DOI: https://doi.org/10.11144/Javeriana.umed64-2.cost

Cost and Performance Indicators Comparison of two Dual-Head Contrast Medium Injectors during Contrast Enhanced Computed Tomography

Comparación de costos e indicadores de desempeño de dos inyectores de medios de contraste de doble cabezal en tomografías computarizadas con contraste

Received: 03 august 2022 | Accepted: 24 may 2023

Daniel Upegui
Head of Diagnostic Imaging and Nuclear Medicine Department, Fundación Centro de Tratamiento e Investigación en Cáncer, Bogotá – Colombia. Abdominal imaging radiologist, Hospital Universitario Mayor (Méderi), Bogotá, Colombia
ORCID: https://orcid.org/0000-0002-5474-0982
Juan Carlos Aldana Leal
MD. Radiologist, neuro radiologist, Shaio Clinic Foundation and Palermo Clinic. Director of the Radiology and Diagnostic Imaging Program, Universidad de La Sabana, Colombia
ORCID: https://orcid.org//0000-0003-4047-9709
Emily Vargas[a]
Career professor, School of Medicine, Autonomous University of Yucatan, Merida, Yucatan, México
ORCID: https://orcid.org/0000-0002-4477-4572

ABSTRACT
The progress towards the adoption of complex technologies for medical diagnosis, requires analyzing their economic and technical advantages. Two dual-head injectors were compared regarding cost, time and volume of contrast medium used during computed tomography, in a prospective analysis of 103 procedures. Two observers recorded consumable goods and performance indicators during the use of (OptiVantage®) and (Medrad® Stellant) combined with the use of Medrad Stellant Multi-Patient Kit; the costs associated with routine use and recommended use in a third level care institution in Colombia were determined. Preparation time was 23.3 seconds more ($p < 0.000$) with OptiVantage® (52.2 seconds; 95%CI: 46.7-56.7) compared to the Medrad® Stellant injector group (28.9 seconds; 95%CI: 21.8-39.5). The volume of injected contrast medium was greater by 8.7 mL ($p < 0.005$) with OptiVantage® (68.4 mL; 95%CI: 63.4-73.3) versus the Medrad® Stellant injector (59.7 mL; 95%CI: 56.7-62.7). The total cost per use of Medrad® Stellant is 8% lower in the routine mode of use. The Medrad® Stellant CT Injection System combined with the use of the Medrad Stellant Multi-Patient Kit is more efficient, offers safety and a lower total cost per procedure performed.

Keywords
dual-syringe power injector; contrast medium; cost analysis; tomography scanners.

[a] Correspondence author: emilymariavr@gmail.com

Cómo citar: Upegui D, Aldana Leal JC, Vargas E. Cost and performance indicators comparison of two dual-head contrast medium injectors during contrast enhanced computed tomography. *Univ. Med. 2023;64*(2). https://doi.org/10.11144/Javeriana.umed64-2.cost

RESUMEN

La adopción de tecnologías complejas para el diagnóstico médico exige el análisis de sus ventajas económicas y técnicas. Se compararon dos inyectores de doble cabezal en términos de costos, tiempos y volumen de medio de contraste durante la tomografía computarizada, en un análisis prospectivo de 103 procedimientos. Dos observadores registraron consumibles e indicadores de desempeño durante el uso de OptiVantage® y Medrad® Stellant combinado con el uso de Medrad Stellant Multi-Patient Kit. Se determinaron los costos asociados al uso habitual y al uso recomendado en una institución de tercer nivel de atención en Colombia. Se evidenció un tiempo de preparación mayor de 23,3 segundos ($p < 0,000$) con OptiVantage® (52,2 segundos; IC95%: 46.7-56.7) respecto del grupo del inyector Medrad® Stellant (28.9 segundos; IC95%: 21,8-39,5). El volumen de medio de contraste inyectado fue mayor por 8,7 ml ($p < 0,005$) con OptiVantage® (68,4 ml; IC95%: 63,4-73,3) versus el inyector Medrad® Stellant (59,7 ml; IC95%: 56,7-62,7). El costo total por el uso de Medrad® Stellant es un 8% más bajo en la modalidad habitual de uso. El Medrad® Stellant CT Injection System combinado con el uso del Medrad Stellant Multi-Patient Kit es más eficiente, ofrece seguridad y un menor costo total por procedimiento realizado.

Palabras clave
inyector de doble jeringa; medio de contraste; análisis de costos; tomografía computarizada.

Introduction

The analyses of costs and performance indicators of health technologies (1) are necessary inputs for Health Technology Assessment (HTA), which provides elements to guide strategic decision-making related to the transfer of knowledge and technologies among members of the health system, including the acquisition of medical devices and other technologies (2,3). Within the institutional context, and according to the World Health Organization, HTA supports clinical management during the process of defining needs, alternatives and specifications of the equipment or technologies to be implemented or acquired, increasing their efficiency and benefits for the system, institution and patients (4). Computed tomography (CT) was first introduced 50 years ago and has since become an integral part in the diagnosis and follow-up of various medical conditions (5). As of 2019, Japan had the most CT scanners per million population (111.49), followed by Australia with 70.25 scanners per million people. In Latin America, Chile had the highest number of scanners per million inhabitants (24.21), followed by Mexico with 5.9 (6). The constant increase of patients undergoing computed tomography (CT) requires a methodical exercise by the institutions to assess the relevance of acquisition and use, as well as a rigorous adherence to the manufacturer's indications and institutional protocols, to ensure its proper implementation, optimizing cost management and thus increasing efficiency (7). In clinical practice, contrast-enhanced CT (CECT) represents, on average, 40% to 60% of the volume of CT procedures performed in a hospital with less than 200 beds (8,9). Therefore, the optimal management of processes and procedures associated with the use of consumable goods and equipment for CECT can positively and significantly influence the efficiency of operations, as well as patient safety (7).

Contrast medium (CM) pressure injectors are an electromechanical single or dual-syringe injection system, which control the administration of intravenous CM and saline through an interface (10). The system is operated through a panel from which the volume (mL) of the contrast medium, the flow rate (mL/s) and the injection pressure (psi) are managed. State-of-the-art equipment includes safety sensors to avoid extravasation of the CM and position sensors that prevent the production or passage of air bubbles, along with other benefits (10). Comparable features among the different contrast delivery systems with dual-head injectors are: the concentration and volume of the CM injected; the phases, speed and duration of the injection; whether they are single or dual-headed; the use or not of saline solution; the incorporation of heat maintainers, the time delay between the injection of contrast and the start of the scan; and adjustments for variations in the patient's cardiac output (11). Also, the consumable goods associated with their use. These variables are directly related to the operating costs of the CT procedure (12).

The dual-head injectors are designed to allow the injection of saline solution (SS) immediately

after the injection of the CM, pushing it into the patient's vascular system, avoiding anterograde movement of the CM and allowing the consolidation of an optimal bolus. This marginally increases the amount of contrast during image acquisition (10). Recent studies show that this SS injection avoids the occurrence of thoracic venous artifacts, and favors the residual contrast clearance from the vascular access (11).

The medical technology industry is an important part of the healthcare sector. It includes, most notably, medical devices that simplify the prevention, diagnosis and treatment of diseases and ailments (13). The introduction of these technological innovations, in a continuous work activity, must be followed by the adaptation and adoption of organizational and regulatory processes in order to: i) the hospitals and health care system to take full advantage of the opportunities offered, and ii) to guarantee the return on investment, with the rational, standardized and optimal use of them (7). The objective of this study was to compare two dual-syringe contrast medium injectors in the area of costs, time and volume of CM used in the CECT procedure. This analysis covers the routine institutional use and the use recommended by the manufacturer in its sanitary registry (14,15), of the consumables for the prefilled syringe kit, compared to an empty syringe kit.

Materials and methods

Study design

Prospective study to analyze performance indicators and the cost of diagnostic imaging examinations with contrast performed in the radiology area of a tertiary care hospital in Colombia. The objective was to compare the cost, time and volume of contrast medium in the use of resources between an empty syringe injector (Medrad® Stellant; Bayer HealthCare Pharmaceuticals, Berlin) and a prefilled syringe injector (OptiVantage®; Guerbet, Villepinte), for the injection of Ultravist and Optiray® contrast media, respectively.

Data collection

With prior authorization from the institution, every consecutive CECT procedure was recorded during four days; two (Wednesday and Thursday of week 1) using a dual-head system, one for pre-filled syringe of CM (Optiray®) and another one for empty syringe (200 mL) of Saline Solution (Product: OptiVantage® Dual Head CT Contrast Medium Delivery System, Brand: Optivantage™); and two days (Wednesday and Thursday of week 2) using a dual-head injector (one for CM [Ultravist]) and the other for SS of 200 mL each) (Product: Medrad Stellant CT Injection System Brand: Medrad®) and Medrad Stellant Multi-Patient Kit (Code: SDS MP1).

Two independent observers, with expertise in the area and without knowledge about the objective of the study, recorded for each procedure, in a Microsoft Excel matrix (Microsoft Corporation, Redmond, Washington), data related to the time spent by the user in the area and the preparation time of the injector, consumables used, user weight in kg, estimated glomerular filtration rate (eGFR), nephroprotection requirement, type of CT performed, volume of CM injected and volume of CM discarded. The technical, specialized and administrative personnel of the radiology area were informed of the study and were asked to perform the routine procedure during CT scanning. Through secondary searches and direct requests to the administrative unit of the institution, the purchase prices of consumables, contrast media, depreciation of CT equipment, invoiced value for general services of the area, value/hour of health and administrative personnel involved in the procedure were obtained.

Data processing and analysis

Data was processed and analyzed by a specialized professional hired independently

for the processing and analysis of the information, poor quality screenshots were removed, used Microsoft Excel (Microsoft Corporation, Redmond, Washington) and Stata/IC v. 16.1 (StataCorp, Lakeway, Texas). Differences between groups were verified with t-tests and χ^2 tests, with weight, GFR, patient nephroprotection requirement and type of CT scan used as variables T-tests were used to verify differences in the performance of the radiology area in contrast examinations, using as variables the injector preparation time (in seconds), the total time spent in the CT procedure room (in minutes), the time spent in the radiology suite (in minutes), the total volume of contrast medium injected (in mL), and the volume injected in relation to weight (in mL/kg). Confidence intervals around the mean value were estimated by nonparametric resampling with correction for bias. (16) In all cases, a p-value < 0.05 was considered statistically significant.

The average cost of each examination was estimated by micro-costing (1); the cost of consumables, CM and personnel involved was estimated with the product of the unit price and the quantity used, in units or time. The unit price of general services (i.e., security personnel, cleaning, electricity, telecommunication) was estimated by dividing the amount billed in a year by the total number of diagnostic tests performed in the radiology area, adjusting for the proportion of the total corresponding to contrast examinations (40%). This unit price was assigned equally to the procedures of both groups (Table 1).

Table 1.
Unit prices by cost category, and resource utilization schemes by injector

Category	Unit price*	Use					
		OptiVantage®, routine use		OptiVantage®, recommended use		Medrad® Stellant	
		Per patient	Per 12-hour day	Per patient	Per 12-hour day	Per patient	Per 12-hour day
Inputs							
Low pressure connector	3.26	-	1	-	-	1	-
Saline solution bag, 500 mL	0.001	According to use	-	According to use	-	According to use	-
Syringe, 10 mL	0.1	-	1	1	-	-	-
Syringe, 50 mL	0.53	1	-	1	-	1	-
Macro-drip equipment	0.43	-	1	-	1	-	-
Three-way stopcock	1.1	-	1	1	-	-	-
Anesthesia extension	0.32	1	1	-	-	-	-
Heparin lock	0.11	1	-	-	-	-	-
Y-extension	7.25	-	-	1	-	-	-
Multi-patient kit	15.08	-	1	1	-	-	-
Contrast medium			-	-	-	-	-
Pre-filled syringe, Optiray® (presentation in mL)							
50	15.95	One piece, according to use and presentation	-	One piece, according to use and presentation	-	-	One piece, according to use and presentation
75	22.33						
100	30.44						
125	36.24						
Bottle, Ultravist (presentation in mL)							
50	15.08	-	-	-	-	-	According to presentation
100	21.31						
200	46.97						
500	117.43						
Personnel							
Nursing assistant (per patient)	0.64	1	-	1	-	1	-
Radiologist (per patient)	10.63	1	-	1	-	1	-
Radiology technologist (per minute)	0.07	1	-	1	-	1	-
General services	1.06	1	-	1	-	1	-

*In 2020 US dollars (1 USD = 3448.89 Colombian pesos).

Three cost scenarios were estimated. The first, refers to the routine use of available resources with the Optivantage™ brand injector over a twelve-hour working day. In the second, the cost of using the OptiVantage® injector was estimated assuming the manufacturer's recommended resource consumption (14). The scenarios and consumables are described in Table 1. The third scenario refers to the cost for the use of resources with the Medrad® Stellant injector and Medrad Stellant Multi-Patient Kit (Code: SDS MP1) as requested by the manufacturer. The cost was estimated in 2020 U.S. dollars, at an exchange rate of 1 dollar for 3448,89 Colombian pesos (16). Cost differences were established using t-tests, and confidence intervals were established using nonparametric re-sampling with bias correction (17). Finally, the

total costs corresponding to the three scenarios were estimated by multiplying the average cost in each category by the number of diagnostic contrast examinations performed in one year (n = 10,811) at the study site.

Results

A total of 103 procedures were recorded, 47 using OptiVantage® prefilled syringes, and 56 with Medrad® Stellant empty syringe system and Multipatient Kit (SDS MP1). As reported in Table 2, the groups did not show statistically significant differences in weight, GFR, need for nephroprotection, and type of study performed. The average weight of each user was 66.5 kg (±11.09) in the prefilled syringe injector group and 63.7 kg (±11.51) in the empty syringe injector group. GFR was 80.9 (±14.62) and 79.8 kg (±20.91) in prefilled syringe and empty syringes, respectively. The most frequently examined area in both groups was the thoracic-abdominal area.

Table 2.
Characteristics of patients and studies performed in each group

Variable	OptiVantage® (n = 47)		Medrad® Stellant (n=56)		*p* value
	Mean value (o%)	SD	Mean value (o%)	SD	
Weight (kg)	66.5	11.09	63.7	11.51	0.22
Glomerular filtration rate (GFR)	80.9	14.62	79.8	20.91	0.75
Nephroprotection (%)					0.70
Yes	9		13		
No	91		87		
Type of study (%)					0.62
Abdomen	34		30		
Abdomen Angio	2		2		
Cerebral Angio	0		4		
Lower limb Angio	0		2		
Transcatheter Aortic Valve Implantation Angio	2		0		
Angio-TC Pulmonary arteries	4		5		
Face	0		2		
Cerebral	0		5		
Cerebral-Neck	0		2		
Neck	13		9		
Paranasal sinuses	2		0		
Thorax	15		16		
Thorax-abdomen	28		21		
Urotac	0		2		

SD:Standard deviation.

Statistically significant differences were observed in the injector preparation time and the volume of contrast medium injected (Table 3). In the first case, a difference of 23.2 seconds ($p < 0.000$) was estimated between the loading of both injectors. In the OptiVantage® injector group, the time to prepare the injector took 52.2 seconds on average (95%CI: 46.7-56.7), while in Medrad® Stellant it took 28.9 seconds (95%CI: 21.8-39.5). In terms of volume injected, a difference of 8.7 mL ($p < 0.005$) was estimated; in the pre-filled syringe injector group an average of 68.4 mL (95%CI: 63.4-73.3) per patient was injected, and in the empty syringe injector group an average of 59.7 mL (95%CI: 56.7-62.7) was injected. No differences were observed in the time spent in the tomography room (12.4 minutes in the prefilled syringe injector group vs. 12.2 in the empty syringe group), the time in the radiology area (35.3 minutes in the prefilled syringe injector group vs. 41.3 in the empty syringe group), the amount of contrast medium wasted (1.8 mL in the prefilled syringe injector group vs. 1.4 in the empty syringe injector group), nor in the volume of contrast medium injected in relation to weight (1.04 mL/kg in the prefilled syringe injector group vs. 0.96 mL/kg in the empty syringe group).

Table 3.
Comparison of the performance of both injectors

Indicator	OptiVantage® (n = 47)				Medrad® Stellant (n = 56)				Difference	*p* value
	Mean value	SD	95% CI*		Mean value	SD	95% CI*			
Injector preparation time (seconds)	52.2	17.4	46.7	56.7	28.9	33.3	21.8	39.5	23.2	<0.000
Time spent in the tomography cubicle (minutes)	12.4	6.5	10.8	14.5	12.2	6.2	10.7	13.96	0.2	0.85
Total time spent in the radiology area (minutes)	35.3	15.9	31	39.96	41.3	18.2	36.9	46.2	−6.0	0.08
Volume of contrast medium wasted (mL)	1.8	6.1	0.3	3.6	1.4	9.5	0	4.1	0.4	0.81
Volume injected of CM (mL)	68.4	17.3	63.4	73.3	59.7	11.9	56.7	62.7	8.7	<0.005
Volume injected of CM in relation to weight (mL/kg)	1.04	0.2	0.97	1.11	0.96	0.2	0.92	1.02	0.08	0.07

SD:Standard deviation.
*95% confidence interval.

The estimated average cost in both groups, and its 95% confidence interval, is presented in Figure 1. The graph is divided into two panels, where the first panel represents the comparison between routine resource use (observed with the data collected) with OptiVantage® and

Medrad® Stellant. The second one presents the hypothetical scenario in which resources were used according to the manufacturer's recommendations. Each graph contains five cost categories. The category identified as *Diagnostic Test* is the sum of the previous four. With routine resource use (panel A of the figure), significant differences were found in the cost of consumables (USD 1.48 in the OptiVantage® injector group vs USD 3.71 in the Medrad® Stellant group, $p < 0.05$) and contrast medium (USD 19.52 in the OptiVantage® injector group vs USD 13.94 in the Medrad® Stellant group, $p < 0.000$). The average cost of a diagnostic test showed a non-significant difference under this scenario ($35.85 in the OptiVantage® injector group vs. $32.93 in the Medrad® Stellant group).

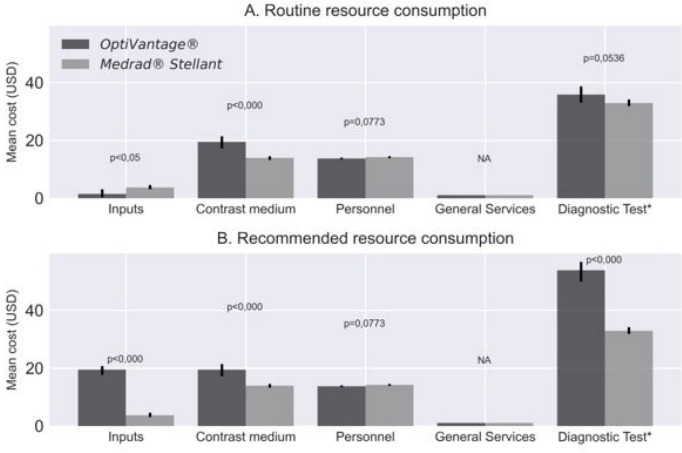

Figure 1.
Price comparison of routine and recommended resource consumption
* Diagnostic test accumulates the sum of Inputs, Contrast Medium, Personnel and General Services.

Under the hypothetical resource consumption scenario (panel B of Figure 1), the cost for consumables use increases considerably in the OptiVantage® injector group, from USD 1.48 to USD 19.5, thus increasing the cost differential with respect to the Medrad® Stellant injector from USD −2.2 to USD 15.8. The above situation raises the average cost of a diagnostic test from USD 35.85 to USD 53.88. This, in turn, implies a statistically significant difference between this group and the Medrad® Stellant injector group of USD 20.9 ($p < 0.000$).

The total estimated cost for the three scenarios is presented in Table 4. The total cost of diagnostic tests considering the routine use of resources on the OptiVantage® injector (scenario A) was estimated at USD 387,581; the total cost of its recommended use (scenario B) was estimated at USD 582,489; and the total cost with the use of Medrad® Stellant (scenario C) was estimated at USD 365,027. The difference in total cost can increase from 8% (Difference C-A) to 39% (Difference C-B), modulated by the continuous use of consumables during a 12-hour working day, when the manufacturer recommends a single use per patient.

Table 4.
Estimated total cost for both technologies, in two OptiVantage injector usage scenarios*

Category	A. OptiVantage, routine use	B. OptiVantage, recommended use	C. Medrad Stellant	Difference (C-A)	Percentage (%)	Difference (C-B)	Percentage (%)
Inputs	15.95	210.86	40.11	24.16	151	−17.08	−81
Contrast medium	211.01	211.01	150.69	−60.32	−29	−60,32	−29
Personnel	149.11	149.11	153.72	4.61	3	4.61	3
General services	11.51	11.51	11.51	---	0	---	0
Total	387.58	582.49	356.03	---	−8	---	−39

* In 2020 US dollars (1 USD = 3448.89 Colombian pesos).
Note: The time period for the total estimated costs is per year.

Discussion

The results of this study conflicts with what is described in the literature, where the habitual reuse of medical equipment and devices is justified, despite the fact that current legal regulations and national and international control agencies restrict it, arguing several factors, including: economic (the most representative) (18), followed by the low availability of consumables or the perception of healthcare personnel when they see them in good condition and do not consider that it compromises the integrity of the patient (19).

According to the results, the Medrad® Stellant CT Injection System, combined with

the use of the Medrad Stellant Multi-Patient Kit (Code: SDS MP1) is more efficient in the process of loading the CM and preparing the CT injector for operation; it offers greater patient safety by favoring the injection of a smaller amount of total CM, and a lower cost per test. This was done while maintaining the parameters of use recommended by the manufacturer in the sanitary registries in Colombia (14,15) of both injectors under study.

According to the operation times, although the reduction in loading and preparation time of the injector did not statistically influence the total time the user spent in the tomography room, it is worth noting that this reduction in time can be translated in a greater satisfaction of the radiology technologist while working, together with the optimization of the use of CM. Thus, the innovation of the loading and CM administration approach (cascade) favors the organization of the workflow in the hospital, while offering a better quality of the service provided and a higher level of safety; a hypothesis that should be confirmed in subsequent studies.

The optimal use of CM is essential in the CT scanning process because, in addition to reducing costs, it avoids risks for the patient Saving 8.7 mL of CM per exam, which would represent an average monthly saving of 11,484 mL in a CT service of a third level care institution, and about 10811 contrast procedures annually is substantial. It is worth noting that, although the amount of CM injected per user in relation to body weight did not show a statistically significant difference between the two devices analyzed, it is important to highlight that it is recommended to follow the dosage indications of the manufacturer or the country's regulatory institution, which establish that the dose varies depending on the type of examination, age, weight, cardiac output and general health status of the patient and the technique used (20). Limiting the dose per patient, without affecting the quality of the diagnostic image, prevents the occurrence of adverse events derived from CM, classified as mild, moderate or severe with a prevalence not higher than 3%, 0.02% and 0.04%, respectively (21,22).

The limitations of this study are: first, it is not possible to generalize the routine use scenario of the OptiVantage® injector and its consumables, as it depends on each institution and in some instances on each radiology technologist (RT). Second, the CM injection protocols and injection rates used in each subspecialty practice vary according to the institution. Third, being an advantageous sample, the number of procedures analyzed may not be representative to determine the long-term performance of the technologies under study. Finally, the protocol recommended by the manufacturers of both the injector and the consumables varies depending on the accessories, code, model, or reference of the consumables acquired by the institution.

Conclusion

The Medrad® Stellant CT Injection System combined with the use of the Medrad Stellant Multi-Patient Kit (Code: SDS MP1) is more efficient in the process of loading the CM and preparing the CT Injector for operation; it offers a lower total cost per procedure performed.

Disclosure

This study was funded by Bayer SA Colombia. The authors are independent consultants, who maintained independence in the design of the study, including data analysis and interpretation of the final results.

Sources of funding

This study was funded by Bayer SA Colombia [OC No. 750097321].

Conflict of interest

Juan Carlos Aldana Leal and Daniel Upegui are guest speakers for Bayer S.A. on topics related to Radiology. Emily Vargas was CEO and founder of Evidence Knowledge in Public Health during the study development.

Acknowledgments

The authors would like to thank the consulting team of Evidence Knowledge Brokering in Public Health SAS for the technical and administrative coordination of this study, and for their support in the methodological development and data analysis.

References

1. Drummond MF, Sculpher MJ, Claxton K, Stoddart GL, Torrance GW. Methods for the economic evaluation of health care programmes. 4th ed. Oxford: Oxford University Press; 2015.

2. Rettig RA, Harman AJ. The development of medical technology: a policy perspective. Santa Mónica (CA): RAND Corporation; 1979.

3. Barrientos Gómez JG, Marín Castro AE, Becerra Ruiz L, Tobón Arango MA. La evaluación de nuevas tecnologías en salud en hospitales: revisión narrativa. Med UPB. 2016;35(2):120-34. https://doi.org/10.18566/medupb.v35n2.a0

4. Word Health Organization. Evaluación de tecnologías sanitarias aplicada a los dispositivos médicos [Internet]. Geneva: WHO; 2012. Available from: https://apps.who.int/iris/handle/10665/44824

5. Conall GJ. Computed tomography in clinical practice. BMJ. 2002 May 4;324(7345):1077-80. https://doi.org/10.1136/bmj.324.7345.1077

6. Stewart C. Computer tomography scanner density by country 2019 [Internet]. Statista; 2020. Available from: https://www.statista.com/statistics/266539/distribution-of-equipment-for-computer-tomography/

7. Colombo GL, Bergamo AI, Matteo SD, Bruno GM, Mondellini C. Syringeless power injector versus dual-syringe power injector: economic evaluation of user performance, the impact on contrast enhanced computed tomography (CECT) workflow exams, and hospital costs. Med Devices. 2013;6:169–74. https://doi.org/10.2147/MDER.S51757

8. Boland GW. Enhancing CT productivity: strategies for increasing capacity. AJR Am J Roentgenol. 2008;191(3):3–10. https://doi.org/10.2214/AJR.07.3208?mobileUi=0

9. Ma X, Singh A, Fay J, Boland G, Sahani DV. Comparison of dual syringe and syringeless power injectors in outpatient MDCT practice: impact on the operator's performance, CT workflow, and operation costs. J Am Coll Radiol. 2012;8(9):578–82. https://doi.org/10.1016/j.jacr.2012.04.007

10. Indrajit IK, Sivasankar R, D'Souza J, Pant R, Negi RS, Sahu S, Hashim PI. Pressure injectors for radiologists: a review and what is new. Indian J Radiol Imaging. 2015;25(1):2–10. https://doi.org/10.4103/0971-3026.150105

11. Bae, KT. Technical aspects of contrast delivery in advanced CT. Appl Radiol. 2003;32(1):12–19. https://doi.org/10.1007/88-470-0413-6_2

12. Centro Nacional de Excelencia Tecnológica en Salud. Guía para la evaluación económica de dispositivos médicos [Internet]. Ciudad de México; 2017. Available from: https://www.gob.mx/cms/uploads/attachment/file/460006/Guia_para_la_Evaluacion_Economica_de_Dispositivos_Medicos.pdf

13. Mikulic M. Medical technology industry-Statistics & Facts [Internet]. Statista. Available from: https://www.statista.com/topics/1702/medical-technology-industry/#topicOverview

14. Instituto Nacional de Vigilancia de Medicamentos y Alimentos (Invima). Resolución 2017019365/2017 de 16 de mayo, por la cual se concede la renovación de un registro sanitario [Internet]. Available from: https://es.scribd.com/document/409447055/Resolution-2017019365-Injectors-Renewal#

15. DiCiccio TJ, Bradley E. Bootstrap confidence intervals. Stat Sci [Internet]. 1996;11(3):189–212. Available from: https://www.jstor.org/stable/2246110

16. Instituto Nacional de Medicamentos y Alimentos (Invima). Resolución 2019028297/2019 de 10 de julio, de registro sanitario.

17. Banco de la República de Colombia. Tasa representativa del mercado (TRM-peso por dólar) [Internet]. Available from: https://www.banrep.gov.co/es/estadisticas/trm

18. García D. El reúso de dispositivos médicos en las instituciones de salud en Colombia. El Hospital [Internet]. 2015 dic 9. Available from: https://www.elhospital.com/es/noticias/el-reuso-de-dispositivos-medicos-en-las-instituciones-de-salud-en-colombia

19. Organización Panamericana de la Salud, Colegio Nacional de Químicos Farmacéuticos de Colombia. Descripción de uso y reusó de dispositivos médicos en instituciones de atención en salud de alto nivel de complejidad en Colombia. Bogotá: Pan American Health Organization; 2004.

20. Sanitarios, Agencia Española de Medicamentos y Productos. Ficha técnica-Optiray Ultraject 320 mg/ml solución inyectable. España; 2017.

21. Sartori P, Rizzo F, Taborda N, Anaya V, Caraballo A, Saleme C, et al.. Medios de contraste en imágenes. Rev Argent Radiol. 2013;77(1):49–62. https://doi.org/10.7811/rarv77n1a08

22. Brown JR, Robb JF, Block CA, Schoolwerth AC, Kaplan AV, O'Connor GT, et al. Does safe dosing of iodinated contrast prevent contrast-induced acute kidney injury? Circ Cardiovasc Interv. 2010 Aug 1;3(4):346–50.