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Characterization of add-on testing before and after automation at a core laboratory

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ABSTRACT

Objectives: Add-on testing refers to the process that occurs in clinical laboratories when clinicians request that additional tests be performed on a previously analysed specimen. This is a common but inefficient procedure, highly time-consuming, especially at core laboratories and could be optimised by automating these procedures. The aims of this study are: 1) To describe patterns of add-on testing at a core laboratory at a tertiary hospital, 2) To evaluate turnaround time (TAT) before and after automation of the pre-, post- and analytical phases.

Methods: Retrospective, observational study conducted at the biochemistry area of a core laboratory of all add-on orders received in two different months (pre-automation and post-automation).

Results: A total of 2464 add-on orders were analysed, representing around 5 % of total requests. Most orders were for either one (>50 %) or two (≈20 %) tests. Most orders were received during the week (from Monday to Friday), particularly during the morning shift (>50 %). More than 50 % of requests were made by the Emergency Department. The two most common add-on parameters were C-reactive protein and N-terminal pro-brain natriuretic peptide. After automation, the median TAT decreased by 42.3 % (from 52 to 22 min). The largest decreases in TAT were observed for routine samples (58.89 %) and fully automated analyses (56.86 %).

Conclusions: Automation of our core laboratory substantially reduced turnaround time for add-on testing, indicating an increase in efficiency. Automation eliminated several manual steps in the process, leading to a mean reduction of 15 work hours per day (more than 2 full-time equivalents).

Abbreviations: CK, Creatine kinase; CRP, C-reactive protein; ED, Emergency department; HIS, Hospital information System; ICU, Intensive care unit; IQR, interquartile range; GGT, Gamma-glutamyl transferase; LIS, Laboratory information system; NT-proBNP, N-terminal pro-brain natriuretic peptide; STAT, Short turnaround time; TAT, Turnaround time.

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1. Introduction

Add-on testing is the process that takes place in clinical laboratories when clinicians request that additional tests be performed on previously analysed specimens [1]. Clinicians routinely order add-on tests, generally in response to the results of the original tests or to changes in the patient's clinical status. However, in some cases, requests for add-on tests may be due to poor adherence to best practice guidelines or simply to an inadvertent omission in the original order [2].

The operational impact of add-on testing on clinical laboratories was already described twenty years ago [3]. Although add-on testing accounts for less than 1 % of tests performed in clinical laboratories, these tests consume a disproportionate amount of time, with some studies suggesting that the extra time requires up to two full-time laboratory technicians per day to manage these tests. Add-on orders are time-consuming, in part due to the multiple steps involved. Despite the extra time involved in performing add-on tests, this process does have certain advantages, mainly that it reduces the need for additional blood extractions and thus minimizes patient exposure to the risks associated with phlebotomy (e.g., infection, nerve injury, or iatrogenic anaemia), thereby enhancing patient safety [4]. In fact, studies have shown that a single blood draw provides more than 45 times the amount of blood needed for testing purposes [5]. Nonetheless, it is clear that laboratory efficiency could be increased by reducing the number of add-on orders and/or by improving the process.

A core laboratory is a type of structure within a healthcare organization in which expensive technological resources and personnel are centralized and can be shared by various sub-specialties (i.e., biochemistry, haematology, etc), thus offering greater efficiency [6]. In recent decades, in an effort to increase productivity and reduce costs [7], a growing number of laboratories in our region have begun to automate these processes. Several studies have shown that laboratory automation improves sample management, including add-on testing [8]. In this regard, turnaround time (TAT) is a key indicator, and the evaluation of this parameter can help improve efficiency, quality assurance, and safety [9]. The core laboratory model is characterized by short TATs for both urgent and routine samples [6]. Although automation of core laboratories has been shown to reduce TAT in general [10],[11]. to our knowledge, the specific influence of automation on add-on testing has not been examined to date.

The laboratory at our 600-bed tertiary care hospital performs more than 4.5 million tests annually, with the core laboratory accounting for 90 % of this activity. More than 75 % of these tests are performed in the biochemistry area, which receives about 1000 orders per day (70 % routine samples; 30 % STAT samples); of these, approximately 5 % are add-on orders. The pattern of add-on orders has not been previously investigated at our centre. The biochemistry area at our laboratory was recently automated with new pre- and post-analytical systems connected by a tracking system to various different analytical modules.

In this context, the aim of the present study was to characterize the add-on testing process in the biochemistry area of our core laboratory and to evaluate the add-on testing TAT before and after automation of the pre-, post- and analytical phases.

2. Materials and methods

This was a retrospective, observational study conducted at the Hospital de la Santa Creu i Sant Pau (Barcelona, Spain). We evaluated all add-on orders sent to our laboratory during the one-month period before (November 2021) and after (November 2022) automation. Routine tests are performed in serum separator tubes meanwhile STAT tests are analysed in plasma anticoagulated with lithium-heparin.

Pre-automation, the laboratory equipment consisted of three biochemistry and immunoassay integrated systems (Alinity ci; Abbott Laboratories, Chicago, USA), two immunoassay analysers (Cobas e601; Roche Diagnostics GmbH, Mannheim, Germany), an osmometer (Osmo1; Tecil S.A., Barcelona, Spain), and a nephelometric analyser (Image 800; Beckman Coulter, Brea, USA). In order to guarantee the stability of the analytes, after completion of the analysis, an aliquot of plasma (STAT samples) and the serum separator tube (routine samples) were manually sorted and stored frozen for 2 days or refrigerated for 7 days, respectively.

In May 2022, new preanalytics and postanalytics systems connected by a track (GLP system; Abbott Laboratories, Chicago, USA) were installed in the analytical area. The new fully-connected equipment consisted of the following: two input areas for samples; a tube decapper; two aliquoters; two output areas for samples or aliquots; three Alinity ci systems; a capper; a buffer module for temporary sample storage; and a refrigerated storage module (6 °C) with a 10000-tube capacity, where the samples are stored for either 4 (STAT plasma aliquot) or 8 days (routine serum separator tube). Two new immunoassay analysers (Cobas e801; Roche Diagnostics GmbH, Mannheim, Germany) and the Osmo1 osmometer were not connected to the GLP system. All of the nephelometric techniques were switched to turbidimetric analysis, and the nephelometer (Immage 800) was discarded.

The core laboratory is active 24 h a day, 7 days a week. The work schedule is divided into three shifts (mornings: 7:15 a.m. to 2:15 p.m.; afternoons: 2:15 to 9:15 p.m.; and nights: 9:15 p.m. to 7:15 a.m.). Clinicians can request an add-on test by telephone (for STAT samples) or by e-mail (routine samples). In both cases, the clinician's identification code and the add-on parameter(s) are registered and entered into the laboratory information system (LIS). Prior to automation, the laboratory technicians had to manually add the new tests in the LIS, locate the sample in the refrigerator (where they were stored for 7 days), and then transport it to the appropriate analyser. Post-automation, the new add-on testing procedures were as follows: the add-on test request is entered into the LIS, which automatically generates an order in the new middleware (AMS, Abbott Laboratories, Chicago, USA) to locate and transport the sample automatically to the analyser (when the test is performed in Alinity ci) or to generate an aliquot if the analyser is not connected to the automated area (Cobas e801 and Osmo1). Based on the in vitro stability of the analytes [12], the middleware applies rules and has the capacity to block the performance of tests when analyte refrigerated stability time has been exceeded. In this cases, frozen aliquot is used. Aliquots have to be transferred manually by laboratory technicians to the non-connected analysers. Once the analysis has been performed, the final steps in the process are the same as those used prior to automation. The test result is sent automatically to the LIS

and incorporated into the patient's medical record in the hospital information system (HIS). For routine samples, a frozen aliquot was kept for one month. Fig. 1 shows the add-on testing process at our institution before and after automation.

Add-on testing data were obtained from the LIS (Openlab; Nexus IT, Madrid, Spain). For this study, only add-on orders that included blood tests performed at the biochemistry area of the core laboratory were included. All of the add-on orders that met these criteria were individually reviewed and included in a purpose-built database.

The following data were collected: parameter(s) requested; date and time of request; time elapse between sample receipt at the laboratory to receipt of the add-on request; setting of the request; type of sample; and analysers used to perform the add-on tests. In addition, the clinicians who made most requests – data obtained from the LIS - for add-on tests in 2021 were surveyed to assess the most

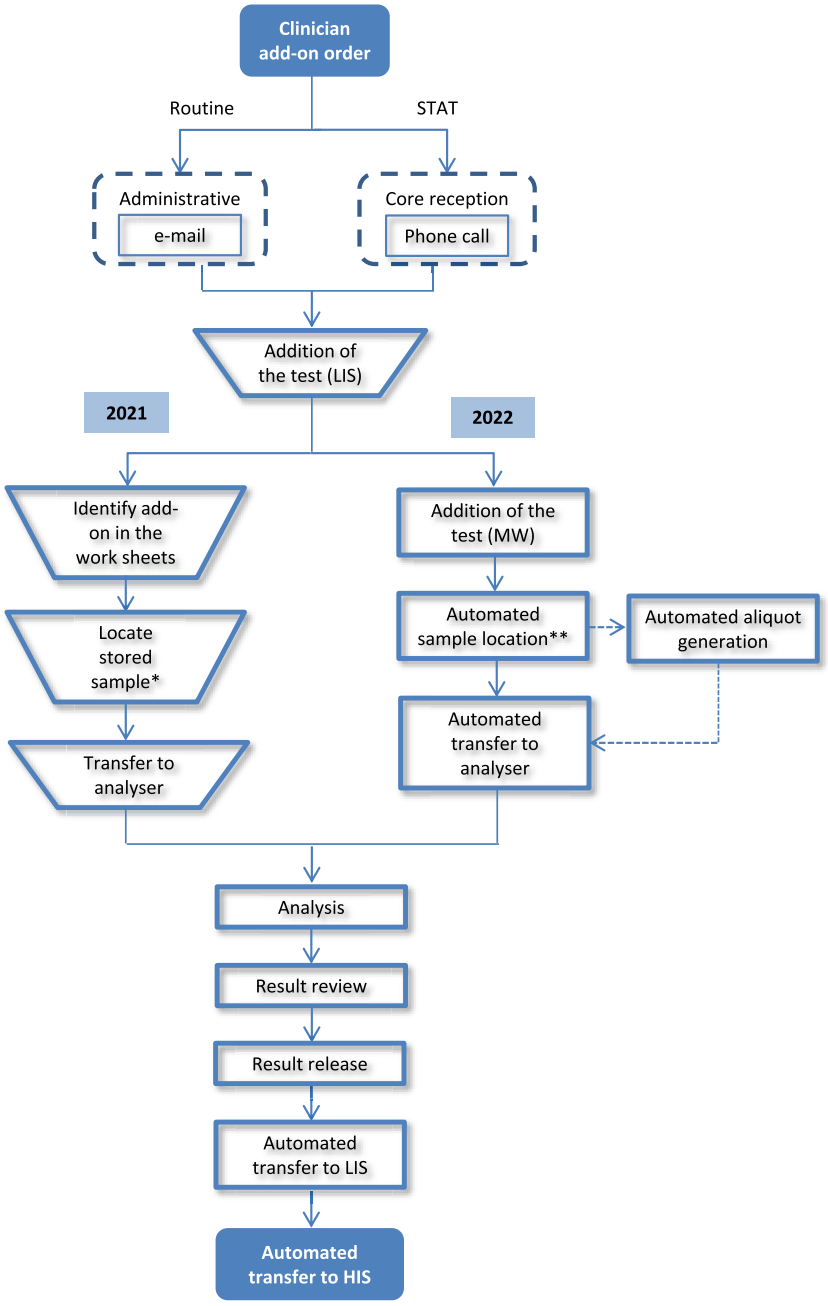

Fig. 1. Add-on testing procedure before and after automation.
Abbreviations: HIS: Hospital Information System; LIS: Laboratory Information System; MW: Middleware; STAT: short turnaround time.
*Sample refrigerator/freezer. Routine samples: 7 days; STAT aliquots: 2 days.
** Refrigerated storage module. Routine samples: 8 days; STAT aliquots: 4 days

common reasons for the add-on orders.

The TAT for add-on tests was calculated as the time elapsed between order entry in the LIS and the time that the test results were available in the HIS. The TAT was assessed based on all add-on tests and sorted by day of the week, setting, type of order, work shift, and analyser. If the add-on order was requested by telephone, the add-on request was immediately entered into the LIS. For requests made by e-mail, we did not include the time between order receipt and initial processing by the administrative staff. The pre- and post-automation TAT values were compared with the Mann Whitney *U* test. The IBM-SPSS Statistics for Windows, v. 24.0 (IBM Corp. Armonk, NY, USA) was used to perform the statistical analyses.

3. Results

3.1. Characterization of add-on testing

During the two-month observation, 2464 add-on orders were revised. In the pre-automation phase (November 2021), a total of 25949 samples were analysed. Of these, 1345 (5.18 %) included add-on tests (804 STAT, 541 routine). A total of 2904 tests were added to existing orders, accounting for 0.83 % of the total number of tests performed. In the post-automation phase (November 2022), a total of 2494 tests (0.63 % of total tests) were added to 1119 existing orders, accounting for 4.23 % of total orders (796 STAT, 323 routine). In most cases, the add-on request involved only one test (56.06 % in 2021 and 55.05 % in 2022) or two tests (20.59 % and 17.78 %). Most of the add-on orders were performed only in Alinity ci (68.55 % and 62.20 %), Cobas (around 19 % in both periods) or in both combined (10.71 % and 14.39 %). The other instrumentation account for less than 5 % of the add-on orders. All the results of the characterization of add-on testing before and after automation can be observed in detail in Table 1 and Figs. 2 and 3.

In 2021, the median time (interquartile range [IQR]) between receipt of the original sample and receipt of the add-on test order was 401 min (310–1512) for routine samples and 119 min (56–265) for STAT samples. Most of the add-on requests (74.9 % for routine samples and 95.7 % for STAT) were made within 24 h from receipt of the original sample. Only 5.6 % (routine) and 1.4 % (STAT) of add-on orders were received after the samples had already been removed from storage and discarded. In 2022, the median (IQR) time between receipt of the original sample and the add-on order was 428 min (340–591) routine orders and 127 min (60–283) for STAT samples. Most add-on orders (79.9 % and 96.7 % for routine and STAT samples, respectively) were registered within 24 h from the time that the original sample was received by the laboratory. Only 5.4 % of routine add-on orders were received when the sample was no longer available in the new refrigerated storage module.

In 2021, the most common add-on tests were C-reactive protein (CRP) (8.44 %) followed by N-terminal pro-brain natriuretic peptide (NT-proBNP) (6.78 %), gamma-glutamyl transferase (GGT) (6.13 %), magnesium (5.41 %), creatine kinase (CK) (5.37 %), and alkaline phosphatase (5.27 %). Data for 2022 were similar, with these same biomarkers being the most common add-on tests (data not shown). Table 2 shows detailed information about the most frequent add-on tests pre-automation.

Table 1
Add-on testing patterns before and after automation of the biochemistry area of the core laboratory.

	Pre-automation		Post-automation	
Total laboratory orders, n	25949		26445	
Add-on orders, n (%)	1345	(5.18)	1119	(4.23)
Total tests, n	348872		396652	
Add-on tests, n (%)	2904	(0.83)	2494	(0.63)
Add-on tests per request, n (%)				
n = 1	754	(56.06)	616	(55.05)
n = 2	277	(20.59)	199	(17.78)
n = 3	101	(7.51)	105	(9.38)
n = 4	60	(4.46)	60	(5.36)
n = 5	43	(3.20)	44	(3.94)
n = 6	31	(2.31)	34	(3.04)
n = 7	29	(2.16)	31	(2.80)
n = 8	28	(2.09)	11	(0.98)
n ≥ 9	22	(1.62)	19	(1.71)
Add-on tests according to				
Work shift, n (%)				
Morning shift	792	(58.88)	564	(50.41)
Afternoon shift	318	(23.64)	324	(28.95)
Night shift	235	(17.47)	231	(20.64)
Type of order, n (%)				
STAT samples	804	(59.78)	796	(71.13)
Routine samples	541	(40.22)	323	(28.87)
Setting, n (%)				
ED	644	(47.88)	643	(57.46)
Hospitalization	581	(43.20)	315	(28.15)
ICU	68	(5.06)	90	(8.04)
Out-patient	52	(3.87)	71	(6.34)

Abbreviations: ED: Emergency Department; ICU: Intensive Care Unit; STAT: Short Turnaround Time.

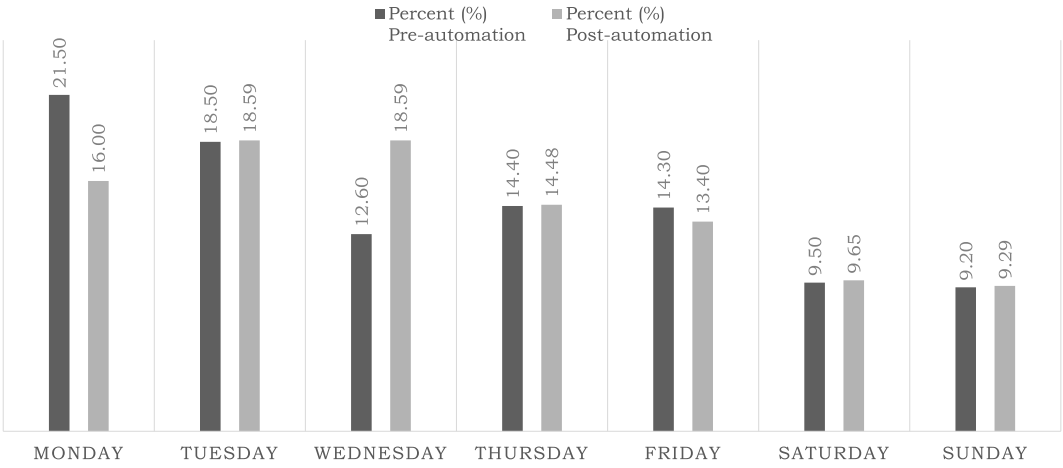

Fig. 2. Percent and timing of add-on orders by day of the week.

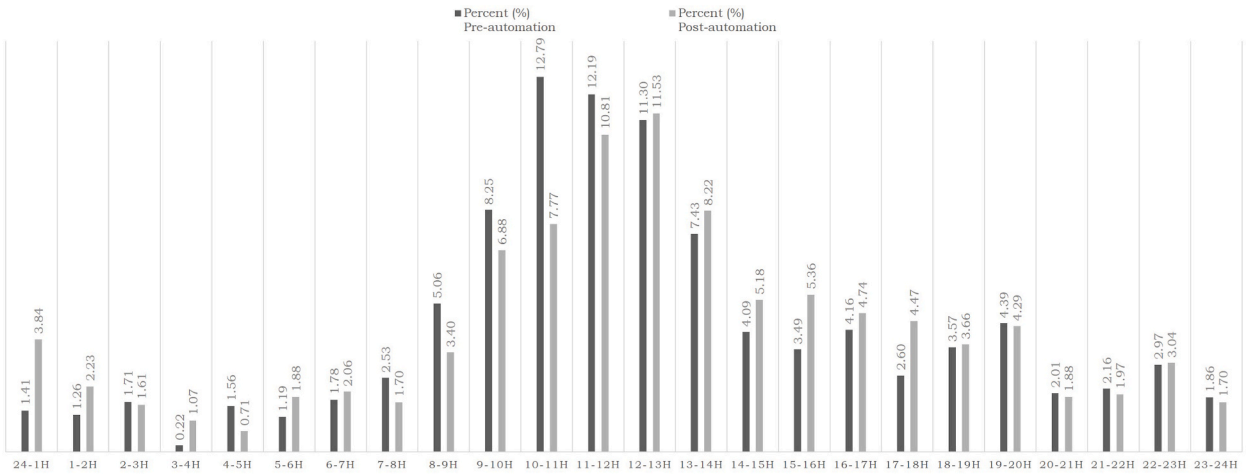

Fig. 3. Percent and timing of add-on orders by 1-h intervals.

A total of 83 clinicians (83/250; 33.2 %) completed the survey designed to assess the most common reasons for making an add-on test request. Clinicians were given five reasons for ordering add-on tests and asked to rank them on a scale from 1 (least common) to 5 (most common). Based on the mean scores, the most commonly reported reasons for ordering add-on tests were as follows: 1) as a response to changes in the patient's symptoms/different diagnostic suspicion (mean score, 3.44); 2) as a response to a previous laboratory result (3.30); 3) due to omission (3.11); 4) due to a mistake on the original request (2.82); and 5) inability to locate the test on the electronic request form (2.26) (Supplemental Material 1).

3.2. Evaluation of add-on testing TAT before and after automation

The turnaround time for add-on tests decreased significantly from 2021 to 2022, both overall and on all subanalyses ($p < 0.001$; Mann Whitney *U* test). Different add-on TATs can be observed in detail in Table 3.

Before automation, 6.72 % of STAT add-on tests exceeded the maximum turnaround time (established by agreement between the hospital clinicians and the core laboratory) versus only 3.26 % after automation.

Overall, the median decrease in TAT was 22 min (from 52 to 30 min) per add-on order, which translates to a savings of 15 h/day after automation.

4. Discussion

In this study, we sought to describe patterns of add-on testing at our core laboratory and to evaluate turnaround time before and after automation. At our laboratory, we had long suspected that add-on testing placed a disproportionate time burden on the biochemistry area. However, this burden had not been fully assessed and characterized until now. After automating the testing

Table 2
Characteristics of the most commonly ordered add-on parameters (>100 tests per month).

Parameter	Pre-automation			
	Add-on tests[a]	Add-on-tests/Total add-ons (%)[b]	Total tests[c]	Add-on tests/Total tests (%)[d]
CRP[e]	245	8.44	11342	2.16
NT-proBNP[f]	197	6.78	1442	13.66
GGT[e]	178	6.13	12002	1.48
Magnesium[e]	157	5.41	3690	4.25
CK[e]	156	5.37	2275	6.86
Alkaline Phosphatase[e]	153	5.27	12852	1.19
Bilirubin (total)[e]	139	4.79	12923	1.08
hs-cTnT[f]	134	4.61	1802	7.44
AST[e]	133	4.58	14391	0.92
ALT[e]	131	4.51	14378	0.91
Albumin[e]	129	4.44	10023	1.29
Lipase[e]	110	3.79	2451	4.49
LDH[e]	107	3.68	4727	2.26
Calcium[e]	105	3.62	10085	1.04

Abbreviations: ALT: Alanine aminotransferase; AST: Aspartate aminotransferase; CK: Creatine kinase; CRP: C-reactive protein; GGT: Gamma-glutamil transferase; hs-cTnT: High sensitivity cardiac troponin T; LDH: Lactate dehydrogenase; NT-proBNP: N-terminal pro-brain natriuretic peptide.
[a] Number of add-on tests for each parameter.
[b] Add-on tests per each parameter as a percentage of total add-on orders (n, pre-automation = 2904; n, post-automation = 2494).
[c] Number of total tests for each parameter.
[d] Add-on tests as a percentage of total analysed tests for each parameter.
[e] Test performed on Alinity ci (Abbott Laboratories).
[f] Test performed on Cobas (Roche Diagnostics).

Table 3
Turnaround time (TAT) broken down into day of the week, location, type of order, work shift and analyser and compared before and after the automation of the area.

	Pre-automation			Post-automation			Delta Change (%)	p-value[a]
All add-ons TAT, median (90^{th}p)	n = 1345	52 min	(205 min)	n = 1119	30 min	(84 min)	−42.31	<0.001
By setting [add-ons TAT, median (90^{th}p)]								
ED	n = 664	41 min	(101 min)	n = 643	25 min	(71 min)	−39.02	<0.001
Hospitalization	n = 581	76 min	(278 min)	n = 315	34 min	(92 min)	−55.26	<0.001
ICU	n = 68	52 min	(178 min)	n = 90	33 min	(111 min)	−36.54	<0.001
Out-patient	n = 52	93 min	(377 min)	n = 71	43 min	(344 min)	−53.76	<0.001
By type of order [add-ons TAT, median (90^{th}p)]								
STAT samples	n = 804	40 min	(102 min)	n = 796	26 min	(72 min)	−35.00	<0.001
Routine samples	n = 541	90 min	(312 min)	n = 323	37 min	(147 min)	−58.89	<0.001
By work shift [add-ons TAT, median (90^{th}p)]								
Morning shift	n = 792	64 min	(250 min)	n = 546	33 min	(87 min)	−48.44	<0.001
Afternoon shift	n = 318	48 min	(124 min)	n = 324	26 min	(95 min)	−45.83	<0.001
Night shift	n = 235	34 min	(101 min)	n = 231	23 min	(62 min)	−32.35	<0.001
By analyser [add-ons TAT, median (90^{th}p)]								
Alinity ci	n = 922	51 min	(184 min)	n = 696	22 min	(69 min)	−56.86	<0.001
Cobas	n = 248	48 min	(202 min)	n = 211	40 min	(92 min)	−16.67	<0.001
Alinity ci and Cobas	n = 144	69 min	(278 min)	n = 161	49 min	(108 min)	−28.99	<0.001
Osmo1	n = 17	22 min	(154 min)	n = 38	18 min	(37 min)	−18.18	<0.001

Abbreviations: 90th p: 90th percentile; ED: Emergency Department; ICU: Intensive Care Unit; STAT: Short Turnaround Time; TAT: Turnaround Time.
[a] Mann-Whitney *U* test.

processes in 2022, we realized that this was an opportunity to evaluate and compare the impact of automation on add-on orders.

Add-on orders accounted for 5.18 % (November 2021) and 4.23 % (November 2022) of total orders received in the core laboratory, which is similar to the high rates observed at comparable laboratories. For example, a multicentre study at five Australian hospitals (total beds: 1688) found that add-on orders for the clinical chemistry department accounted for 5.4 % of all orders [13]. Another large study characterized add-on orders for a period >5 years at the University of Iowa (hospitals and clinics), a 730-bed academic medical centre, with add-on tests accounting for 3.3 % of the total number of tests performed during that period [14]. Although that rate is substantially higher than observed in our study (0.83 % in 2021 and 0.62 % in 2022), these differences can be explained by the characteristics of our institution. Hospital de la Santa Creu i Sant Pau is an academic hospital that treats high complexity patients. Consequently, each order typically contains more parameters when compared to other centres. Thus, even though add-on orders represented a high percentage of all orders at our laboratory, the add-on orders only made up a relatively low percentage of tests overall due to the high volumes at our centre. Moreover, in most cases, the add-on orders only included one (>55 % of requests) or two

parameters (≈20 %). By contrast, in the Iowa study, multiple add-on test orders were requested at different points in time for some patients, leading to a mean of 9.15 add-on parameters per patient [14]. Other studies conducted in hospitals comparable to ours have reported add-on testing rates of 1.6 % [13], 1.5 %, and 0.7 % [3].

In 2022, most add-on orders were received in the first 24 h after receipt of the original sample (79.9 % and 96.7 % for routine and STAT samples, respectively). Since most of these orders were made when the samples were still available in storage, only around 5 % of routine add-on orders could not be assessed from the stored samples but rather required an aliquot from the long-term storage module. All STAT add-on orders were received in time to perform the test. In fact, some other groups, which also found that the samples were available for 100 % of STAT orders, have used these data to reduce the time they retain the samples [1,3]. However, given the large capacity of our refrigerated storage module and the absence of regulatory specification regarding minimum storage time, we do not plan to modify the current protocols (frozen aliquots are stored for one month) at our laboratory. In fact, sample storage times increased after automation (from 7 to 8 days for routine samples and from 2 to 4 days for STAT samples), which allowed us to complete 0.8 % and 0.4 % additional add-ons orders compared to the pre-automation period. The increase in storage times for STAT samples was especially useful for those add-on orders coming from the Emergency Department (ED), which is the main source of add-on orders (47.88 % in 2021 and 57.46 % in 2022), followed by requests from the inpatient setting (both wards and the Intensive Care Unit [ICU]) [13]. Outpatient clinics accounted for <7 % of total add-on orders.

By day of week, add-on orders were less common during weekends a pattern that is consistent with that observed at other centres with a similar structure to ours (i.e., only samples from the ED and inpatient wards are analysed during the weekend) [14]. The peak time for add-on orders was during the morning shift (9:00 a.m. to 2:00 p.m.), when approximately half of all add-on orders were made. By contrast, less than 20 % of add-on orders were ordered during the night shift. Other centres have reported slightly different peak times, such as 7:00 a.m. to 12 p.m [4]. or 7:00 a.m. to 1 p.m [14]. Given that the new laboratory instrumentation at our hospital has sufficient capacity to handle all add-on orders, even at peak times, we currently have no plans to take steps to reduce the number of orders during this time period. The rate of add-on testing orders differed between the pre- and post-automation observation (especially on Monday and Wednesday and in the 10–11 h' time interval) but these differences are not attributable to the automation so they were not further examined.

The most commonly requests add-on parameters were for tests to determine drug levels, procalcitonin, or NT-proBNP. These tests were commonly requested as add-on orders rather than in the original order. For some variables (e.g., procalcitonin), this is due to the demand management strategy at our institution, which only allows certain departments (the ICU, ED, and paediatrics) to order this particular test. In this regard, it is difficult to directly compare our data with other studies because some centres encourage the addition of panels (e.g., metabolic panel, including electrolytes, urea, creatinine, and glucose) [1](14), whereas we only perform the specific add-on tests requested.

In the clinician survey to determine the main reasons for ordering add-on tests, the most common responses were "in response to changes in the patient's symptoms/different diagnostic suspicion" followed by "in response to a previous test result". It is worth emphasizing that, in these cases, requesting an add-on test is a normal part of the routine clinical diagnostic process, rather than a deviation from institutional protocols or guidelines, in contrast to the findings of some studies [1]. Although the survey response rate was only 33.2 %, it was considered representative, as indicated by the confidence level between 90 % and 95 % (from 14.8 to 49.6 %) [15].

Several studies have evaluated how partial automation (especially after introduction of storage-retrieval units) affects changes in add-on procedures [2](14). However, to our knowledge, no studies have assessed the impact of automation on turnaround times for add-on testing. Automation resulted in a median decrease in TAT of 22 min (from 52 to 30 min, a 42 % decrease) per add-on order, with even larger reductions achieved depending on the type of request. For example, for routine samples, the TAT decreased by approximately 60 %. Other studies conducted at automated laboratories have found that turnaround times for routine and STAT samples are similar, mainly because the automated system handles all of the sample types in the same way [6]. Prior to automation, technicians handled all STAT samples, especially the manual steps. By automating these processes, we were able to reduce the median TAT by 15 min. This improvement is important, as it could have a major positive impact on the diagnosis and management of patients and on the length of stay in the ED [16].

As expected, the greatest reduction in TAT for add-on tests was observed in tests performed on the Alinity ci, with a median reduction of 29 min per sample. However, for samples requiring the use of non-connected analysers (Cobas and Osmo1), the post-automation reduction in median TAT was minimal although great differences in the 90th percentile of TAT were observed. When the main add-on testing steps are not automated – e.g., the register of the add-on data or the location of the stored sample – even rates of 1 % of add-on tests needs 1–2 full-time equivalents [3]. We found that automation led to a total median decrease of 15 h per day (based on TAT values) of manual effort. A similar study reported post-automation decreases similar to ours. In a centre with a rate of 3.3 % of add-on testing, the introduction of a robotic specimen archival/retrieval unit led to a reduction of manual effort of 24.1 h/day [14].

4.1. Limitations

Although this study extensively characterized add-on testing patterns, it has several limitations. First, in the last five years, only a few studies have been published on add-on testing. As a result, we can only compare our results to data from older studies, which were mainly based on outdated technologies with different degrees of automation. Another limitation is related to routine add-on requests received by e-mail: we did not account for the gap between the time the clinician sent the order by e-mail to the time it was read and subsequently include in the LIS. Nevertheless, it can be assumed that the delay in the management of these add-on orders was the same

before and after automation, which means that TATs in the two time periods are still comparable and that the differences observed are attributable to automation. Moreover, it is worth noting that it is difficult to monitor and measure every step in the process (especially those outside of our control), which is why only the steps that are under the direct control of the laboratory are usually considered when calculating TAT (i.e., the "intralaboratory TAT") [6]. However, the best option to reduce the "extralaboratory TAT" and achieve a further improvement of the add-on process could be the implementation of an electronic add-on test order module in an existing computerized physician order entry (CPOE) [4].

The calculation of the time saved was based on the reduction of TAT per sample. This method is not optimal since it assumes that a laboratory technician only managed one add-on testing order at a time when in reality they could manage more than one in parallel. Anyhow, this limitation was also not considered in other studies [3,13] so the time-reduction comparison remains valid.

5. Conclusions

Add-on testing has a clear impact on the workload at clinical laboratories. In this study, we characterized add-on testing patterns (frequency, setting, common causes, type of request, daily and weekly distribution, most common tests) and evaluated the impact of these tests on TAT after automating add-on testing procedures at the biochemistry area of a core lab in an academic medical centre. Based on the observed reduction in TAT (median decrease of 22 min), it seems clear that the automation increased efficiency.

Authors contribution

Conceptualization and writing: Álvaro García-Osuna; Data curation: María Costa Pallaruelo, Andrea Mansilla Usero; Investigation: Álvaro García-Osuna, Leonor Guiñón Muñoz, Francisco Illana Cámara; Drafting, revising and approval of the manuscript: all authors.

Ethics declaration

Review and/or approval by an ethics committee was not needed for this study because it does not include human subjects but collects data for measuring quality indicators.

Data availability

The authors are unable or have chosen not to specify which data has been used.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e22096.

References

[1] S. Melanson, J. Flood, K. Lewandrowski, Add-on testing in the clinical laboratory: observations from two large academic medical centers, Lab. Med. 37 (11) (2006) 675–678, https://doi.org/10.1309/BT8WH8M27YFETE9P.
[2] N.N. Naumova, J. Schappert, L.A. Kaplan, Patterns of add-on tests for hospitalized and for private patient populations, Arch. Pathol. Lab Med. 131 (12) (2007) 1794–1799, https://doi.org/10.5858/2007-131-1794-poatfh.
[3] S.F. Melanson, B. Hsieh, J.G. Flood, K.B. Lewandrowski, Evaluation of add-on testing in the clinical chemistry laboratory of a large academic medical center: operational considerations, Arch. Pathol. Lab Med. 128 (8) (2004) 885–889, https://doi.org/10.5858/2004-128-885-eoatit.
[4] J.Y. Kim, I.K. Kamis, B. Singh, S. Batra, R.H. Dixon, A.S. Dighe, Implementation of computerized add-on testing for hospitalized patients in a large academic medical center, Clin. Chem. Lab. Med. 49 (5) (2011) 845–850, https://doi.org/10.1515/CCLM.2011.140.
[5] V. Shahnazarian, P. Mehta, Improving the laboratory add-on process and increasing housestaff satisfaction with an EMR intervention, BMJ Qual Improv Rep 5 (1) (2016), https://doi.org/10.1136/bmjquality.u208549.w4294 u208549.w4294.
[6] A. Dolci, D. Giavarina, S. Pasqualetti, D. Szőke, M. Panteghini, Total laboratory automation: do stat tests still matter? Clin. Biochem. 50 (10–11) (2017) 605–611, https://doi.org/10.1016/j.clinbiochem.2017.04.002.
[7] V.L. Ng, Utilization management in the core laboratory, Clin. Chim. Acta 427 (2014) 154–157, https://doi.org/10.1016/j.cca.2013.09.038.

[8] G. Lippi, G. Da Rin, Advantages and limitations of total laboratory automation: a personal overview, Clin. Chem. Lab. Med. 57 (6) (2019) 802–811, https://doi.org/10.1515/cclm-2018-1323.
[9] L. Sciacovelli, M. Panteghini, G. Lippi, et al., Defining a roadmap for harmonizing quality indicators in Laboratory Medicine: a consensus statement on behalf of the IFCC Working Group "laboratory Error and Patient Safety" and EFLM Task and Finish Group "performance specifications for the extra-analytical phases.", Clin. Chem. Lab. Med. 55 (10) (2017) 1478–1488, https://doi.org/10.1515/cclm-2017-0412.
[10] C. Ialongo, O. Porzio, I. Giambini, S. Bernardini, Total automation for the core laboratory: improving the turnaround time helps to reduce the volume of ordered STAT tests, J. Lab. Autom. 21 (3) (2016) 451–458, https://doi.org/10.1177/2211068215581488.
[11] A.H. Lou, M.O. Elnenaei, I. Sadek, S. Thompson, B.D. Crocker, B. Nassar, Evaluation of the impact of a total automation system in a large core laboratory on turnaround time, Clin. Biochem. 49 (16–17) (2016) 1254–1258, https://doi.org/10.1016/j.clinbiochem.2016.08.018.
[12] E.C. Taylor, B. Sethi, Stability of 27 biochemistry analytes in storage at a range of temperatures after centrifugation, Br. J. Biomed. Sci. 68 (3) (2011) 147–157, https://doi.org/10.1080/09674845.2011.11730343.
[13] E. Vecellio, A. Georgiou, G. Toouli, J.I. Westbrook, Volume, rates, source and types of add-on pathology test requests across five hospitals, Clin. Chem. Lab. Med. 50 (6) (2012) 1041–1048, https://doi.org/10.1515/cclm-2011-0756.
[14] L.S. Nelson, S.R. Davis, R.M. Humble, J. Kulhavy, D.R. Aman, M.D. Krasowski, Impact of add-on laboratory testing at an academic medical center: a five year retrospective study, BMC Clin. Pathol. 15 (1) (2015) 1–9, https://doi.org/10.1186/s12907-015-0011-7.
[15] International Organization for Standardization (ISO), ISO 20252:2019 Market, Opinion and Social Research, Including Insights and Data Analytics – Vocabulary and Service Requirements, International Organization for Standardization, Geneva, 2019. Published online.
[16] S. Angeletti, M. De Cesaris, J.G. Hart, et al., Laboratory automation and intra-laboratory turnaround time: experience at the university hospital campus biomedico of rome, J. Lab. Autom. 20 (6) (2015) 652–658, https://doi.org/10.1177/2211068214566458.