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Switching from serum to plasma: Implementation of BD Vacutainer® Barricor™ Plasma Blood Collection Tubes improves sample quality and laboratory turnaround time

Christian Ramakers [a,*], Brendan Meyer [c], Wanfei Yang [b], Elizabeth Plokhoy [b], Yan Xiong [b], Stephen Church [c], Nitin Kaushik [b]

[a] Department of Clinical Chemistry, Erasmus MC, University Medical Center Rotterdam, Rotterdam, the Netherlands
[b] Becton Dickinson, Franklin Lakes, NJ, USA
[c] Becton Dickinson, Winnersh, UK

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ABSTRACT

Background: For blood, most 24/7 standard (immuno)chemistry parameters are either measured in serum or in lithium heparin plasma. Standard serum and plasma gel tubes have their shortcomings when timely analysis of high quality results is required. Serum requires clotting time and interference of gel globules in the plasma and adsorption of hydrophobic analytes into the gel layer potentially compromises high quality results from lithium heparin gel tubes. We sought to evaluate the impact of BD Vacutainer® Barricor™ Tube (Barricor™) on laboratory efficiency by measuring its effect on TAT and sample quality, as well as evaluate potential cost opportunities resulting from improved sample quality.

Methods: TAT data and remediation activities were extracted and captured during two 6 months phases. Serum was used as the predominant matrix in the first phase and Barricor™ plasma was used in the second phase.

Results: Barricor™ significantly reduced the median TAT, especially for routine-priority samples during peak-hours. The TAT key-performance-indicator (percentage of results available within 90 min) improved to >90% for STAT as well as routine priority samples. Converting from serum gel, Barricor™ reduced fibrin-related remediation activities from 2.3% to 0.4%. This resulted in remediation-related cost reduction of €6.010,47 over the study period.

Conclusions: By implementing Barricor™, we saw a significant reduction in TAT and a reduction in fibrin-related remediation time and costs, when compared to a predominant serum workflow. The improved TAT opens up the possibility of consolidating to one single priority level, eliminating the need for the use of the STAT priority level.

1. Introduction

The quality of samples allocated for 24/7 (immuno)chemistry analysis can be significantly impacted by the type of sample collected (plasma versus serum) and the type of blood collection device [1]. Standard serum tubes require time to allow blood to clot and are

* Corresponding author. Laboratory Director Pre-analysis & Core (Immuno)chemistry Laboratory, Erasmus MC, University Medical Center Rotterdam, 's-Gravendijkwal 230, 3015 CE, Rotterdam, Netherlands.
E-mail address: c.ramakers@erasmusmc.nl (C. Ramakers).

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contraindicated for use in patients on anticoagulant therapy. Insufficiently-clotted serum samples can lead to the formation of fibrin strands or masses that can interfere with sensitive immunoassay binding and contribute to clogging of analyzer probes [1,2]. Fibrin strands have a reported incidence rate of 2.8% in blood samples [2]. Switching from serum to plasma gel samples may reduce fibrin-related issues. Further, gel tubes (serum or plasma) are often preferred over non-gel tubes for enabling sample transport and longer-term analyte stability in the primary gel tube. However, prolonged cold storage of the primary gel tubes can interfere with the analysis of hydrophobic analytes such as steroid hormones [3] and drugs [4], due to adsorption over time onto hydrophobic separator gels. This can lead to a decrease in serum or plasma analyte/drug concentrations by as much as 20% to 50% after 24 h at 4 °C [4,5]. Gel tubes in general can present additional sample quality challenges. Gel globules or silicone oil droplets may be released and confused with fibrin, resulting in issues with sample probes, tubes and cuvettes, solid-phase immunoassay systems, and electrode surfaces and assay interference [1,6].

Sample quality issues due to fibrin or gel can interfere with automated sample processing and often require manual remediation. This utilizes healthcare worker time and hospital resources, which can have a significant effect on clinical laboratory performance, including test turnaround time (TAT) [2]. In most laboratories, TAT is defined as the time between laboratory registration and result reporting. TAT is considered a key performance measure of laboratory efficiency and is often used by laboratory professionals to monitor and optimize laboratory performance and is sometimes used by clinicians when evaluating and selecting a laboratory for services [7]. Studies report that interventions which improve sample quality lead to reductions in TAT, improved workflow and result reporting [8–10]. Solutions that eliminate the need for clotting may improve sample logistics and achieve savings in TAT. This is particularly relevant for those hospitals capable of fast sample transport and preanalytical processing, such as those with an efficient pneumatic tube system in place, allowing for fast transport of tubes from wards and phlebotomy units to the laboratory.

BD Life Sciences has developed a blood collection tube – BD Vacutainer® Barricor™ Plasma Blood Collection Tube (BD Barricor™) – that utilises a novel mechanical separator technology instead of gel. Compared to standard gel tubes, BD Barricor™ tubes provide a plasma sample with less cellular contamination, improved sample stability, reduced centrifugation time, no gel globules, and no fibrin due to insufficiently clotted serum tubes [11–16]. In addition, BD Barricor™ tubes are compatible with testing for hydrophobic drugs and for patients on anticoagulant therapy [17]. BD Barricor™ has the potential to improve important clinical indicators, such as

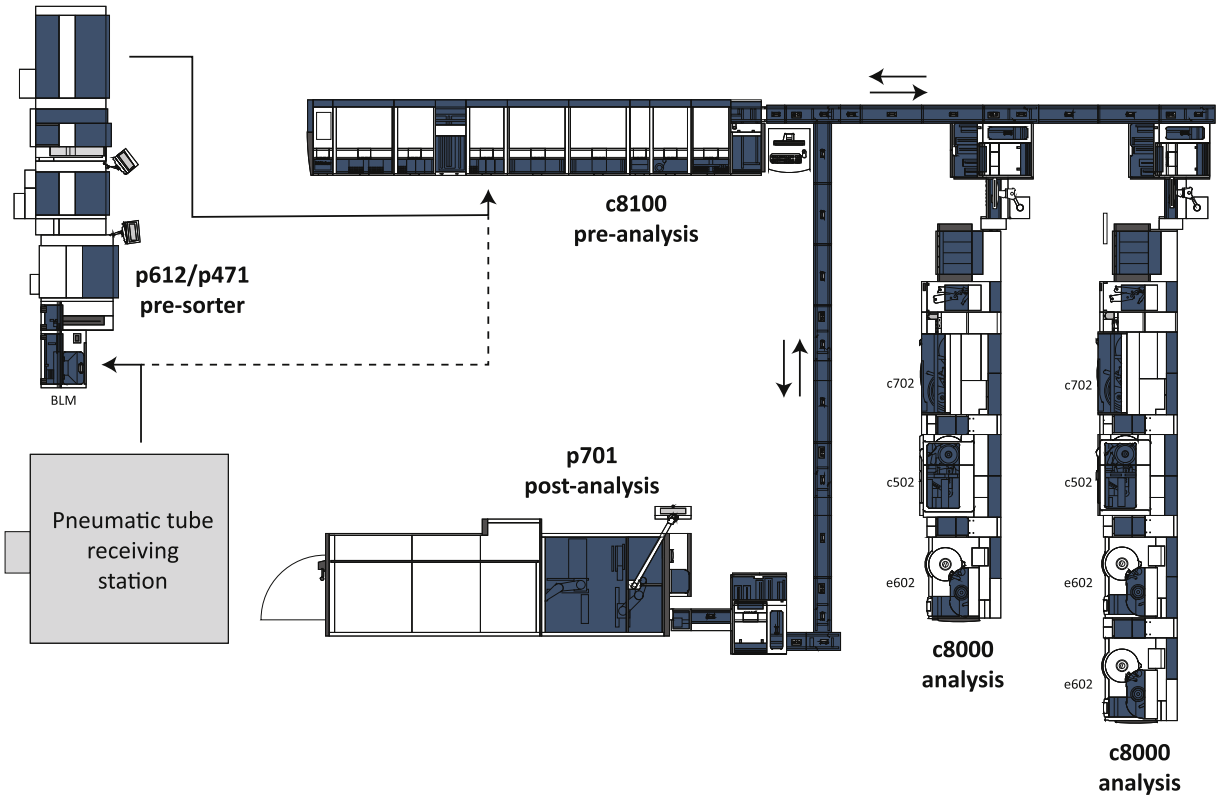

Fig. 1. Floorplan of the core lab TLA solution for (immuno)chemistry of the clinical chemistry laboratory of the Erasmus MC. The majority of tubes enter the laboratory via the pneumatic tube system. While routine priority samples are processed via the bulk loader module (BLM) of the Roche cobas® p612/p471 pre-sorter, most STAT priority samples (dotted line) are put directly on the cobas® c8100. In daily routine, the cobas® p612/p471 sorts all tubes into their respective target racks (chemistry, hematology, hemostasis, endocrinology, etc.). Chemistry racks with routine priority samples are manually transported from the cobas® p612/p471 to the cobas® c8100 (solid line). Upon centrifugation and decapping on the cobas® c8100, primary tubes are automatically transported to the cobas® c8000s for analysis (chemistry: c702, c502; immunochemistry: e602). Upon analysis, tubes are temporarily stored in the cobas® c8100 (1 h) after which they are transported to the cobas® p701 for definitive archiving at 4 °C.

laboratory TAT, by improving sample quality and eliminating time needed for clotting when switching from serum samples.

2. Materials and methods

This study sought to evaluate the impact of BD Barricor™ on clinical chemistry laboratory efficiency within the department of clinical chemistry of the Erasmus MC by measuring its effect on TAT and sample quality, as well as evaluate potential cost opportunities resulting from improved sample quality.

2.1. Site characteristics, study design and data sources

The study was conducted in the 24/7 clinical chemistry laboratory at the Erasmus MC. As one of the largest hospitals in the Netherlands, this academic hospital focusses primarily on complex tertiary care patients. In 2017 the laboratory accepted 776,586 orders from requestors, processed 1,195,029 tubes and reported 9,273,809 biomarker results. To facilitate all of this, the logistical processes in the laboratory are largely automated from sample transport, receipt of tubes to sample preparation, analysis and storage. A prospective observational study was conducted in 2 phases: a pre-phase, where primarily BD Vacutainer® SST™II Advance serum gel tubes (BD SST™II; 3.5 mL, 5.0 mL and 8.5 mL) were used for 24/7 (immuno)chemistry testing; and a post-phase, where predominantly BD Barricor™ plasma (3.5 mL and 5.5 mL) tubes were used. Each phase of the study had a duration of six months (183 days), with the pre-phase running from November 8, 2015 through May 8, 2016 and the post-phase period running from February 23, 2017 through August 24, 2017. Upon the analytical verification of the agreement between serum and lithium heparin plasma of the 24/7 (immuno) chemistry portfolio (manuscript in preparation, in short we verified the interchangeability between serum and BD Barricor lithium heparin of 68 (immuno)chemistry biomarkers), BD Barricor™ was implemented November 1, 2016 to allow for a four month familiarization period with BD Barricor™ prior to the start of the post-phase. Two key factors affecting laboratory operational efficiency, turnaround time (TAT) and remediation activities related to sample quality, were captured and analyzed. TAT data by tube type and lab operation hours were extracted from the Laboratory Information System (LIS, Labtrain, Bodegro, The Netherlands) for the duration of the study. To thoroughly understand the workflow associated with sample quality-related activities, each phase of the study included three observation periods (8 h per observation for a total of 24 h per phase distributed evenly over each phase). Observations were made on types and duration of activities from when tubes were received in the laboratory, until the release of the requested test results. During the study, (immuno)chemistry sample logistics within the laboratory made use of a bulkloader, connected to a pre-sorting station (cobas® p471/cobas p612, Roche Diagnostics, Switzerland) in combination with a preanalytical station (cobas® c8100, Roche Diagnostics, Switzerland) which was connected via a bidirectional track with two cobas® c8000 analytical stations (cobas® c702, c502, e602). Primary tubes were automatically archived via a bidirectionally connected archiving station (cobas® p701, Roche Diagnostics, Switzerland) (Fig. 1).

Note: centrifugation variables between the pre- and post-phases remained unchanged (i.e. 3000 rcf for 5 min) and within the specifications recommended by BD Life Sciences. During the pre-phase, sample logistics to the laboratory was such that the majority of BD SST™II serum tubes had ample time to clot during transport. So there was no additional delay to allow for clotting upon laboratory registration of BD SST™II serum tubes in the pre-phase.

2.2. TAT analysis

TAT was defined as the time (in minutes) from sample receipt in laboratory until ordered test results were verified and made available for the requestor in the hospital information system. In the Erasmus MC clinical chemistry laboratory result reporting for 24/7 clinical chemistry tests is such that a requested panel is reported as a whole. For example, if a hypothetical panel consisting of potassium, sodium, creatinine and urea is ordered, the results of all four tests have to be available before they are re-laid to the requestor so that he or she can interpret all four results as a whole.

Blood creatinine is one of the most frequently-requested parameters in routine as well as in high priority (i.e. STAT) requests. In light of that, combined with the abovementioned result reporting strategy, this marker was used as a TAT benchmark for all 24/7 (immuno) chemistry tests allocated to the cobas® c8000 analyzers (60–75% of all tubes analyzed on the cobas® c8000 have a creatinine in the requested test panel in Erasmus MC). Routine priority tests were processed continuously but non-urgently. STAT tests were defined as urgent tests requiring immediate processing upon registration in the laboratory. While the majority of STAT priority tests were registered manually and put directly on the cobas® c8100 pre-analytical module, routine priority tests were automatically processed and registered via the bulkloader module connected to the cobas® p612/p471 pre-sorter (Fig. 1). During processing the STAT priority samples were given right-of-way on the cobas® c8100 pre-analytical as well as the cobas® c8000 analytical modules. TAT data were also analyzed during peak and non-peak hours. Based on empirical tube throughput per hour, peak hours were defined as 9.00–14.00 for both pre- and post-phases. Non-peak day hours were defined as 8:00–9.00 and 14.00–16.00. Non-peak evening and night hours were defined as 17.00–8.00. The TAT data were analyzed for all priorities (overall), and for STAT versus routine tests. To compare TATs between pre- and post-phase we calculated the timeliness, which we defined as the number of minutes needed for 90% of all creatinine results to be reported in the hospital information system. To evaluate the impact of switching from serum to plasma on extreme creatinine TATs we also calculated the percentage of reported creatinines with a TAT of more than 180 min from registration in the laboratory.

2.3. Remediation analysis

Problems with sample quality, i.e. fibrin strands and clot related issues, were evaluated based on the type of remediation process required, the active remediation process time required by the technician, as well as additional materials utilized. Remediation processes resulting from fibrin and clot related issues were grouped into four categories as per Supplemental Table 1 (1: rim, 2: rim and re-centrifuge, 3: aliquot for serum only and 4: rim, addition of reptilase (primary tube), water bath incubation, aliquot, re-centrifuge). Per observation visit (3 visits per phase), remediation activities were logged over a time period of 250 consecutive minutes within daytime office hours (09:00–17:00). With this we calculated an averaged observed number of remediated tubes per visit and an incidence percentage per remediation type. Together with the total number of processed BD SST™II and BD Barricor™ in the pre- and post-phase, respectively, we calculated the extrapolated number of tubes impacted. This number was then multiplied by the average active hands-on time spent on remediation for each activity per event to give the extrapolated active hands-on remediation time per remediation type, per phase.

2.4. Economic analysis

Costs associated with the remediation of sample quality issues were calculated from the number of incidences and the active technician time spent on each of the remediation processes associated with clotting or fibrin, using associated material and hourly labor costs for a technician. The cost data was collected from the clinical chemistry laboratory at Erasmus MC. The total cost of the remediation process over each phase of the study was calculated using the following formula: $\sum\{(T_i \times C_i) + (H_i \times L)\}$, with "T" being the extrapolated number of tubes impacted for a specific remediation activity "i", "C" the total material cost for that remediation activity, "H" the extrapolated active hands on remediation time in hours for that activity and "L" the hourly labor cost of a technician. The labor cost of €30,58 was based on the basic hourly salary of a laboratory technician (source: 2015–2017 Dutch Collective Agreements University Medical Centers, salary scale 7/10) with the addition of employer costs, which amongst others included taxes, holiday allowance and end-of-year bonus.

The cost of each remediation process was then summed as the total cost of remediation activities for each of the pre- and post-phase periods of the study. Sample remediation cost opportunities associated with the implementation of BD Barricor™ were calculated as the cost difference between the pre- and post-phase. The cost opportunity per BD Barricor™ tube used during the post-phase was then determined.

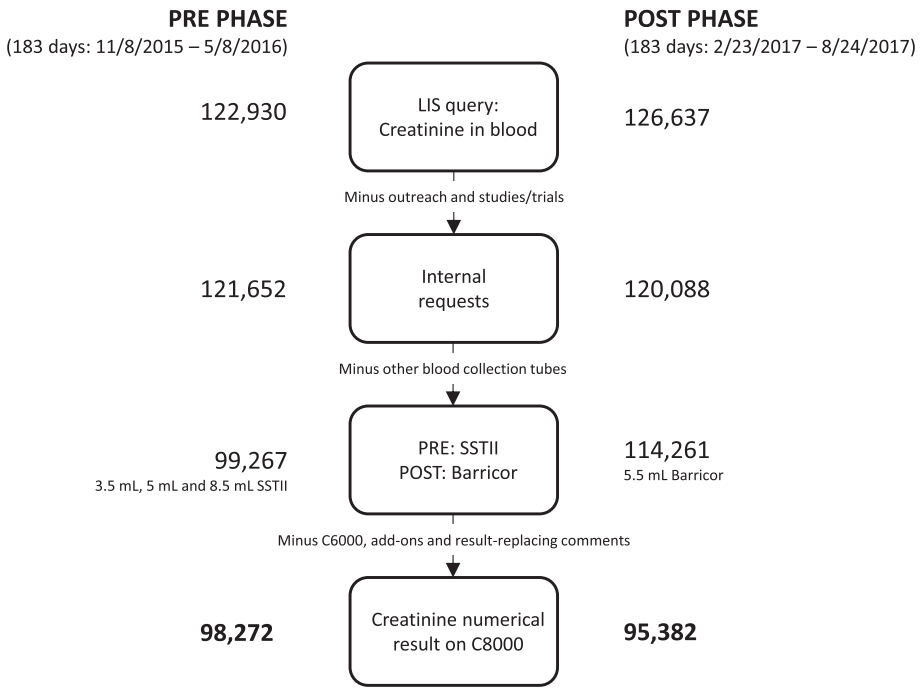

Fig. 2. Data filtering process. The pre- and post-phases ran for 183 days, respectively. An LIS query was performed, per phase, to retrieve all creatinine results in blood. The focus was on requests from Erasmus MC physicians from all clinical specialties for routine patient care (admitted, non-admitted ED, as well as out-patient clinic patients). For both phases, collection containers other than BD SST™II and Barricor™ tubes (i.e. BD Microtainer®, BD Vacutainer® PST™ II tubes, etc.) were excluded. Cobas® 6000 creatinine results from our satellite laboratory at the Erasmus MC Cancer Center, result-replacing comments, as well as add-on creatinine orders to a tube which had already been processed, were also excluded.

2.5. Statistical analysis

TAT calculations, timeliness and other miscellaneous calculations were performed using Microsoft Excel.

Ethical approval: This research did not use investigational products and did not require ethics committee approval.

3. Results

3.1. Data query and tube processing

Fig. 2 shows the filtering steps of the number of tubes with a creatinine in the initial order included in the TAT analysis. For the pre-phase (183 days; November 8, 2015 to May 8, 2016), the initial LIS query yielded 122,930 creatinine results which, after filtering, resulted in 98,272 results used for TAT analysis. For the post-phase (183 days; February 23, 2017 to August 24, 2017), this was 126,637 and 95,382 creatinine results, respectively. The majority of creatinine tests were processed with a routine priority (pre-phase: 75.2%, post-phase: 77.6%) with the remainder being STAT priority (pre-phase: 24.8%; post-phase: 22.4%). More than half of these tests were processed during peak hours (pre-phase: 54.9%; post-phase: 55.7%), with the rest processed during non-peak day hours (pre-phase: 26.6%; post-phase 26.8%) and non-peak evening/night hours (pre-phase 18.5%; post-phase 17.6%) (Table 1).

3.2. TAT analysis

Compared to the pre-phase, we saw an improvement in timeliness with an overall shortening of the number of minutes needed for 90% of the creatinine results to become available for the requestor (Table 2). Over a 24 h period, an overall (i.e. routine + STAT) −10.2% improvement in TAT was found in the post-phase using BD Barricor™, when compared to the pre-phase using BD SST™II serum gel tubes (pre-phase 88 min; post-phase 79 min). Scrutinizing the TAT results, we identified small nuances. During non-peak evening and night hours we saw an average improvement of −6.0 and −6.1% for routine and STAT priority samples, respectively. During day-time hours (peak and non-peak, routine and STAT) we found an average improvement of −10.1%, with the most consistent improvement for routine sample priorities.

Looking at the higher end of TATs, we also looked at differences in extreme TATs (i.e. >180 min from registration in the laboratory) in the pre-vs. post-phase. Table 3 shows that compared to the pre-phase, there was a lower percentage of samples with an extreme TAT>180 min when using BD Barricor™ in the post-phase. Overall, the improvement was −0.5% compared to the pre-phase. In absolute creatinine results, this translates to 491 creatinine results (98,272 ÷ 100 × 0.5%) that would have had a more timely TAT if BD Barricor™ had been used.

3.3. Remediation analysis: time and economic

Table 4 shows the remediation activities in the pre- and post-phase. To clarify the data in Table 4 we provide a calculation example. For rimming, we observed a total number of 7 tubes needing rimming over three visits in the pre-phase. This averages to 2.3 observed tubes over 250 min of observation. Based on an average tube throughput of 261 tubes over 250 min this comes to a rimming incidence percentage of 0.88% (2.3 ÷ 261 × 100%). With a total of 125,509 SST™II tubes being processed during the pre-phase this would potentially impact 1104 tubes (0.0088 × 125,509). On average, rimming a tube (from first identifying the tube in the sample output of the cobas® c8000 to putting it back on the system for processing) took 2 min and 10 s. For 1104 tubes this would accumulate to 39 h and 52 min. Summed-up and extrapolated over 6 months for each phase of the study, the total incidence of clotting- or fibrin-related remediation activities decreased from 2.3% in the pre-phase to 0.4% in the post-phase (Table 4). The total hands-on time spent on clotting- or fibrin-related remediation activities decreased from 170:03:57 (h:m:s) in the pre-phase to 14:43:12 in the post-phase

Table 1
Number of creatinines (PRE SSTII, POST 5.5 mL Barricor) analyzed during peak and non-peak hours on 24/7 chemistry analyzers. SSTII: 3.5 mL, 5.0 mL and 8.5 mL tubes.

Tubes, N (%)	PRE-phase November 08, 2015–May 08, 2016	POST-phase February 23, 2017–August 24, 2017
Overall (00:00–23:59)	98,272	95,382
Routine	73,933 (75.2%)	74,065 (77,6%)
STAT	24,339 (24.8%)	21,317 (22,4%)
Peak versus non-peak hours		
Peak hours (09:00–14:00)	53,951 (54.9%)	53,093 (55.7%)
Routine	43,709	42,907
STAT	10,242	10,186
Non-peak day hours (08:00–09:00; 14:00–17:00)	26,109 (26.6%)	25,529 (26.8%)
Routine	20,551	20,484
STAT	5558	5045
Non-peak evening/night hours (17:00–08:00)	18,212 (18.5%)	16,760 (17.6%)
Routine	9673	10,674
STAT	8539	6086

Table 2
Time (in minutes) needed for 90% of creatinine results to be reported in the hospital information system (HIS) in the PRE and POST phase. Time calculated from first registration in lab to result reporting in HIS. Δ TAT = POST – PRE. % = (ΔTAT ÷ PRE TAT) × 100%.

	Overall 00:00–23:39	Peak hours 09:00–14:00	Non-peak day hours 08:00–09:00; 14:00–17:00	Non-peak evening/night hours 17:00–08:00
Overall TAT				
PRE (minutes)	88	91	84	83
POST (minutes)	79	82	75	78
Δ (minutes)	−9	−9	−9	−5
%	−10.2%	−9.9%	−10.7%	−6.0%
Routine TAT				
PRE (minutes)	90	93	86	84
POST (minutes)	80	83	76	79
Δ (minutes)	−10	−10	−10	−5
%	−11.1%	−10.7%	−11.6%	−6.0%
STAT TAT				
PRE (minutes)	80	79	77	82
POST (minutes)	73	75	67	77
Δ (minutes)	−7	−4	−10	−5
%	−8.8%	−5.1%	−13.0%	−6.1%

Table 3
Percentage of creatinine results reported with a TAT of more than 180 min during peak and non-peak hours for all, routine and STAT priority samples. Δ = POST – PRE.

Time period	All			Routine			STAT		
	PRE (%)	**POST** (%)	**Δ** (%)	**PRE** (%)	**POST** (%)	**Δ** (%)	**PRE** (%)	**POST** (%)	**Δ** (%)
Overall (00:00–23:59)	1.3	0.8	**−0.5**	1.4	0.8	**−0.6**	1.1	0.5	**−0.6**
Peak (09:00–14:00)	1.5	0.9	**−0.6**	1.6	1.0	**−0.6**	1.3	0.6	**−0.7**
Non-peak day (08:00–09:00; 14:00–17:00)	1.3	0.6	**−0.7**	1.3	0.6	**−0.7**	1.2	0.4	**−0.8**
Non-peak evening/night (17:00–08:00)	0.9	0.5	**−0.4**	1.0	0.7	**−0.3**	0.8	0.2	**−0.6**

Table 4
Remediation process. Observations were performed for 250 consecutive minutes within day time office hours (09:00–17:00) in the pre- and post-phase. The calculated incidence percentage was based on an average tube throughput of 261 and 248 tubes/250 min for the pre- and post-phase, respectively. The extrapolated number of tubes impacted are calculated by multiplying the total number of tubes with the incidence percentage. Time in hours:minutes:seconds.

Remediation type	Averaged observed number remediated tubes per visit	Incidence	Extrapolated number of tubes impacted	Averaged active hands-on remediation time per event	Extrapolated active hands-on remediation time per phase
PRE PHASE (total number of tubes on Cobas 8000: 125,509 STII tubes, 8.5, 5.0 and 3.5 mL)					
Rim	2.3	0.88%	1104	00:02:10	39:52:00
Rim & recentrifuge	1.0	0.38%	477	00:02:30	19:52:30
Aliquot only	0.7	0.27%	339	00:01:43	09:41:57
Rim, add reptilase, water bath & recentrifuge	2.0	0.77%	966	00:06:15	100:37:30
Total					**170:03:57**
POST PHASE (total number of tubes on Cobas 8000: 119,288 Barricor tubes, 5.5 mL)					
Rim	0.3	0.12%	143	00:02:10	05:09:50
Rim & recentrifuge	None observed				
Aliquot only	0.7	0.28%	334	00:01:43	09:33:22
Rim, add reptilase, water bath & recentrifuge	None observed				
Total					**14:43:12**

(Table 4).

Table 5 shows the cost overview relating to remediation activities in the pre- and post-phase. To clarify the data in Table 5 we provide a calculation example. For rimming, a thin wooden stick (material cost €0,02 per stick) is used to remove the fibrin strand from the tube. For 1104 extrapolated tubes (Table 4) this comes to a total material cost of €22,08 (1104 × €0,02). The total extrapolated

Table 5
Cost overview relating to remediation activities. Total cost was calculated as the sum of cost of each individual remediation activity using $\sum\{(T_i \times C_i) + (H_i \times L)\}$. The hourly labor cost (L) of a technician was taken from the 2015–2017 Dutch Collective Agreements University Medical Centers and set at €30,58 (scale 7–10, this includes an estimation of all added costs paid by employer).

Remediation type (i)	Material cost per tube (C)	Extrapolated number of tubes impacted (T)	Extrapolated active hands-on remediation time per phase (H)	Total cost per remediation activity
PRE PHASE				
Rim	€0,02	1104	39:52:00	€1.241,20
Rim & recentrifuge	€0,02	477	19:52:30	€617,32
Aliquot only	€0,10	339	09:41:57	€497,67
Rim, add reptilase, water bath & recentrifuge	€1,12	966	100:37:30	€4.159,03
Total				**€6.515,22**
POST PHASE				
Rim	€0,02	143	05:09:50	€179,12
Rim & recentrifuge	€0,02	None observed		
Aliquot only	€0,10	334	09:33:22	€325,63
Rim, add reptilase, water bath & recentrifuge	€1,12	None observed		
Total				**€504,75**

active hands-on time for rimming is calculated to be 39 h and 52 min (Table 4). Together with the hourly labor cost of a technician, total labor costs were calculated to be €1.219,12 (39:52 × €30,58). This brings the total remediation cost for rimming to €1.241,20 in the pre-phase.

Overall, pre-phase remediation costs were calculated to be €6.515,22 over 6 months, compared to post-phase remediation costs of €504,75 over 6 months (Table 5). In the pre-phase, €1.147,44 was associated with material costs and €5.367,78 with technician time associated with sample remediation, while in the post-phase, €36,26 was associated with material costs and €468,49 with technician time associated with sample remediation. This translated to a total cost opportunity of €6.010,47 over 6 months, which, when taking only the BD Barricor™ tubes in the post-phase into account (119,288 tubes), corresponded to 5.0 Euro cents of saving per BD Barricor™ tube processed in the laboratory, due to remediation activities alone.

4. Discussion

To our knowledge, this single-site pre- and post-phase observational study is the first study to evaluate how adoption of BD Barricor™ in a previously predominantly serum-based workflow would impact laboratory efficiency at a clinical laboratory in a large academic medical center in the Netherlands.

As seen in Table 2, we saw an overall improvement of −10.2% in timeliness in the post-phase using BD Barricor™ tubes (90% of all blood creatinine results available within 79 min) when compared to the use of BD SST™II serum gel tubes in the pre-phase (90% of all blood creatinine results available within 88 min). One of the most important key performance indicators (KPI) in laboratory medicine is the timely report of laboratory results, especially for samples with a STAT priority. During the study period (pre- and post-phase), the TAT KPI for creatinine in the department of clinical chemistry in the Erasmus MC was that 90% of all STAT creatinines had to be available within 90 min. Table 2 shows that this KPI was met throughout the study (80 vs. 73 min, pre- and post-phase respectively).

There are several reports advocating the consolidation to a single (routine) priority, suggesting that the use of a STAT priority has become obsolete, especially in laboratories with a total lab automation (TLA) solution [18–20]. The study by Ellison et al. [18] even goes so far as to state that in a TLA environment, the use of a STAT priority slows down the performance of the TLA and that moving from a STAT to an overall routine priority workflow reduces the TAT. Looking at the timeliness results in Table 2, we found that the gap (in minutes) between routine and STAT TAT in the post-phase shortened, when compared to the pre-phase. This was to such an extent that even routine priority creatinine results during peak hours, in which 55.7% of all creatinines are processed, are reported within the 90 min cut-off value of the STAT KPI (90% of all creatinines ready within 83 min). This suggest that introducing BD Barricor™ not only improves overall timeliness, it might also enable the consolidation to a single priority level, thereby streamlining the 24/7 (immuno) chemistry workflow.

Looking at the extreme TATs of creatinine results (TAT>180 min) we also see a strong improvement through the introduction of BD Barricor™ (Table 3). In general, extreme TATs are suggestive of either analyzer down-time, sample quality issues, or a combination of both. While we did not look at analyzer down-time we did investigate sample quality issues, more particularly, fibrin-related remediation activities.

Remediation data showed that, compared to the pre-phase using BD SST™II, sample quality using BD Barricor™ improved dramatically, which translated into decreased time needed by the laboratory staff for clotting- and fibrin-related remediation activities in the post-phase. Overall, the incidence of clotting- and fibrin-related remediation activities decreased from 2.3% to 0.4% following implementation of BD Barricor™. While this was not directly investigated, the decrease in remediation activities fits with the decrease in extreme TATs, as shown in Table 3.

As a direct consequence of the decreased remediation activities, the active time spent on remediation activities also decreased from 170:03:57 to 14:43:12 (h:m:s) over a 6 month period. To understand the impact of improved sample quality, and reduced time and

materials needed for sample remediation activities, the total cost savings following implementation of BD Barricor™ were calculated. BD Barricor™ led to an estimated total cost opportunity of €6.010,47 over 6 months (5 Euro cents per BD Barricor™ tube used).

4.1. Limitations of the study

It is important to note certain limitations of this study. Like many, the clinical chemistry department of the Erasmus MC is continuously optimizing and updating, which introduced a number of variables to the study, other than implementation of BD Barricor™. The ones identified included a hospital information system change during the post-phase and a gradual transition during the study to a centralized front office in which the pre-analytical hardware (i.e. cobas® p612/p471) of the clinical chemistry laboratory was used to consolidate tube handling in the pre-analytical phase for other laboratories within the Erasmus MC. In this study, the short term challenge of the blood collection tube conversion was underestimated. Seemingly insignificant nuances, such as change in tube outer diameter (from 16 mm for serum gel to 13 mm BD Barricor™) and a different visual fill pattern of BD Barricor™ tubes resulted in unintended consequences which were, in all cases, transient and ultimately resolved. The change in tube outer diameter (16 to 13 mm) created a spike in labelling errors due to a smaller surface on the 13 mm tube for label placement. During the post-phase, severely underfilled BD Barricor™ tubes (less than 1.5 mL whole blood) also posed a problem on the Roche pre-analytical systems (i.e. cobas® p612/p471 and cobas® c8100) due to the fact that the Roche systems were unable to detect and intercept these underfilled BD Barricor™ tubes. Phlebotomist training and increased awareness of laboratory staff to actively check the filling level during tube processing resolved most of these issues.

The economic calculations in this study accounted only for the cost opportunities for the laboratory and did not calculate the potential upstream clinical opportunities related to improved sample quality and shorter TAT of results. Potential opportunity costs in the lab, which included redraw and retest, analyzer maintenance and downtime, were not captured during the observation periods.

Author contributions

All the authors have accepted responsibility for the entire content of this submitted manuscript and approved submission.

Author declaration of interest

BM, WY, EP, YX, SC and NK are employed by Becton Dickinson and Company. Regarding the scientific content of the manuscript all authors explicitly state no conflict of interest.

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Declaration of interests

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.plabm.2019.e00149.

References

[1] R.A.R. Bowen, G.L. Hortin, G. Csako, O.H. Otañez, A.T. Remaley, Impact of blood collection devices on clinical chemistry assays, Clin. Biochem. 43 (1–2) (2010) 4–25.

[2] E.P. Erdal, D. Mitra, V.S. Khangulov, S. Church, E. Plokhoy, The economic impact of poor sample quality in clinical chemistry laboratories: results from a global survey, Ann Clin Biochem [Internet] 54 (2) (2017) 230–239.

[3] S. Hepburn, M.J. Wright, C. Boyder, R.C. Sahertian, B. Lu, R. Zhang, C.P. White, A.R. Horvath, Sex steroid hormone stability in serum tubes with and without separator gels, Clin. Chem. Lab. Med. 54 (9) (2016 Sep 1) 1451–1459.

[4] T.R. Koch, G. Platoff, Suitability of collection tubes with separator gels for therapeutic drug monitoring, Ther. Drug Monit. 12 (3) (1990 May) 277–280.
[5] A. Dasgupta, M.A. Yared, A. Wells, Time-dependent absorption of therapeutic drugs by the gel of the Greiner Vacuette blood collection tube, Ther. Drug Monit. 22 (4) (2000 Aug) 427–431.
[6] M. Daves, G. Lippi, G. Cosio, A. Raffagnini, E. Peer, A. Dangella, et al., An unusual case of a primary blood collection tube with floating separator gel, J. Clin. Lab. Anal. 26 (4) (2012) 246–247.
[7] Hawkins R. Laboratory, Turnaround time, Clin. Biochem. Rev. 28 (2007) 179–194.
[8] S.M. Straszewski, L. Sanchez, D. McGillicuddy, K. Boyd, J. DuFresne, N. Joyce, et al., Use of separate venipunctures for IV access and laboratory studies decreases hemolysis rates, Intern. Emerg. Med. 6 (4) (2011) 357–359.
[9] Y.M. Alahmadi, M.A. Aldeyab, J.C. McElnay, M.G. Scott, F.W. Darwish Elhajji, F.A. Magee, et al., Clinical and economic impact of contaminated blood cultures within the hospital setting, J. Hosp. Infect. 77 (3) (2011) 233–236.
[10] C. Ramakers, BD Vacutainer® Barricor tube in the emergency department: reduced hemolysis rates using partial draw tubes with reduced vacuum, Clin. Chem. Lab. Med. 56 (2) (2018) e31–e32.
[11] A.K. Füzéry, J.E. Raizman, B.L. Goudreau, K. Moses, K. Niemann, J. Park, et al., The BD Barricor blood collection tube is an acceptable and robust alternative to the PST for use with the Beckman AccuTnI+3 assay, Clin. Biochem. [Internet] 50 (15) (2017) 851–857.
[12] A. Dupuy, S. Badiou, D. Daubin, A. Bargnoux, C. Magnan, K. Klouche, et al., Comparison of Barricor™ vs. lithium heparin tubes for selected routine biochemical analytes and evaluation of post centrifugation stability, Biochem. Med. 28 (2) (2018).
[13] A. Padoan, M. Zaninotto, E. Piva, L. Sciacovelli, A. Aita, A. Tasinato, et al., Quality of plasma samples and BD Vacutainer Barricor tubes : E ff ects of centrifugation, Clin. Chim. Acta 483 (2018) 271–274. April.
[14] J. Cadamuro, C. Mrazek, A.B. Leichtle, U. Kipman, T.K. Felder, H. Wiedemann, et al., Influence of centrifugation conditions on the results of 77 routine clinical chemistry analytes using standard vacuum blood collection tubes and the new BD-Barricor tubes, Biochem. Med. 28 (1) (2018).
[15] S. Demeester, K. Lanckmans, P. Heyvaert, I. Weets, M. Martin, Stability of 21 routine chemistry tests in the BD barricor ™ tube and the sarstedt S- monovette ® LH tube up to 7 Days after blood collection, J. Clin. Chem. Lab. Med. 1 (1) (2017).
[16] C. Mazur, J. Hayden, The Becton Dickinson Barricor™ tube does not introduce isobaric interferences in mass spectrometry-based measurements of testosterone, J. Appl. Lab. Med. An. AACC Publ [Internet] 2 (6) (2018) 920–924.
[17] A. Schrapp, C. Mory, T. Duflot, T. Pereira, L. Imbert, F. Lamoureux, The right blood collection tube for therapeutic drug monitoring and toxicology screening procedures: standard tubes, gel or mechanical separator? Clin. Chim. Acta 488 (2019) 196–201.
[18] T.L. Elison, M. Alharbi, M. Alkaf, S. Elimam, M. Alfaries, R.A. Nounou, R. Nasr, T. Owaidah, Implementation of total laboratory automation at a tertiary care hospital in Saudi Arabia: effect on turnaround time and cost efficiency, Ann. Saudi Med. 38 (5) (2018) 352–357.
[19] 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.
[20] A. Dolci, D. Giavarina, S. Pasqualetti, D. Szoke, M. Pantheghini, Total laboratory automation: do stat tests still matter? Clin. Biochem. 50 (10–11) (2017) 605–611.