Cost and Benefit Analysis of Surgeon-performed Point-of-Care Ultrasound (SP-POCUS) supporting decision making in a General Surgery Department

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Background: There still is reluctance among surgeons when it comes to using bedside US in their daily clinical practice, except for very specific fields. Generally, the decision-making process relies on imaging techniques (e.g. CT, MRI). This may lead to a latency of execution, and consequently to a delay in decision making.
Objectives: The purpose of this study is to assess the economic impact of systematic and routine use of surgeon-performed point-of-care US (SP-POCUS) in the everyday activities of a surgical department, both for urgent and elective cases.
Methods: We conducted a cost-benefit analysis comparing the incremental costs and savings of diagnostic strategies based on alternative procedures to bedside US. The dataset refers to 478 SP-POCUS performed at the General Surgery Department of Policlinico San Pietro (Bergamo, Italy) between January 2018 and February 2020. The alternatives to SP-POCUS were computed tomography (CT), X-ray (RX), magnetic resonance imaging (MRI), and US performed by the Radiologist. Per-exam costs, including personnel time expenditure, were calculated.
Results: The economic evaluation revealed that the use of SP-POCUS allowed the hospital to generate €355 net savings per patient, mainly from avoided hospitalizations, fewer hospital days and hours of operating room. Extrapolating these results to a wider scenario, in a similar setting they could have represented a potential annual

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S O M M A R I O

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savings of more than €1.1 million for the Regional healthcare system in Lombardy, and more than €5.7 millions for the whole NHS in Italy.
Conclusions: We provided evidence that SP-POCUS may generate important costs savings for health care providers, as it represents the most cost-effective initial diagnostic procedure compared to standard alternatives. The wide applicability of SP-POCUS could be obtained at rather negligible costs for investment in staff training.

Keywords: SP-POCUS, bedside US, routinely use, surgeon, cost-benefit analysis, costs, benefits, hospital stay, hospitalization, surgery.

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1. Introduction

The use of bedside ultrasound (US) has been increasing in the past decades with many applications in urgent and intensive care (1). Indeed, since 1970s it has become ever-more portable and more affordable, leading to the diffusion of point-of-care ultrasound (POCUS) in medicine (2) (3). Ultrasound is a diagnostic procedure with several benefits: harmless, appreciated by patients, affordable, technologically feasible in all situations, legally enforceable by any doctor, not invasive, portable, safe, and provider of real-time acquisitions to diagnose in a variety of pathological contexts (2) (4) (5), (6), (7), (8). Therefore, POCUS has proven to be a reliable and affirmed diagnostic procedure in many clinical fields (9) (10) (11). Despite this, the literature shows that there is still reluctance among surgeons when it comes to using POCUS in their daily clinical practice, with the exception of very specific fields, as the intraoperative US (12) (13).
The vast majority of surgeons generally rely on traditional radiological reports and on the use of heavy imaging techniques (i.e. CT, MRI) for their decision making. Often, this leads to a latency of execution, and consequently to a delay in decision making (14). Notwithstanding, it can be argued that US has all the necessary characteristics as a potential tool to stem health spending in a time of growing medical demand.
Our study relates to the previous literature on the use of bedside US in specific medical specialities, such as obstetrics, gynaecology and cardiology (15) (16). In most of these cases surgeon-performed POCUS (SP-POCUS) is not always the standard, but the first medical diagnostic technology (17) (18) (19) (20). This literature is lacking in demonstrating the substantial economic benefits that ultrasound can provide, merely analysing its accuracy.
The purpose of this study is to assess the economic impact of systematic and routine use of SP-POCUS in the everyday activities of a surgical department, both in urgent and elective settings.

2. Materials & Methods

2.1. Study design and setting

We conducted a cost and outcome and a cost-benefit analysis comparing the use of SP-POCUS with standard alternatives applied to patients reaching the General Surgery Department of Policlinico San Pietro (Bergamo, Italy) between January 2018 and February 2020. The dataset refers to 577

SP-POCUS performed in the ward and in emergency department and collected in a prospective registry, 478 out of which were considered to carry out the economic evaluation. The remaining 99 patients were not included because SP-POCUS was not an alternative option for an initial or a secondary diagnosis, but simply used to monitor specific ongoing treatments, therefore not comparable with an alternative exam.

The registry was established with the aim to objectively assess the number and the reasons for performing POCUS in a standard General Surgery unit, the impact of the result of POCUS on the type and timing of the clinical decision (observation, treatment, further imaging otherwise not pursued, etc.), and the comprehensive economic impact of SP-POCUS. Other clinical data were included in the record of any enrolled patient, in order to allow some clinical comparisons, which are out of the scope of this analysis.

We supplemented this information with additional data, regarding the economic cost of SP-POCUS and of the different alternative procedures. Thereafter, we run a cost-benefit analysis (CBA) that compares SP-POCUS with each of the four alternatives (CT, X-ray, MRI and US in Radiology), assessing their costs and their related benefits in monetary terms.

2.2. Study population

The study applied to 212 (44.4%) male and 266 (55.6%) females with a mean age of 65.4 years (range 6-93 years). Among the 478 patients enrolled for the study, 363 patients (76%) underwent SP-POCUS as a primary diagnostic tool (treatment group), while the remaining 115 (24%) had a different diagnostic procedure (control group), followed by SP-POCUS as a check. The two groups were quite well balanced in terms of demographic and clinical characteristics. Average age was 62 and 58 years, while male proportion was 58% and 48%, respectively for the treatment and the control group. The null hypothesis of equal age and gender distribution in the two groups (t-test) could not be rejected at less than 4% significance level. Initial clinical suspicion (see Section "Results" for details on clinical categories) for the 5 most frequent categories (with more than 50 observations each) represented similar percentages in the two groups, precisely 50% and 57%, respectively for the treatment and the control group.

2.3. Data source and acquisition

The dataset was recorded and supervised by the surgical team of Policlinico San Pietro, using a prospective structured registry to collect demographic and clinical information of patients. This includes birth date, age, sex, date of exam execution, if SP-POCUS was the first exam or a check, clinical suspicion, diagnosis, decision-making after the exam, what happened/would have happened with/without SP-POCUS, and resource savings. Patient did consent to the use of data. The dataset was then supplemented with cost data from other sources to perform the economic evaluation (see details in the "Costs" section).

2.4. Execution of SP-POCUS

Each patient received SP-POCUS or another diagnostic procedure based on the type of symptoms, patient charac-

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teristics, and severity. Any clinical suspicion was detected using SP-POCUS and/or the best alternative procedure, in terms of information potentially provided according to the view of the radiologist and the surgeon.

2.5. Diagnostic alternatives

The alternatives to SP-POCUS were Computed Tomography (CT), X-ray (RX), Magnetic Resonance Imaging (MRI) and US performed by the radiologist. A preliminary investigation by the specialist identified the most appropriate diagnostic procedure as an alternative to SP-POCUS. Therefore, we defined four sub-samples of patients (Table 1), where the largest group (45.4%) had CT as alternative to SP-POCUS. Only 1.3% of patients received MRI.

The outcome of each procedure was analysed in terms of level of satisfaction to support decision-making. Precisely, we considered whether a procedure provided sufficient information to address the following step of patient's treatment, or the exam was unclear and, therefore, a second diagnostic imaging was needed. Consequently, each diagnostic procedure had two possible outcomes:

1) Effective, if the diagnosis was satisfactory and no further exam was required;
2) Not effective, if the diagnosis was unclear and further investigation was required.

2.6. Statistical analysis and cost-benefit analysis tool

We conducted a cost and outcome and a cost-benefit analysis from the perspective of the Italian National Health Service (INHS) aiming at the efficient use of resources in the healthcare sector. In the cost and outcome analysis, we calculated the costs of diagnosis using different initial diagnostic procedures and the outcomes in terms of effective diagnosis. In the cost-benefit analysis, we measured benefits in terms of incremental savings (avoided hospital days, hours of operating room, and hospital admissions) for patient's treatment when moving from alternative procedures to SP-POCUS. Then, we combined incremental diagnostic costs and savings from treatment to obtain incremental net benefits per patient. For the analysis, we used the statistical software STATA (version 16). A cost-effectiveness analysis was not considered since, in this case, a comprehensive effectiveness measure to evaluate the effects of bedside US (SP-POCUS) was difficult to identify. Several aspects of effectiveness could be considered, but their aggregation would then be challenging. The effectiveness of different

Table 1 – Diagnostic procedures compared to SP-POCUS for decision model

Comparison of diagnostic procedures	Frequency (Percentage)
SP-POCUS vs. CT	217 (45.4%)
SP-POCUS vs. X-ray	146 (30.5%)
SP-POCUS vs. MRI	6 (1.3%)
SP-POCUS vs. US in Radiology	109 (22.8%)

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diagnostic procedures lays mainly on diagnosis precision and speed, which generates savings in terms of hospital days, hours of operating room, and further admissions. Our cost-benefit analysis allows to consider all relevant aspects of effectiveness at the same time since we convert them into monetary units.

2.7. Costs

The costs considered in the analysis are the direct costs of healthcare resources necessary to perform diagnoses using different procedures. These costs include the fixed cost of capital (machines) and the variable cost of labour (healthcare staff performing and reading the exams and moving the patient). Indirect costs, such as travel cost from patient's home to the hospital and working time loss, are neglected since all patients are already in the hospital and the use of different alternative procedures does not affect them.

Therefore, the cost of each procedure includes the unit cost of capital, i.e. the sum of the opportunity cost and depreciation of medical equipment over an 8-year period and the variable unit cost of labour to carry out the procedure (the value of time spent by the healthcare staff). Since we are interested in the incremental amount of resources used when moving from one procedure to the alternative, we neglect costs that are common to all alternatives, such as the cost of administrative staff.

For the computation of variable unit cost, we applied the time-driven activity-based costing (TDABC) method. TDABC is a method that allows to calculate actual resources consumed to perform a task, based on a detailed decomposition into all simple activities involved in the task. For each activity, the consumption of resources is measured in terms of time. The specific cost of one unit of time for each activity is then multiplied by the time spent in each activity and aggregated over activities to calculate the cost of a procedure. Since the main variable cost to perform a diagnostic procedure consists of time allocated by different personnel, the TDABC method allows to measure costs with a good degree of precision (21) (22).

To do this, we first map all the activities involved in each diagnostic procedure. Table 2 reports all the steps and the personnel involved in each diagnostic exam. For SP-POCUS, the decision-making process combines images production and reporting, because the surgeon can elaborate a decision while acquiring the images (23). These two steps are instead separated for all the exams performed in a Radiology department. It is worth nothing that, the CT exam is performed by both radiologist and radiology technician, while X-ray and MRI only by the radiology technician, and the US by the radiologist.

We then assessed the time needed to complete each activity (Table 3). This was measured by the Authors on a sample of 15 observations for each exam. The reported mean time excluded few outliers, i.e. the transportation of very sick patients who required more time for each step. Since time may vary depending on the hospital logistics, we performed 15 observations for each exam in three different hospitals of different size in the Lombardy region: Policlinico San Pietro (Ponte S. Pietro), Papa Giovanni XXIII Hospital (Berga-

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Table 2 – Human resources assigned to each activity for SP-POCUS (left-hand side) and for other exams (right-hand side)

SP-POCUS	Involved health personnel	Diagnostic exam in Radiology	Involved health personnel
US catch up and setting	Surgeon	Patient preparation	Nurse
Exam performance	Surgeon	Transfer to Radiology	Operator sanitary partner (OSS)
Bring back US	Surgeon	Exam performance	Rad. technician/Radiologist
Image reporting (decision-making)	Surgeon	Transfer to the ward	OSS
		Patient accommodation to bed	Nurse
		Diagnostics image reporting	Radiologist
		Reading report (decision making)	Surgeon

mo), and A. Manzoni Hospital (Lecco). Although patients undertaking medical procedures were all from the same hospital, the General Surgery Department of Policlinico San Pietro, measuring the time of activity completion in different hospital settings may allow improve precision and, therefore, the external validity of our study.

Note that all different activities, except transportation, are very similar across hospitals in terms of time consumption since they are standardised. Transportation activities (transfer to Radiology unit and transfer to the ward) vary by 2-3 minutes, depending on the average distance of the Radiology suite from the surgical wards, the time for availability of an elevator and other minor aspects. The average latency in reading a report depends on many factors, such as the burden of work in the Radiology department or in the General Surgery. This affects to some extent all the exams performed in the Radiology department and may delay the decision-making, ranging from min-

Table 3 – Average time for each activity and type of exam

Activities	Average time (in minutes)				
	SP-POCUS	CT	X-ray	MRI	US in Radiology
Patient preparation	–	2	2	2	2
Transfer to radiology	–	6.67	5.33	6.67	5.33
US catch up and setting	1	–	–	–	–
Exam performance	5	10	3	25	5
Bring back US	1	–	–	–	–
Transfer to the ward	–	8.67	7.33	8.67	7.67
Patient accommodation to bed	–	1	1	1	1
Diagnostics image reporting	–	4	2	4	1
Average latency before reading report	–	15	30	15	30
Reading report (decision making)	1	3	2	3	2

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utes to a full day. This latency is not present in SP-POCUS.
In order to objectively assess the personnel costs, we relied on data on salaries provided by one the health authority of Lombardy region (ATS MB – Azienda Tutela della Salute Monza/Brianza). We were able to calculate the cost per minute for each healthcare personnel (surgeon, radiologist, radiologist technician, nurse and healthcare assistant) involved in the processes. The unit cost for each procedure was obtained by multiplying the cost per minute of each healthcare professional by the average time required for each activity. Finally, we assessed the unit cost of capital of each diagnostic procedure. We calculated the unit cost of each procedure drawing data from two medium-large scale hospitals in Lombardy Region (Italy): A. Manzoni Hospital in Lecco and Maggiore Hospital in Cremona.

3. Results

The key premise for an appropriate use of SP-POCUS is the initial clinical suspicion following the collection of a series of signs and symptoms that suggest any possible disease. The distribution of clinical suspicions for the study sample is reported in Table 4.

3.1. Analysis of outcomes

We performed some preliminary analyses on the distribution of outcomes and decision-making after SP-POCUS. The exam was useful to address the following step of patient treatment mainly for symptoms of pleural effusion (15%), abdominal pain (12%) and pneumothorax (12%). In some cases (10%) the exam allowed to rule out a clinically relevant problem like abdominal pain. The decision afterwards was "conservative" in 38% of cases, meaning that the patient did not receive any additional treatment (Fig. 1). Drainage was adopted in 20% of cases, and surgery in 15% of cases. In many cases the role of US was decisive to shorten the time to patient surgery or to rule out a surgery. Indeed, in the case of no surgery decision, SP-POCUS allowed to address the problem with a pharmacological therapy (conservative).
In Table 5 we report the distribution of outcomes for each pair of alternative procedures. If the outcome of SP-POCUS was Not effective, a second exam followed using the best alternative procedure. Conversely, when the initial exam was CT, RX, MRI or US in radiology, and the outcome was Not effective, the initial exam was repeated. Therefore, the two groups of patients received the same diagnostic procedure after the first exam in the case of Not effective outcome for decision making.
Findings revealed that SP-POCUS was superior in terms of effectiveness against most alternatives. For instance, SP-POCUS as initial exam was effective in 91.3% of cases as compared to 30% of cases for the X-ray exam. SP-POCUS turned out to be less effective only against MRI (41.6% vs. 87.5%).

3.2. Analysis of Costs

The cost of capital shows that some procedures (CT and MRI) are generally more expensive than SP-POCUS while others (X-ray and US in Radiology) are cheaper. Variable and capital costs per

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Table 4 – Clinical suspicion and frequency of exams

Clinical suspicion	SP-POCUS as primary procedure	Other initial procedures (SP-POCUS as check)	Total frequency	Percentage
Trauma	47	12	59	12.3
Postop. complications	46	6	52	10.9
Appendicitis	34	18	52	10.9
Cholecystitis	32	20	52	10.9
PTX	46	5	51	10.7
Other	36	9	45	9.4
Pleural effusion	34	10	44	9.2
Diverticulitis	12	20	32	6.7
Cholelithiasis	15	6	21	4.4
Pancreatitis	13	3	16	3.3
Abdominal pain	13	2	15	3.1
Check	12	-	12	2.5
Small bowel obstruction	10	-	10	2.1
Postop. bleeding	8	-	8	1.7
Hernia	3	-	3	0.6
Unknown acute abdomen	1	2	3	0.6
Dispnea	1	2	3	0.6
Total	363	115	478	100%

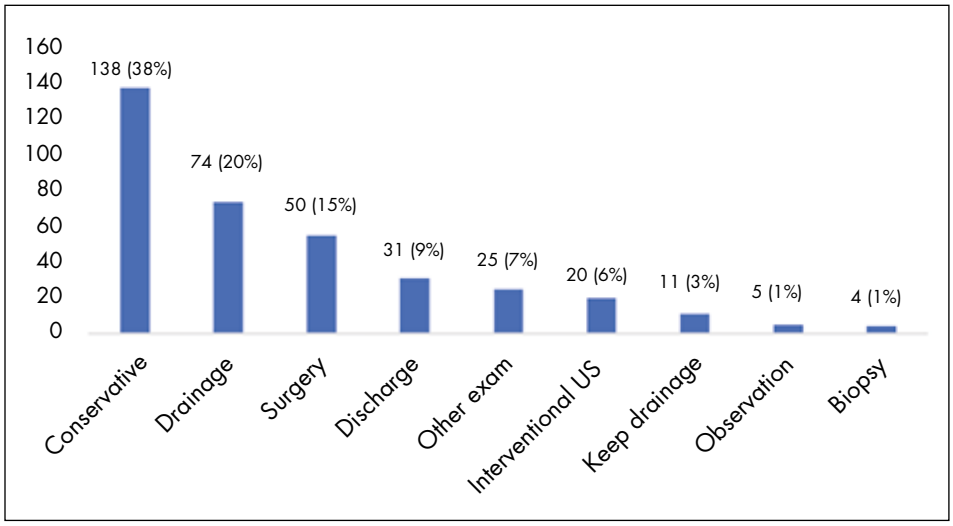

Fig. 1
Decision-making after US

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Table 5 – Effective/not effective cases for each diagnostic procedure as compared to bedside US

Comparison of diagnostic procedures	SP-POCUS as primary procedure		Alternative initial procedure	
	Effective	Not effective	Effective	Not effective
SP-POCUS vs. CT	92 (70.2%)	39 (29.8%)	38 (44.2%)	48 (55.8%)
SP-POCUS vs. X-ray	115 (91.3%)	11 (8.7%)	6 (30%)	14 (70%)
SP-POCUS vs. MRI	42 (41.6%)	59 (58.4%)	7 (87.5%)	1 (12.5%)
SP-POCUS vs. US in Radiology	2 (40%)	3 (60%)	–	1 (100%)
SP-POCUS vs. All alternatives	251 (69%)	112 (31%)	51 (44%)	64 (56%)

procedure are summarised in Table 6. We observe that SP-POCUS is the least costly procedure, mainly because of time required to perform the exam as compared to other procedures.

Total costs for each alternative in both groups and costs per patient are detailed in Table 7. In each group, the cost per patient adds up the cost of the initial procedure and the cost of the second exam conditional on the probability that the initial exam was not effective, using information provided in Table 5. Since SP-POCUS was always performed in the ward, while waiting for the standard exam initially planned, our cost per patient neglects the possibility that the need for a second exam could delay the diagnosis, involving additional costs due to late treatment. In the last column of Table 7, we report the incremental costs per patient of SP-POCUS as initial exam compared to each alternative. As expected, the incremental costs are always negative, which implies that moving to SP-POCUS is a cost-saving strategy.

Table 6 – Unit variable and capital costs of each diagnostic procedure

Procedure	Unit variable cost	Unit cost of capital	Total unit cost
SP-POCUS	6.13	8.00	14.13
CT	21.65	8.26	29.91
X-ray	8.51	4.92	13.43
MRI	19.23	43.69	63.92
US in Radiology	10.62	4.21	14.83

Table 7 – Cost per patient and total costs in treatment and control groups

Comparison of diagnostic procedures	Treatment group			Control group			Incremental costs of SP-POCUS per patient
	Patients	Total costs	Cost per patient	Patients	Total costs	Cost per patient	
SP-POCUS vs. CT	131	3018.24	23.04	86	4007.6	46.6	-23.56
SP-POCUS vs. X-ray	126	1925.28	15.28	20	381	19.05	-3.77
SP-POCUS vs. MRI	5	254.35	50.87	1	70.79	70.79	-19.92
SP-POCUS vs. US in Radiology	101	2325.02	23.02	8	237.28	29.66	-6.64

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3.3. Benefits

We considered the benefits of each diagnostic procedure in terms of incremental resource savings as compared to SP-POCUS. The main benefits are represented by savings in terms of days of hospital stay and hours of operating room (OR), since some effective SP-POCUS diagnoses have changed or anticipated the clinical decision. Other benefits, such as possible improvements of patient's satisfaction or quality of life (due to faster recovery), related to the precision and the speed of different diagnosis procedures, could have been of interest. However, these benefits were not monitored in the clinical study and are expected to have a marginal impact in this case.

In our study sample, surgery was avoided for 16 patients and the number of hospital days was reduced for 52 patients. The total number of avoided hospital days was 81. We considered an average cost per hospital day of €967 (24) (25). Therefore, the total cost savings due to shorter hospital stay in the sample study group were €78,327. The average cost for one hour of operating room was considered €1320 (26), and total hours of avoided operating room were 18.5. Hence, we registered additional cost savings for €24,420 for avoided use of operating room.

Finally, some patients in our treatment group avoided hospitalization for further treatment because of information provided by the SP-POCUS procedure. In particular, 10 hospitalizations were avoided in our sample. Using DRG tariffs for specific diagnosis, we calculated that SP-POCUS allowed to save €14,908 (€7,454 annually).[1] In Table 8 we report cost savings, in terms of avoided hospital days, hours of operating room and hospitalizations, generated by SP-POCUS against each alternative procedure. Notice that the greatest impact on avoided use of resources comes from patients who could perform a CT exam.

We furtherly combined the cost of each procedure and the benefits (cost savings) from avoided days of hospital stay, operating room hours and avoided hospitalizations obtained with SP-POCUS. In order to calculate the net benefits (benefit – cost) per patient of bedside US as compared to each alternative, we summed up the incremental benefits and costs arising from the adoption of bedside US ver-

[1] *The values of DRG used as reference is the tariff of services for hospitalizations related to the latest available version (2015) of the Lombardy region,* 2015 (41).

Table 8 – Savings from bedside US vs alternative procedures

SP-POCUS vs. alternative procedure	Avoided hospital days	Avoided hours of operating room	Avoided hospitalizations	Monetary savings per patient (€)
CT	44	9	4	447.85
X-ray	14	2.5	3	188.08
MRI	4	–	–	773.6
US in Radiology	19	7	3	311.09
All alternatives	81	18.5	10	341.41

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sus each alternative procedure reported in Table 7 and 8. Therefore, our economic evaluation shows that using SP-POCUS generated net benefit per patient of €471.41, €191.85, €793.52 and €317.73 respectively for CT, X-ray, MRI, and US in Radiology as alternative.

Since different diagnostic procedures are generally used in different proportions, within a hospital, depending on the initial suspicion for patients, we calculated the average net benefits, i.e. net benefits calculated by considering the frequency of different alternative diagnostic procedures. To do this, we weighted net benefits for each procedure by the frequency of use of each procedure (the size of groups in rows of Table 5). On average, net benefits were €355.02 per patient.

3.4. Projection analysis

In order to assess the impact of routine use of SP-POCUS for the regional (Lombardy) and national healthcare systems, we project the results obtained from our study focusing on the most frequent hospital cases avoided thanks to SP-POCUS: 7% of avoided hospitalizations for appendicitis (DRG 167) and 4% of avoided hospitalizations for abdominal pain/diverticulitis (DRG 183). Considering the average number of hospital admissions with these two DRGs on regional and national basis in 2016 and 2017 (27) (28), we calculated that total annual savings amount to €1,161,055 and €5,773,979, respectively for the Regional and the National Health Service (see Table 9).

3.5. Sensitivity results

To investigate the strength of our results, we conducted a deterministic sensitivity analysis on variables affecting costs and benefits. Considering costs, we varied salaries of health personnel and the time needed for each activity involved in the process of exam execution. Using the upper bound values of resources needed to perform SP-POCUS and lower bound values for the related alternatives, SP-POCUS as initial option remains the least costly strategy. Precisely, we varied salaries between ±15%, and time needed for each activity between ±35%.

Finally, we reduced the level of effectiveness of SP-POCUS by 20%, which affects the incremental cost of tests as well as savings for lower hospitalizations. Total net benefits against all alternatives are still positive but drop to €248.03 per patient, i.e. by 27.4%. To reduce net benefits to zero the level of effectiveness of bedside US should drop by almost 90%.

4. Discussion

Our findings suggest that important savings my arise from the routine use of

Table 9 – Hospitalizations and projected annual savings for DRGs 183 and 167

Setting	Avoided hospitalizations (yearly average)		Projected annual savings (€)		
	DRG 183	DRG 167	DRG 183	DRG 167	Total
Lombardy	9,553x0.04=382.12	4,208x0.07=294.56	409,632.6	751,422.6	1,161,055.2
Italy	53,621x0.04=2,148.8	20,722x0.07=1450.5	2,060,699.2	3,713,280	5,773,979.2

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SP-POCUS. We showed that SP-POCUS reduces unnecessary hospital stays and surgery, which have a high impact on healthcare expenditure.

Many studies in the literature report that bedside US is a reducing cost procedure in several cases (29) (30) (31) (32) (33). Additionally, different studies prove the economic impact of prolonged length of stays, unnecessary surgery, and hospitalizations (34) (35) (36), and how their reduction can improve quality of care and decrease costs (37) (38) (39).

Further potential savings of SP-POCUS not considered in the main analysis are worth of discussion. In our sample, 124 patients received SP-POCUS as a control only after another exam, and other few patients received SP-POCUS thanks to the trained surgeon's availability after hospitalization based on an alternative exam (mainly CT or X-ray). In all these cases, SP-POCUS would have avoided hospital days if it had been performed as initial exam. Adding patients with a diagnosis confirmed by SP-POCUS after a previous procedure, effective US cases (in Table 5) would have increased by 15.2% and 8.9%, respectively against CT and X-ray. As a result, additional 50 hospital days and 11 hospitalizations could have been avoided in the SP-POCUS group vs CT. This would have provided an increase in net benefits of about 18.2% (up to €85.85) as compared to our baseline (first row of Table 8).

Our results may have important policy implications regarding the possible introduction of SP-POCUS as a preliminary diagnostic procedure in everyday surgical practice everywhere. The estimated net benefits per patient of SP-POCUS against all standard alternatives (between €192 and €794, depending on the procedure, and calculated on the basis of Lombardy Regional health system costs) suggest that the adoption of SP-POCUS may allow health care systems to save money. One possible intervention could be to subsidize hospitals for the purchasing of US machines, where not yet available, linking this action to a structured staff training. There are still some effective educational proposals, specifically addressed to SP-POCUS (5), that could progressively help in getting the goal, with very limited investments.

Routine clinical practice is rich of clinical situations where the systematic use of POCUS, based on literature evidence, could shorten processing time and avoid less useful exams. For instance, SP-POCUS facing a suspected bowel obstruction in emergency department could avoid a plain abdominal X-Ray, currently performed routinely almost everywhere. Also, SP-POCUS for the follow-up of patients admitted with rib fracture could reduce the number of chest X-Rays in the follow-up period. The prevalence of these two pathologies would generate relevant economic benefits.

Providing incentives to hospitals with a clear plan for implementing POCUS would also be advised. The adoption of SP-POCUS as an initial diagnostic procedure could also be promoted through the inclusion of a specific regional tariff to perform SP-POCUS upon patient admission and before other standard procedures.

5. Conclusions

We provided evidence on the economic impact of routine use of SP-PO-

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CUS in surgery, in terms of possible cost savings and better outcomes, due to detailed and accurate information to formulate precise diagnoses and take rapid decisions. Our evidence relies on observational data from patients using bedside US or alternative procedures during a two-year period in a mid-size hospital setting. From a cost and outcome perspective, we showed that the routine use of SP-POCUS as initial exam was superior to standard alternatives since it is less expensive (incremental costs per patient moving from SP-POCUS to any other alternative were always negative) and generally more effective (69% of effective diagnoses as compared to 44% with alternative procedures), with the exception of MRI (41.6% vs. 87.5%). From a cost and benefit perspective, we showed that SP-POCUS provides important benefits in terms of avoided days of hospital stay, operating room hours and hospitalizations, leading to positive net benefit per patient against all standard alternatives (€471, €192, €794 and €318, respectively against CT, X-ray, MRI, and US in Radiology).

The main limitation of this study is represented by the relatively small sample and the fact that SP-POCUS was provided by a minority of the surgical team, due to a lack of specific education. Also, because of our sample heterogeneity in clinical aspects, we could not reliably measure the sensitivity and the specificity of SP-POCUS in emergency and elective settings. Notwithstanding, POCUS is based on a binary thinking process, according to a simple step by step path: 1. clinical suspicion; 2. POCUS; 3. yes/no answer to the clinical suspicion by US. The very short time of execution of POCUS, as a true direct extension of clinical exam, cannot entail per se a delay in further diagnostic steps or decision. For those reasons, individual sensitivity and specificity rates do not affect the clinical outcome of the patient. From the cost and benefit perspective, a low sensitivity might only reduce the number of patients taking advantage of POCUS, and therefore decrease the overall economic advantage.

Further to the latter considerations, the insight of our study entails a need to increase the educational efforts in the field of POCUS education, which could further strongly enhance the clinical and economic advantages.

Even though all patients reaching the hospital in the study period and potentially suitable for the use of SP-POCUS were assessed, our design cannot fully address concerns arising from the possible selection of patients with specific US diagnosis. Still, we provided sufficient evidence that SP-POCUS allows the surgeon to make rapid decisions and to formulate precise diagnoses at relatively low cost. This procedure is therefore helpful in saving resources and improving the efficiency of healthcare providers. The major limit to the wide applicability of SP-POCUS remains the need for initial staff training, even though the investment required is rather negligible.

6. Declaration

Ethical approval and consent to participate:

This study did not perform any experiment on humans. Observational patient data were collected anonymously in accordance with relevant guidelines and regulations, in daily activities by the medical and the administrative staff at the general

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hospital Policlinico San Pietro, Bergamo, Italy. Informed consent was obtained from all patients included in the study. The study protocol was approved by the ethical committee of the general hospital Policlinico San Pietro, Bergamo, Italy, and the research method was carried out in accordance with relevant guidelines and regulations.

Consent for publication:
Not applicable.

Availability of data and materials:
The datasets generated and analyzed during the current study are not publicly available because part of them refers to patient level data collected at the general hospital Policlinico San Pietro in Bergamo, Italy. However, data are available from the corresponding author on reasonable request.

Competing interest:
None of the authors have competing interests of any type with the research purpose and the analysis performed in this project.

Funding:
No funding supported this research.

Authors' contribution:
MZ conceived the study and established the database; MZ, AM, SB, GC, and AB collected data and performed SP-POCUS; GM, GP, AM, and MZ analysed data; GM and GP made economical and statistical analysis; GP, AM, GM, and MZ wrote the manuscript; GM and MZ reviewed the manuscript.

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