showed a variation of +0.7°C. However, the passive box consistently exhibited greater temperature fluctuations throughout the study period compared to the active electric box.

Table 1 – Evaluation of the difference in means, with standard deviation (SD), of the temperatures (in °C) at departure and arrival at collection units within the same box. Goiânia, Goiás, 2023

Day of transport	Active box				*p-valor*	Passive Box				*p-valor*
	Departure Temp		Arrival Temp.			Departure Temp.		Arrival Temp.		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
03/08/2023	**4.7**	1.9	**4.3**	1.5	0.5514	**19.6**	2.5	**19.3**	2.6	0.6434
03/09/2023	**5.5**	1.8	**5.7**	1.5	0.8175	**17.9**	3.5	**17.8**	3.6	0.9258
03/10/2023	**5.0**	1.4	**5.3**	1.6	0.3986	**19.6**	4.6	**19.3**	4.4	0.8256
03/14/2023	**5.6**	1.9	**5.4**	1.6	0.8010	**16.4**	3.0	**16.0**	2.9	0.6597
03/15/2023	**5.6**	1.6	**5.4**	1.6	0.8212	**17.4**	2.2	**18.1**	2.0	**0.0388**
03/16/2023	**6.1**	2.5	**5.8**	1.6	0.7300	**18.7**	3.4	**19.0**	3.9	0.6643
Total	**5.4**	1.9	**5.3**	1.6	0.7572	**18.3**	3.4	**18.3**	3.4	0.9780

Source: Prepared by author.

Table 2 presents the average daily temperature between the boxes, with standard deviation, during the departure and arrival of each collection unit. On all days, there was a significant difference ($p<0.001$) in the average temperature, as well as greater temperature fluctuation in the passive box.

Table 2 – Evaluation of the difference in means, with standard deviation (SD), of the temperatures (in °C) at departure and arrival at collection units between the boxes. Goiânia, Goiás, 2023

Day of transport	Departure Temperature				*p-valor*	Arrival Temperature				*p-valor*
	Active Box		Passive Box			Active Box		Passive Box		
	Mean	*SD*	*Mean*	*SD*		*Mean*	*SD*	*Mean*	*SD*	
03/08/2023	**4.7**	1.9	**19.6**	2.5	**<0.0001**	**4.3**	1.5	**19.3**	2.6	**<0.0001**
03/09/2023	**5.5**	1.8	**17.9**	3.5	**<0.0001**	**5.7**	1.5	**17.8**	3.6	**<0.0001**
03/10/2023	**5.0**	1.4	**19.6**	4.6	**<0.0001**	**5.3**	1.6	**19.3**	4.4	**<0.0001**
03/14/2023	**5.6**	1.9	**16.4**	3.0	**<0.0001**	**5.4**	1.6	**16.0**	2.9	**<0.0001**
03/15/2023	**5.6**	1.6	**17.4**	2.2	**<0.0001**	**5.4**	1.6	**18.1**	2.0	**<0.0001**
03/16/2023	**6.1**	2.5	**18.7**	3.4	**<0.0001**	**5.8**	1.6	**19.0**	3.9	**<0.0001**
Total	**5.4**	1.9	**18.3**	3.4	**<0.0001**	**5.3**	1.6	**18.3**	3.4	**<0.0001**

Source: Prepared by the author.

Although the temperature variation in the passive box between departure and arrival at each unit was smaller, it was observed that, from the start to the end of the route, the temperature in the active box remained stable due to its active cooling system, which allows temperature recovery after the lid is opened during transport. The average temperature in the active electric box stayed within the established range on all days, whereas the passive box showed results outside the recommended range.

Table 3 presents the correlation between the distance traveled, time, and the temperature variation of the active box (TVM01) and the passive box (TVM02). A weak statistical correlation was observed between TVM01 and the distance traveled (r=0.2969, p=0.0113), as well as with time (r=0.3475, p=0.0028). A moderate correlation between TVM02 and time (r = 0.6263, p < 0.0001) as well as with distance traveled (r = 0.7278, p < 0.0001) was observed.

Table 3 – Pearson correlation between the variables: temperature variation modulus (TVM) of active and passive boxes (in °C), distance traveled (in km), and time (in min). Goiânia, Goiás, 2023

Variables	Pearson	TVM01	TVM02	Distance	Time
TVM Active Box (°C)	**R**	1			
	p-valor	--			
TVM Passive Box (°C)	**R**	0.0708	1		
	p-valor	0.5542	--		
Distance (km)	**R**	**0.2969**	**0.7278**	1	
	p-valor	**0.0113**	**<0.0001**	--	
Time (min.)	**R**	**0.3475**	**0.6263**	**0.8942**	1
	p-valor	**0.0028**	**<0.0001**	**<0.0001**	--

Source: Prepared by the author.

Table 4 shows the correlation between ambient temperature variation (ATV) and average ambient temperature (AAT) with the temperature variation modulus of the active box (TVMAB) and the temperature variation modulus of the passive box (TVMPB).

The correlation between ATV and AAT in both the passive and active boxes was very weak and not statistically significant. Additionally, the ambient temperature variation during transport showed a moderate correlation with the temperature variation in the passive box and a very weak correlation with the temperature variation in the active box, but neither correlation was statistically significant (Table 4).

Table 4 – Pearson correlation between the variables: ambient temperature variation (VTA), absolute temperature variation of the active box (MVTCA), absolute temperature variation of the passive box (MVTCP), and average ambient temperature (all in °C). Goiânia, Goiás, 2023.

Variables	Pearson	VTA	MVTCA	MVTCP	TAM
VTA	**r**	1,0000			
	p-valor				
MVTCA	**r**	0,1055	1,0000		
	p-valor	0,8423			
MVTCP	**r**	-0,4172	-0,7656	1,0000	
	p-valor	0,4106	0,0760		
TAM	**r**	**0,9080**	-0,1788	-0,0321	1,0000
	p-valor	**0,0123**	0,7347	0,9518	

Source: Prepared by the authors

The box plot diagram shown in Figure 1 provides a summary and overview of all the study findings. In the active electric box, the highest and lowest departure temperatures recorded were 7.3°C and 3.5°C, respectively, while the highest and lowest arrival temperatures were 6.9°C and 3.7°C, respectively. In the passive box, the highest and lowest departure temperatures recorded were 21.6°C and 14.9°C, respectively, while the highest and lowest arrival temperatures were 21.7°C and 14.8°C, respectively. When comparing the departure and arrival temperatures of the active box, there was no statistically significant difference, as well as, no statistical difference was observed in relation to the passive box. However, when comparing the temperatures (with standard deviation) between the active and passive boxes, both at departure and arrival, was observed a significant difference (p < 0.001) (Figure 1).

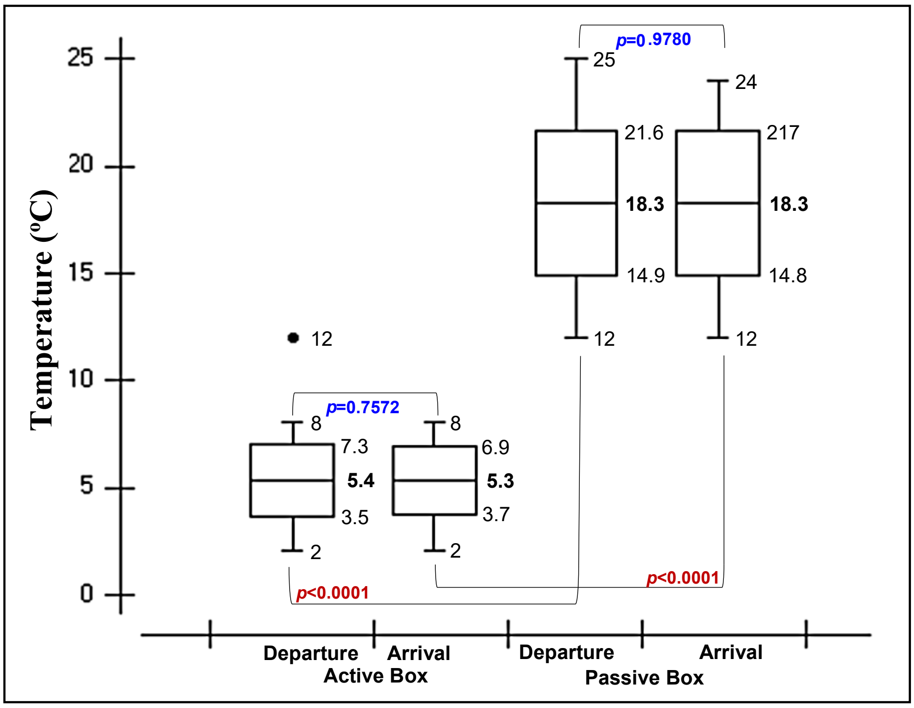

Figure 1 – Box plot diagram showing the mean, standard deviation, and minimum and maximum values of the temperatures (in °C) at departure and arrival at collection units for active and passive boxes, considering all collection days and the p-value. Goiânia, Goiás, 2023.

Source: Prepared by the authors

Throughout the daily transport, 9 artificial ice packs were used in the passive box to preserve the biological material. If transport had been carried out exclusively using the active electric box, 54 artificial ice packs would not be used during the study.

Since this route is operated continuously for 20 days per month, it is estimated that 2,160 artificial ice packs would no longer be used annually if biological material transport were exclusively done with the active electric box.

DISCUSSION

Studies over time have demonstrated the importance of temperature during the transport of biological material[7,14], whether for research, clinical analysis, or other purposes. The evolution of packaging has been crucial in ensuring safe transport that meets the requirements of regulatory agencies[2,15].

Temperature is a critical factor when transporting any thermolabile product. Recently, this discussion has gained traction due to losses related to the transport of Covid vaccines, as well as regulations aimed at preventing temperature-related losses during transportation[16].

Currently, the vast majority of biological material transport is carried out in refrigerated thermal boxes with the help of artificial ice packs[17], which consist of an acrylic polymer-based gel. In long-distance transport, where frequent opening of the box is required, temperature loss may occur, compromising the stability of the transported product[18].

New packaging with an active refrigeration system eliminates the need for artificial ice, making transportation safer and more stable. This gradual shift in the way biological material is transported still requires further consideration, given the new regulations and requirements imposed by regulatory and accrediting agencies.

There are various models and sizes of packaging with an active refrigeration system. The packaging used in this study has an average cost of R$5,500.00 (five thousand five hundred reais), with maintenance costs of R$250.00 (two hundred and fifthy reais), according to the manufacturer. The lithium battery lasts five years and costs R$1,500.00 (one Thousand and five hundred reais). For the analyzed route, if only the electric box were used, 2,160 artificial ice packs would no longer be required. The average price of the artificial ice pack (21 x 14 x 2.5 cm), commonly used for transporting biological material, is R$3.50. Over 12 months, an estimated R$7,560.00 (seven thousand and five hundred and sixthy reais) would no longer be spent on artificial ice.

This economic analysis reflects that investing in advanced technologies not only improves transportation efficiency but also offers a positive financial return. Clinical laboratories make significant investments in new technologies and in vitro diagnostic equipment. It is essential that managers, leaders, and individuals involved in biological material transport understand the importance of regulations and guidelines so that transportation investments are proportional and appropriate.

The expansion of healthcare networks has increased the demand for biological material transport. It is evident that proper care and standardization must be in place to meet logistics and quality assurance guidelines and regulations, preventing samples from being compromised and affecting material analysis[9,10].

For reliable diagnosis, all steps within the analytical process are crucial. It has long been unanimously recognized that most laboratory errors are directly linked to pre-analytical events[18]. Studies and internal analyses conducted in clinical laboratories reinforce that this stage requires special attention.

Within the pre-analytical process, the transport of biological materials can impact the entire subsequent processing chain of this material and directly affect the average service time, leading to delays in diagnoses and initiation of possible therapies.

Traceability and temperature monitoring of biological material allow for both corrective and preventive actions, such as risk management, route mapping, contingency planning, and strategies to minimize risks related to improper storage or loss. There are few studies on the transport of biological materials; however, by analyzing other health-related products that require cold chain logistics, a parallel can be drawn.

Each year, according to the WHO, approximately 50% of vaccines produced worldwide arrive at their destination in a deteriorated state. Once again, failures in temperature control during transportation are identified as the main cause[19].

The WHO has always emphasized the need for "end-to-end" monitoring. However, it is evident that all efforts made by major healthcare centers to ensure quality, efficiency, and satisfaction may be at risk if transportation is inadequate.

Since the beginning of development of the cold chain, several challenges have been overcome with technological solutions[20-22]. With the pandemic and the expansion of healthcare networks, including care units and centralized processing points, effective management, traceability, and route monitoring have become essential.

When biological material is analyzed, it is assumed that all processes and guidelines – from sample collection and preparation to transportation and processing – have been followed. It is the responsibility of professionals involved at all stages to carry out all necessary verifications and take corrective actions if any step is compromised.

Throughout the process leading up to final analysis, biological material may pass through multiple hands, making control and monitoring more challenging[23]. To enhance efficiency, technologies are available that provide real-time end-to-end traceability, issuing alerts in case of route deviations or temperature excursions.

Monitoring the physical, chemical, and biological integrity of immunological analytes is directly related to the cold chain, which plays a crucial role in maintaining temperature stability[23]. In addition to new software-related technologies, over time, advancements in packaging have also significantly improved the transport of human biological material.

This study found that packaging with an active refrigeration system, compared to passive system packaging, is superior in all aspects, including storage, temperature recovery, and temperature conservation. It ensures stability, maintenance, and temperature recovery throughout the transportation of human biological material.

On all biological material collection route days, the active electric box maintained the temperature within the desired range (2 to 8°C). Upon arrival at collection units, where the box is opened – causing an increase in internal temperature—the temperature recovered quickly, preventing deviations or excursions.

On the other hand, the passive box, even with the proper use of artificial ice packs, did not maintain the required temperature on any of the days. It was also observed that time directly affects biological material transport, and after opening and closing this packaging, temperature recovery did not occur.

Regarding ambient temperature variations, no significant impact was observed on the internal temperature of the boxes. This may be explained by the minimal time the lids were open for biological material insertion. It is important to note that in Brazil, particularly in the Central-West region where the study was conducted, seasons are not well-defined. It is essential that similar studies be conducted in different locations with diverse climates over longer periods.

The use of new technologies provides traceability throughout the entire biological material transport process, generating critical data that enables actions to prevent losses that could cause immeasurable and incalculable harm to both patients and institutions.

This study did not directly analyze the impact on the analytes of transported biological samples, area for future research. However, it demonstrated that new packaging and advanced technologies are essential for effective control that meets regulatory requirements.

CONCLUSION

Active electric packaging is more efficient compared to passive packaging refrigerated with artificial ice packs, as it maintained the correct temperature throughout the transport of biological material.

Although ambient temperature did not directly affect the internal temperature of the boxes, further studies with longer durations, different locations, and varying climatic conditions should be conducted for a more conclusive analysis.

During the study, numerous artificial ice packs would no longer be needed if biological material transport were carried out exclusively with the active box. The investment capacity of each company and healthcare center is an important variable. However, an internal and individual analysis is necessary, as over time, investing in new technologies and packaging for biological material transport may prove to be financially viable.

REFERENCES

[1] Gabriel Jr. A, Silva AAB, De Martino MC, Razvickas WJ, Silva RC, Viana AM, et al. Validação do sistema de transporte e das dosagens de amostras biológicas enviadas para a central de um laboratório de grande porte. J Bras Patol Med Lab. 2007;43(4):235-240.

[2] Olson WC, Smolkin ME, Farris EM, Fink RJ, Czarkowski AR, Fink JH, et al. Shipping blood to a central laboratory in multicenter clinical trials: effect of ambient temperature on specimen temperature, and effects of temperature on mononuclear cell yield, viability and immunologic function. J Transl Med. 2011;9:26.

[3] Agência Nacional de Vigilância Sanitária (ANVISA). Manual de vigilância sanitária sobre o transporte de material biológico humano para fins de diagnóstico clínico. Brasília: ANVISA, 2015. [access in 20 fev. 2023]. Available from: https://www.gov.br/anvisa/pt-br/assuntos/sangue/trans porte-de-material-biologico/manual-de-transporte-de-material-biologico-humano.pdf

[4] Oliveira RGAM, Silva GAF. Os principais erros da fase pré-analítica de exames laboratoriais. Revista Brasileira de Análises Clínicas. 2022;54(1):e20220330.

[5] Brisolara ML. Controle de qualidade em análises clínicas. In: Xavier RM, et al. (org.). Laboratório na prática clínica: consulta rápida. Porto Alegre: Artmed; 2016. p. 91-109.

[6] Salinas M, López-Garrigós M, Yago M, Ortuño M, Carratala A, Aguado C, et al. Evaluación de la calidad en el laboratorio en la fase preanalítica: un estudio multicéntrico. Rev Calid Asist. 2011;26(4):264-268.

[7] Robertson J, Franzel L, Maire D. Innovations in cold chain equipment for immunization supply chains. Vaccine. 2017;35(17):2252-2259.

[8] Aires CAM, Araújo CFM, Nobre ML, Rusak LA, Assis UG, Lopéz DCM, et al. Biossegurança em transporte de material biológico no âmbito nacional: um guia breve. Rev Pan-Amaz Saude. 2015;6(2):73-81.

[9] Ashmore LM, Shopp GM, Edwards BS. Lymphocyte subset analysis by flow cytometry. Comparison of three different staining techniques and effects of blood storage. J Immunol Methods. 1989;118(2):209-215.

[10] Weiblen BJ, Debell K, Giorgio A, Valeri CR. Monoclonal antibody testing of lymphocytes after overnight storage. J Immunol Methods. 1984;70(2):179-183.

[11] Liu Z, Guo H, Zhao Y, Hu B, Shi L, Lang L, et al. Research on the optimized route of cold chain logistics transportation of fresh products in context of energy-saving and emission reduction. Math Biosci Eng. 2021;18(2):1926-1940.

[12] Hochman B, Nahas FX, Oliveira Filho RS, Ferreira LM. Desenhos de pesquisa. Acta Cir Bras. 2005;20:2-9.

[13] Field A. Descobrindo a estatística usando o SPSS. 6. ed. Porto Alegre: Artmed; 2015.

[14] Guder WG, Narayanan S, Wisser H, Zawta B. Amostras: do paciente para o laboratório, impacto das variáveis pré-analíticas sobre a qualidade dos resultados de laboratório. São Paulo: Câmara Brasileira do Livro; 1996.

[15] Teixeira P, Valle S. (org.). Biossegurança: uma abordagem multidisciplinar. Rio de Janeiro: Fiocruz; 2010.

[16] Patine FS, Lourenção LG, Wysocki AD, Santos MLSG, Rodrigues IC, Vendramini SHF. Analysis of vaccine loss due to temperature change. Rev Bras Enferm. 2021;74(1):e20190762.

[17] Roiz C. Normas e procedimentos em transportes de materiais humanos biológicos. São Paulo: Thecalone Company; 2019.

[18] Hcolnik W. Erros relacionados ao laboratório. In: Sousa P, Mendes W. (Orgs.). Segurança do paciente: conhecendo os riscos nas organizações de saúde. 2. ed. Rio de Janeiro: Fiocruz; 2019, p. 237-262.

[19] Kartoglu U, Ames H. Ensuring quality and integrity of vaccines throughout the cold chain: the role of temperature monitoring. Expert Rev Vaccines. 2022;21(6):799-810.

[20] Lloyd J, Cheyne J. The origins of the vaccine cold chain and a glimpse of the future. Vaccine. 2017;35(17):2115-2120.

[21] Kumar S, Lennon P, Muller N, Uranw S, Mvundura M, Sibole A, et al. Using long-range freeze-preventive vaccine carriers in Nepal: a study of equipment performance, acceptability, systems fit, and cost. Vaccine X. 2022;10:100146.

[22] Kumar S, Lennon P, Uranw S, Fielding T, Mvundura M, Drolet A, et al. Using freeze-preventive cold boxes in rural Nepal: a study of equipment performance, acceptability, system fit, and cost. Vaccine X. 2024;18:100467.

[23] Kumru OS, Joshi SB, Smith DE, Middaugh CR, Prusik T, Volkin DB. Vaccine instability in the cold chain: mechanisms, analysis and formulation strategies. Biologicals. 2014;42(5):237-259.

Submitted: September 22, 2023
Accepted: August 28, 2024
Published: March 18, 2025

Authors' contributions

Rogério Martins Diniz: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Software; Validation; Writing – original draft; Writing – review & editing.

Irmtraut Araci Hoffmann Pfrimer: Conceptualization; Methodology; Project administration; Supervisão; Writing – original draft; Writing – review & editing.

All authors approved the final version of the text.

Conflict of interest: There is no conflict of interest.

There is no financing.

Corresponding Author
Rogério Martins Diniz
Pontifical Catholic University of Goiás – PUC Goiás
Rua 232, 128 – Setor Leste Universitário, Goiânia/GO, Brazil. CEP 74605-120
rogeriomartinsdiniz@gmail.com

Editor: Matias Nunes Frizzo. PhD
Editor-in-Chief: Adriane Cristina Bernat Kolankiewicz. PhD