Analysis of the maintenance process and useful life of echocardiography equipment: An experience in a teaching hospital

Análise do Processo de Manutenção e de Vida Útil dos Equipamentos Médicos Ecocardiográficos: a Experiência de um Hospital de Ensino

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Abstract

Introduction: Echocardiography is a diagnostic tool that is increasingly used in clinical practice in different medical scenarios; however, the preventive (PM) or corrective maintenance (CM) care and processes for this equipment are still poorly standardized. To describe the maintenance process currently implemented for echocardiographic equipment (ECHO) in a medium-sized laboratory in a tertiary-level public teaching hospital. The description of the process includes damage characterization and MP and MC implementation.

Methods: This was a descriptive and exploratory single-center observational study. Data on the maintenance process of echocardiographic equipment were obtained from electronic files from the hospital's equipment management system between 2003 and 2018.

Results: Together with the description of the equipment maintenance process, the ten most common types of malfunctions were identified, including software (23.8%), parts (23.1%), and power outage and accessory damage (13.8%). The implementation of the PM process significantly decreased the maintenance costs (USD 44,472.10 vs USD 25,807.59, $p = 0.029$). Even after the MP, the CM costs related to transesophageal echocardiography equipment (TEE) (USD 7,789.17) were higher than those with other equipment modalities (USD 3,184.37 for transthoracic echocardiography equipment (TTE) and USD 1,813.00 for stress testing).

Conclusion: The maintenance process for ECHO equipment was described. ECHO equipment damage has high costs, especially in special modalities such as TEE. PM significantly reduced maintenance costs.

Keywords: Cardiac function; Cardiovascular disease; COVID-19; Echocardiography; SARS-CoV-2

Resumo

Introdução: A ecocardiografia é uma ferramenta diagnóstica de crescente utilização na prática clínica, aplicada a diversos cenários médicos. Os cuidados e os processos de manutenção preventiva ou corretiva dos equipamentos são ainda pouco padronizados. O objetivo do presente estudo foi descrever o processo de manutenção atualmente aplicado a equipamentos ecocardiográficos em um laboratório. Descrever o processo inclui a caracterização de danos e aplicações de manutenção preventiva ou corretiva.

Métodos: Estudo observacional descritivo e exploratório realizado em centro único. As informações de dados do processo de manutenção de equipamentos ecocardiográficos foram obtidas de arquivos eletrônicos do sistema de gestão de equipamentos de um laboratório de médio porte de um hospital público de nível terciário com características de ensino, no período de 2003 a 2018.

Resultados: Foram identificados dez tipos de avarias mais comuns, como dano a programas (23,8%), peças (23,1%) e relacionadas à queda de energia e de acessórios (13,8%). Após a implementação do processo de manutenção preventiva, houve significativa redução dos custos de manutenções (US\$ 44.472,10 versus US\$ 25.807,59; $p = 0,029$). Mesmo após a manutenção preventiva, os custos de manutenção corretiva em equipamentos aplicados à ecocardiografia transesofágica (US\$ 7.789,17) foram maiores que aqueles a equipamentos aplicados a outras modalidades (US\$ 3.184,37 em ecocardiografia transtorácica e US\$ 1.813,00 em estresse).

Conclusão: O processo de manutenção de equipamentos ecocardiográficos foi descrito. Danos a equipamentos ecocardiográficos estão relacionados a altos custos, principalmente naqueles aplicados a modalidades especiais, como ecocardiografia transesofágica. As manutenções preventivas reduziram significativamente os custos de manutenção.

Descritores: Ecocardiografia; Manutenção de equipamento; Manutenção corretiva; Manutenção preventiva; Engenharia biomédica.

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Introduction

Echocardiography is an essential noninvasive diagnostic imaging method, which is widely used in several medical settings. Clinical applications of echocardiography include transthoracic, transesophageal, intraoperative, and intracardiac examination using several techniques, including two- and three-dimensional imaging, tissue Doppler, myocardial deformation analysis, and use of microbubble contrast agents. Echocardiography requires a complex set of skills, not only clinical but also related to image acquisition and use of technologies embedded in equipment and software¹.

The life cycle of these machines should be monitored by a Biomedical Engineering (BE) department of the health service²⁻⁴. BE actions include maintenance processes (administrative, preventive, and corrective)⁵⁻⁸, as well as managing costs related to the equipment^{9,10}. Healthcare costs include those related to medical equipment. Administrative systems to control equipment costs and their useful life are essential in health units, especially hospitals¹¹. The cost calculation in hospitals is a comprehensive task, which should consider the diversity of the services provided¹², and requires cost system delimitation and an efficient information system. Greater complexity is found in university hospitals¹³, as they are also responsible for training health professionals. Product life cycle costing^{14,15} allows managers to anticipate the costs of a product throughout each phase of its life cycle, especially in the planning phase. Decision-making improves in hospitals when based on the product life cycle concept.

In the current study, we describe the maintenance process currently implemented for echocardiographic equipment (ECHO) in a medium-sized laboratory in a tertiary-level public teaching hospital. The impact of preventive maintenance (PM) implementation by BE in this health service was also evaluated.

Method

This was a descriptive, observational, exploratory study on ECHO equipment processes and maintenance costs in the periods before and after PM implementation.

Study site and sample

The study was conducted at the Echocardiography Laboratory of the Cardiology Center at HCFMRP-USP Campus, which is under maintenance care of the BE center from the same hospital. The sample included all ECHO equipment that was available at the Cardiology Costs Center and registered as HCFMRP-USP campus unit assets from 2003 to 2018. Equipment that, although in use during the study period, was excluded in the laboratory asset system was excluded because the lack of records in the BE center made it impossible to track its maintenance activities.

Ethical aspects

As this study involves medical equipment and administrative processes and non-human subjects, it was exempt from submission to the Research Ethics Committee of the institution, according to resolution 466/12 (Appendix 1).

Data collection process

The maintenance processes used in the laboratory, as well as the tools, applied costing system, and equipment life cycle were retrospectively analyzed from 2003 to 2018. The data were collected by consulting the operations files of the hospital's equipment management system database through OS documents. Information related to (1) equipment, (2) maintenance processes, and (3) costing systems were analyzed, and the variables are described in Table 1.

The study variables were breakdown time (time of equipment use, even with some restriction); breakdown time for accessories (time in which the equipment was out of use due to lack of accessories); application by equipment (if the equipment was used for transthoracic tests [TTE], transesophageal tests [TEE], or stress testing); preventive service orders (SO) (internal maintenance service by the BE center); corrective SO (maintenance performed by the manufacturer); and incorporation costs (equipment acquisition costs, converted into dollars)

Cost analyses considered the US dollar (USD) as base currency (converted according to the average exchange value for the year). The analyses were performed at two different times, pre- and post-implementation of PM for each piece of equipment.

Statistical analysis

Continuous variables are expressed as the mean and standard deviation or median and confidence interval, and categorical variables are expressed as count and percentage. Comparisons between means or medians between groups were performed using the paired t-test for normal distributions or non-parametric tests. Correlation analyses between continuous variables were performed using the Pearson correlation test using GraphPad Prism software (v 8.4.3). Significance was considered when $p < 0.005$.

Results

Ten pieces of equipment (study group) available in the equipment park of the hospital's Echocardiography Laboratory were analyzed from 2003 to 2018 (15 years). Two pieces of equipment were excluded from the analysis due to lack of asset

Table 1 - Description of the variables used to measure the equipment characteristics, maintenance processes, and costing systems.

Equipment	SO	Costs
List of equipment	Total SO	Incorporation cost
Portability	Total corrective SO	Corrective SO costs
Date of acquisition/incorporation	Total preventive SO	Preventive SO costs
Time of use (years)		Costs by type of failure or application
Breakdown time (months)		
Downtime for accessories (months)		
Type of failure		
Equipment application		

SO: Service order, BEC: Biomedical engineering center.

records (equipment acquired with research funds). During the study period, the Echocardiography Laboratory had 90% of its routine in TTE, 5.5% in stress tests, and 4.5% in TEE. All pieces of equipment were used for TTE, three of them were also used for TEE, and one was also used for stress testing (Figure 1).

The equipment was identified by the name and model by replacing these characteristics with a simple sequential numbering from 1 to 8. The equipment characteristic variables are described in Table 2.

As for the number of SO per equipment, eight pieces had a higher prevalence of internal OS, with an average of 10.35 per device compared to external SO (average of 4.12 per device).

Characteristics, such as time of equipment, showed wide variation (2–16 years), with an average of 7.5 years, while three pieces of equipment were used for more than 10 years. Table 3 presents the equipment characteristics by the time of use until the moment of analysis, downtime, damage costs, and incorporation value.

The most frequent malfunctions and their respective costs were software (23.8%, USD 6,356.06), part (23.1%, USD 94,003.95), power outage (USD 557.66), accessory (USD 4,233.24) (both 13.8%), and transducer damages (12.3%, USD 45,347.40) (Table 4 and Figure 2).

The description of cost percentages by the type of damage is shown in Figure 3. The CM costs were USD 44,472.10 before PM and USD 25,807.59 after PM, with a significant difference ($p = 0.029$). Similar patterns were observed with regard to equipment downtime, which was 128.31 months before and 32.23 months after PM ($p = 0.048$) (Figure 4).

There was a correlation between CM costs and the time of equipment use ($r = 0.84$, $p = 0.008$) (Figure 5).

Even after implementing PM, the CM costs were higher for the equipment used for TEE (USD 7,789.17) compared to the other modalities (USD 3,183.37 for TTE and USD 1,813.00 for stress testing) (Figure 6). The analysis of the types of damage specifically to transducers (both transthoracic and transesophageal) showed that the most frequent damage was caused by cable fracture (two events), unknown cause (five events), membrane damage (two events), damage to color flow mapping function (one event), and damage to angulation buttons (one event).

Discussion

The maintenance and life cycle description process of ECHO equipment involve incorporation, damage detection, and cost assessment. This process was characterized in the Echocardiography Laboratory of a tertiary teaching hospital. ECHO equipment damage is significant, not only to transducers and internal parts, but also to accessories and operating software. CM-related cost can be minimized by implementing PM in the maintenance process.

Medical equipment breakdown is a serious problem for healthcare institutions. In addition to economic losses, equipment downtime for repair leads to healthcare loss for a significant number of patients, negatively impacting their health whether due to delayed diagnosis or therapeutic actions¹⁰.

Public institutions have additional aggravating factors, such as impact on outpatient testing schedules, which are often already long. Additionally, equipment repair procedures can be bureaucratic and involve problems related to the scarcity of budgetary resources. Additionally, the characteristics of maintenance companies mean that often parts or software are not replaced immediately, since these products may be imported.

This study identified and categorized malfunctions related to echocardiographic equipment. In current systems, not only are malfunctions in parts and transducers or accessories important, but also those related to software malfunction.

Table 2 - Ultrasound equipment characteristics.

Equipment	Year of incorporation	Application	Portability
1	2017	TTE + TEE	Yes
2	2017	TTE + TEE	No
3	2008	TTE	No
4	2007	TTE	No
5	2012	TTE + STRESS	No
6	2014	TTE + TEE	No
7	2014	TTE	No
8	2003	TTE	Yes

TTE: Transthoracic echocardiography, TEE: Transesophageal echocardiography.

Figure 1 – Number of devices per application.

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Table 3 - Downtime and costs.

Equipment	Time		Maintenance until December 2018 (USD)	Costs	
	Use (years)	Downtime (months)		Preventive maintenance (USD)	Incorporation value (USD)
1	2	0	0.00	0.00	28618.75
2	2	5	40.53	0.00	79010.63
3	11	47.4	22389.46	318.91	36629.38
4	12	11.5	10722.75	417.16	43636.74
5	7	50.7	16026.89	210.00	91050.85
6	5	16.6	10479.70	132.39	43638.99
7	5	9.2	484.25	359.34	40528.81
8	16	20.6	37738.90	0.00	60483.97

Table 4 - Costs by type of damage (units in USD).

Equipment	Outage	Software	Parts	Transducer	Parts cleaning	Software reconfiguration	Accessories
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	9.78	1352.58	14301.69	48.91	304.60	70.28	1008.75
4	148.35	2663.61	5252.75	17.37	6.25	21.65	682.33
5	0	56.79	31033.53	19855.39	25.80	60.14	1083.66
6	318.30	0	134.18	10849.73	0	11.14	32.25
7	81.23	0	0	14564.87	0	0	494.60
8	0	2283.08	43281.10	11.13	4.49	0	931.65

Figure 2 – Most frequent types of malfunctions to echocardiography devices.

This type of software damage can be related to sudden power outages. In theory, equipment manufacturers do not usually provide a “back-up” of their operating software. Thus, the necessary actions to correct these damages may need to be external, that is, company calls. Recognizing this dynamic and its frequency, the hospital’s biomedical engineering center (BEC) recently opted for backing up some operating systems when possible. This may have reduced the need for external SO, and, consequently, decreased costs in an amount that this study cannot quantify.

Part cleaning malfunctions are related to insufficient cleaning of the equipment and the air filter used to cool its internal components which generates heat. The lack of cleaning can generate other larger and more complex

malfunctions with higher costs, such as software malfunction. The use and frequency of cleaning protocols are preventive actions for this type of damage.

Some of the malfunctions identified in this study were classified as malfunctions due to “misuse”, i.e., those that may have been caused by damage resulting from incorrect use of the equipment, identified by lack of training or lack of user knowledge. In a teaching hospital with several users with different experience levels, this type of malfunction can be significant. Actions such as thorough training and implementation of usage protocols can reduce this occurrence. In this study, much of the damage to transducers was either incorrectly identified or incorrectly recorded in the SO files. Some important types of damage recognized were

Figure 3 – Costs (as a percentage of the total) incurred for malfunctions.

Figure 4 – Costs incurred with CM before and after PM (A) and downtime before and after PM (B).

Figure 5 – Correlation between maintenance cost and device usage time.

cable fractures and membrane ruptures. The membrane is the structure that protects the piezoelectric crystals. This piezoelectric material is delicate, expensive, and not always repairable. Transducer maintenance is applicable in some cases of cable, connector, and membrane damage, never with the manufacturer, but with specific external companies, and their replacement always generates high costs.

Few previous studies have performed a similar analysis, but Souza et al.¹⁶ analyzed ten pieces of ultrasound equipment of different brands and models in different departments, and, in contrast to our findings, concluded that the highest proportion of failures was in the transducers. The authors concluded that this was a consequence of higher use in a specific department. However, only four types of damage were listed in the study

Figure 6 – Costs (gross amounts in USD) of corrective maintenance according to the application of echocardiography device per modality.

by Souza et al., including monitor defect, keyboard defect, transducer defect, and other defects, and they did not consider defects in operating systems, which, as described above, are important causes of equipment downtime.

The main limitation of ultrasound equipment, including echocardiography equipment, is the transducer. As they are manageable, transducers are subject to repetitive movements and, in some cases, to falls, and as a consequence, they are more frequently damaged than other components of echocardiography equipment.

This study also quantified equipment downtime, which is proportional to equipment aging, as well as downtime due to accessories. Accessory downtime specifically isolates how long the equipment waited for the purchase or repair of an accessory, such as electrocardiogram (ECG) cables or transducers, even if it was still in use. The equipment itself may have a longer downtime in case of other types of malfunctions.

This failure analysis must be interpreted based on the large volume of procedures performed, many of them with patients in bed, associated with the characteristic of tertiary-level hospital and training to which this laboratory is linked. Other studies, such as the one by Souza et al.¹⁶, have demonstrated a high breakdown incidence in departments with a high number of professionals.

Our data show that the PM costs are much lower than CM costs, as they are performed internally by the BEC itself. Still, when analyzing the total costs for the group of equipment analyzed, there is a significant difference before and after the implementation of the internal PM process. Therefore, low-cost actions, such as PM by the BEC, can immediately and significantly impact the maintenance costs of an Echocardiography Laboratory. CM was decreased after starting the preventive process. This understanding, although already applied to other areas of our institution, has not previously had its impact quantified as in this study.

According to Bonacim¹², who studied the useful life of radiology equipment, including ultrasound and others, the analysis of CM costs is fundamental for decision-making regarding the acquisition of new technologies. Hospital equipment CM costs generally range between 9% and 11% of the equipment acquisition cost, highlighting the importance of this analysis¹³.

An analysis of equipment maintenance costs can guide the administrator in making difficult decisions about equipment deaccessioning, especially in an unfavorable economic scenario. Deaccessioning decisions are of great importance for any organization, as they are usually irreversible, and an inappropriate decision can result in a large amount of money being spent unnecessarily¹⁴.

This study showed high CM costs related to repairing parts (the second largest cause of damage identified) in echocardiography equipment. This commonly occurs because the parts are not manufactured locally, and often require importation.

Although transducer damage was only the fifth most prevalent type, transducer damage repair costs rank second in terms of cost ratio. Since a large part of this damage to transducers was identified as cable fracture, the use of transducer cable protectors, commercially available devices that work as a rigid cover at the origin of the cables, can be used to prevent this type of damage.

This study also showed that equipment CM costs are reduced by almost 50% after the first PM. This demonstrates that PM is important to predict possible problems that the equipment may present in the future. PM should start with users' awareness and training in making the best use of the equipment, followed by cleaning and care, and ending with PM itself, which is the verification and testing of the equipment by the BEC.

Our data also showed a direct relationship between CM costs and time of equipment use. Despite this relationship, there is no definition of "expiration date" for an echocardiography device, although some manufacturing companies suggest 5–10 years.

Considering the type of use or examination modality, the maintenance costs for equipment used for TEE are significantly higher. This is related to transducer costs in this modality, which, as discussed above, are higher. Thus, Echocardiography Laboratories that have this modality should foresee this higher cost and consider probe redundancy so that the modality is not frequently unavailable. Such information is important in planning equipment purchase.

Knowing the CM costs of each piece of equipment allows the identification of whether a piece of equipment is declining

its useful life¹⁵ and supports the decision to replace them. According to Manso¹⁷, acquisition costs added to PM and CM costs provide elements in determining the end of the life cycle of the equipment.

This study presents some limitations. Although covering a wide period, this study had a retrospective observational design, based, therefore, on the collection of information filed in the SO, which may lead to incorrect information. Additionally, during the study period, some equipment analyzed was already at the end of its useful life; therefore, the equipment did not have the same lifetime. The data were collected from the years 2016–2019, with some changes in the BEC maintenance flowchart being added during this period, which may generate an analysis bias during the last years of this study.

Conclusion

The maintenance process of echocardiographic equipment in a general tertiary teaching hospital was described. ECHO

equipment damage is significant, not only to transducers and internal parts but also to accessories and operating software. The cost related to these damages can be reduced by implementing the PM process.

Authors' contribution

Research conception and design: Romano MMD; Data collection: Mazzoni GP; Data analysis and interpretation: Romano MMD, Mazzoni GP, Sapalo AT; Statistical analysis: Mazzoni GP, Sapalo AT; Manuscript writing: Mazzoni GP, Sapalo AT; Critical review of the manuscript for important intellectual content: Romano MMD; others (suggestions and admission to access the work order system): Maciel BC.

Conflict of interest

The authors have declared that they have no conflict of interest.

References

1. Pena JL, Vieira ML. In: Pena JL, Vieira ML, eds. *Ecocardiografia e imagem cardiovascular*. São Paulo: Thieme Revinter; 2020.
2. Antunes E, Vale M, Mordelet P, Graboys V. In: Antunes E, Vale M, Mordelet P, Graboys V, eds. *Gestão da tecnologia biomédica: tecnovigilância e engenharia clínica*. São Paulo: Diretório da Rede de Biblioteca Virtual em Saúde; 2002.
3. Calil SJ, Teixeira MS. In: Neto GV, Terra V, Cutait R, Machado LE, eds. *Gerenciamento de manutenção de equipamentos hospitalares*. 11ª ed. São Paulo: Fundação Peirópolis; 1998. p. 98-4501.
4. Cardoso FH, Negr B, Santos GF. In: Calil SJ, ed. *Equipamentos médico-hospitalares e o gerenciamento da manutenção*. Brasília: Ministério da Saúde, Secretaria de Gestão de Investimentos em Saúde; 2002.
5. Daimon M, Akaishi M, Asanuma T, Hashimoto S, Izumi C, Iwanaga S, et al.; Committee for Guideline Writing, the Japanese Society of Echocardiography. Guideline from Japanese Society of Echocardiography: 2018 focused update incorporated into Guidance for the Management and Maintenance of Echocardiography Equipment. *J Echocardiogr*. 2018;16(1):1-5. doi: <https://doi.org/10.1007/s12574-018-0370-z>
6. Vuille C, C AJ, Buser P, Jeanrenaud X, Lerch R, Seiler C, et al. Recommendations for quality maintenance in echocardiography. *Kardiovask Med*. 2009;12(01):22–3.
7. Fernández LI, Pozo Osinalde E, García BI, Ojeda PS, Rodríguez PL, Íñiguez RA. Criteria for the Management of Technological Assets in Cardiovascular Imaging. *Rev Española Cardiol*. 2018;71(8):643-55.
8. DeWeese JA, Blaisdell FW, Foster JH, Garrett HE, DeWolfe VG. Report of the Inter-Society Commission for Heart Disease Resources. Optimal resources for vascular surgery—a supplement. *Circulation*. 1976;53(5):A-39-50.
9. Branco Filho G. A organização, o planejamento e o controle da manutenção. Rio de Janeiro: Ciência Moderna; 2008.
10. Sullivan GP, Pugh R, Melendez AP, Hunt WD. Operations & maintenance. Best practices. A guide to achieving operational efficiency. USA: Pacific Northwest National Laboratory for the Federal Energy Management Program, U.S. Department of Energy; 2010 [cited 2021 Dec 1]. Available from: https://www.energy.gov/sites/prod/files/2013/10/f3/omguide_complete.pdf
11. Nascimento LN, Calil SJ. Allocation of medical equipment costs to medical procedures. *IFMBE Proc*. 2008;22:1730-3.
12. Bonacim CA, Araújo AM. Gestão de custos aplicada a hospitais universitários públicos: a experiência do Hospital das Clínicas da Faculdade de Medicina de Ribeirão Preto da USP. *Rev Adm Publica*. 2010;44(4):903-31.
13. Silva BN, Alcantara CC, Balochi SV, Abbas K. Gestão de custos em hospitais : análise dos artigos publicados em periódicos e congressos nacionais da área contábil. In: XXIV Congresso Brasileiro de Custos, 15 a 17 de novembro de 2017; Florianópolis, (SC): Florianópolis; 2017. p. 45-89.
14. Ellram LM, Siferd SP. Total cost of ownership: a key concept in strategic cost management decisions. *J Bus Logist*. 1998;19(1):55-84. Available from: <http://content.epnet.com/ContentServer.asp?T=P&P=AN&K=1403161&EbscoContent=dGJyMMv17ESep7Q4y9fwOLCmrGep65Srqi4Sa6WxWXS&ContentCustomer=dGJyMPGrsUizqbZMuePfgeyx+Eu3q64A&D=buh>
15. Santos FA. Proposta de sistema para obtenção de indicador de apoio no processo de decisão de substituição de tecnologia médico-hospitalar. Florianópolis. Dissertação [Engenharia Elétrica] – Universidade Federal de Santa Catarina; 2009 [citado 2021 Dez 1]. Disponível em: <https://repositorio.ufsc.br/xmlui/handle/123456789/92463>
16. Souza AM, Simão EM, Salazar RF, Rodrigues Júnior LF. Estudo da manutenção de equipamentos de ultrassom em um hospital escola Do Rio Grande Do Sul. *Discip Sci*. 2017;18(2):79-88.
17. Manso J. Práticas de gestão de equipamentos médicos no Hospital da Luz. Lisboa. Dissertação [Engenharia Biomédica e Biofísica] – Faculdade de Ciências, Universidade de Lisboa; 2012 [citado 2021 Dez 1]. Disponível em: <http://repositorio.ul.pt/handle/10451/7827>