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international journal of medical informatics 82 (2013) 220–229

journal homepage: www.ijmijournal.com

Improving chemotherapy processes with a protocol-based information system: A pre and post-implementation study

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ARTICLE INFO

Article history:
Received 17 June 2012
Received in revised form
30 November 2012
Accepted 1 December 2012

Keywords:
Chemotherapy
Care protocol
Information technology
Process efficiency
Workflow
Cancer
Turn-around-time
Communication
Collaborative care

ABSTRACT

Background: The medical application domain has been a great challenge for information technology solutions for decades, especially when the target process has been complex and multidisciplinary such as chemotherapy processes.
Objective: To evaluate the impact of a homegrown protocol based information system on the efficiency of chemotherapy workflow processes in an outpatient setting.
Methods: A day care unit of the Hematology/Oncology outpatient clinic of Erasmus Medical Center was the setting for this study. The study consisted of comparison of pre- and post-implementation of four workflow efficiency related external indicators: turn-around times of a commonly administered chemotherapy course (Paclitaxel–Carboplatin), chemotherapy course administration postponing rate, the rate of recording course administration time, and patient admission rate of the outpatient clinic. The data was gathered retrospectively from patient charts and information systems' log files. For the purpose of turn-around-time 109 Paclitaxel–Carboplatin chemotherapy courses of pre-implementation were compared to 118 those of post-implementation. For the other indicators: 247 chemotherapy courses pre-implementation were compared to 324 courses post-implementation. The process maps of pre- and post-implementation were also compared to each other.
Results: The implementation of the system improved the process by removing repetition and sequencing of the tasks. Following the implementation, chemotherapy postponing decreased by 17.2% ($Z = -4.723$, $P = .000$) and there were 5.7% less records with missing administration time ($Z = -3.047$, $P = .002$). The admission rate increased 1.9 patient per working day ($t(94) = -5.974$, $P = .000$). The overall turn-around-time reduced 18.9 min following the implementation ($t(169) = 3.48$, $P = .001$). In a multivariate multiple regression model the reduction in turn-around time was related to the implementation of the system (Pillai's Trace = 0.159, $F(4,161) = 7.613$, $P = .000$).

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http://dx.doi.org/10.1016/j.ijmedinf.2012.12.001

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Conclusion: Information systems based on treatment protocols can reduce communication and synchronization needs between the stakeholders in a complex workflow process. These systems can help reengineering the process and improve workflow efficiency by removing unnecessary sequencing and repetitions of tasks.

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1. Background

Cancer is a major global public health concern and represents a significant burden of disease and health finance allocation. It is the leading cause of death worldwide, accounting for 7.6 million deaths (around 13% of all deaths) in 2008. The mortality rate of cancer is expected to grow to 11 million by 2030 [1]. In the European Union, with 2.9 million new cases and 1.7 million deaths each year, cancer presents an important health problem [2]. The financial burden of cancer therapy is considerable for healthcare systems not only because chemotherapy medications are expensive but also because qualified specialist workforce for handling cancer patients is scarce. In the United States, almost 5% [3] and in The Netherlands 4.1% [4] of total healthcare expenditure is for treating cancer patients. With the trend of population aging, it is expected that the cost of cancer care will continue to rise in the future.

Treating cancer is also complex and error prone. Correct dosing and safe administration of chemotherapy medications are imperative due to their toxicity and narrow therapeutic windows. Optimizing delivery of cancer care often entails complex decision-making, multiple handoffs between different care providers, and coordination among cancer care team members [5]. Chemotherapy protocols are designed to help physicians by providing a road map in managing complex cancer therapy and hence decreasing inefficiency and error. They bring together detailed information about the aim, the methods, the complications, and the expected results of chemotherapy treatments. However, due to the multi-dimensional, complicated, and long term nature of the process, paper-based protocols are in many cases hard for physicians to follow and their outcomes are vulnerable to medical errors and inefficiencies [6,7].

Timelines and efficiency have been accepted as important elements in a broader definition of quality [8]. An efficient chemotherapy workflow is part and parcel of safe and high-quality chemotherapy process. This efficiency issue becomes especially important in outpatient clinics because patients are normally referred from different geographically located healthcare centers. Inefficient workflow can result in longer wait-around time, and delaying or postponing chemotherapy course administration. The inefficiencies not only can lead to patient dissatisfaction, but also can result in worse disease response due to delay in receiving chemotherapy courses.

Implementing new information and communication technology can increase efficiency and effectiveness of chemotherapy processes [9]. Though implementation of IT systems is of growing interest in many healthcare processes [10], the advances in the chemotherapy process computerization have been very slow [11–13]. The body of the literature available on Health IT systems' capabilities to improve complex processes such as the chemotherapy process is limited [14]. Thus, further research on this subject is clearly needed.

Many lessons are yet to be learned in managing clinical workflow with information technology. The chemotherapy process is a shared care process between different care providers. Hence, it is important to note that IT applications may have an impact on workflow of other care providers beyond that of physicians [15,16]. Any unilateral attempt to create order in one part of this highly organized process can create disorder in another part and lead to inefficiency [17,18]. Thus, evaluation studies have to show the effect of IT systems on the efficiency of the whole care process.

In this paper, we evaluate the impact of a protocol-based information system on the chemotherapy workflow in an ambulatory setting. We wanted to know how the system impacted the efficiency of the workflow process. To answer this question, in a pre- and post-implementation setting, we measured and compared four efficiency related indicators: the process turn-around time of a chemotherapy course, the postponing rate of chemotherapy courses, the rate of recording course administration time, and the admission rate of the clinic.

2. Methods

2.1. Study context

2.1.1. Organizational setting

The study was conducted in the outpatient clinic of the Department of Hematology/Oncology of Erasmus Medical Center (Erasmus MC), a 1237-bed third level academic medical center in Rotterdam, The Netherlands. The clinic has a day care unit with 5 beds and 11 chemotherapy chairs. The clinic's patients were mostly referred from different healthcare units throughout the country. Annually, around 2800 patients were admitted to this clinic.

2.2. The workflow process before the implementation

The referring physician or a board of physicians had already selected a treatment protocol before the patient was admitted. Fig. 1 shows that in the pre-implementation stage, the workflow process started from the time when the patient attended to the outpatient clinic and was admitted (T0). The patient's blood sample was then taken and sent to the hospital laboratory for a set of pre-ordered tests. The tests' values are required before the patient's physician can authorize a planned chemotherapy course to be administered. As soon as the Lab tests' results were ready for the physician in the electronic patient record system (named ELPADO®) the patient was invited into a consulting room (T1). This part of the process was considered time consuming and error prone because

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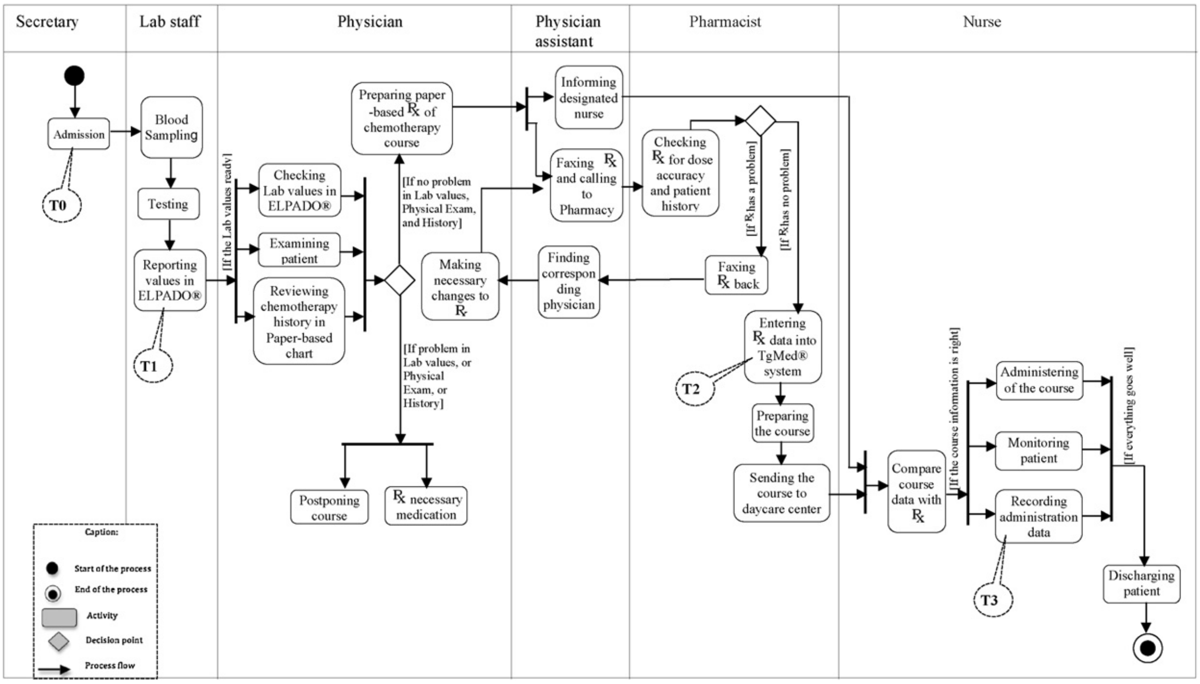

Fig. 1 – The UML activity diagram representing the process of chemotherapy course administration. Activities, swimlans of the stakeholders, and the different recorded time points (T0, T1, T2, T3) in the study are indicated.

it was always hard for physicians to get a quick and accurate perception of the patients' condition based on the chosen protocol. Before taking any further action, they had to answer questions like: where in the timeline of the protocol the patient stands, how many chemotherapy courses he/she has received so far, and whether or not there has been a problem in the patient's past chemotherapies or clinical condition. Creating and/or updating this clinical perception took a lot of physicians' time and could undermine clinical workflow and make managing therapy prone to error. To avoid hurdles in workflow, physicians had to do a lot of backstage work including studying patients' charts, taking necessary notes, and filling in different forms one day before their clinic. During patients' visits, physicians evaluated the patient's current medical condition. If there was no problem in the history, physical exam, and lab values, the chemotherapy medications were adjusted based on a patient's biometric indexes (weight, height, and body surface area) manually. After necessary adjustments, the chemotherapy prescription was signed by the physician and handed over to a physician assistant (in the daycare center) who was in charge of faxing the prescription to and following it up from the hospital pharmacy. At the pharmacy department, the faxed prescriptions were double checked for dose accuracy, biometric indexes, and against patients' past history of chemotherapy. In case of any discrepancy, incorrect calculation, or missing information, the prescriptions were faxed back to the outpatient clinic for required corrections. If everything was in order in the prescriptions, they were endorsed by a pharmacist to be prepared. Then, information about the chemotherapy courses was entered into a specialized information system named the TgMed® system (T2). Exact preparation recipes of the courses were produced by the system. After preparation, the chemotherapy courses were delivered to the day care unit where nurses administered them to patients (T3).

At Erasmus MC, many efforts have already been performed to improve the synchronization and coordination between different involved parties and to prevent delays and postponements of chemotherapy courses. For example, agreements were made with the pharmacy and laboratory departments to prioritize fulfilling the requests coming from the Hematology/Oncology outpatient clinic. Yet, a main complain of outpatient clinic's staff was about inefficiency issues related to collaboration problems in working with the pharmacy and laboratory departments. Work coordination between the day care unit and the pharmacy department was of special concern. Prescriptions were for example missed or even lost in back and forth faxing between the pharmacy department and the day care unit.

2.2.1. *The system implemented*

Kuren is a homegrown software program developed by a pediatric oncologist. It was initially implemented in the Department of Pediatric Oncology of Sophia children's Hospital, Erasmus MC. The system had been used in the pediatric Hematology/Oncology Department for about 5 years. In 2007, the program was developed further to include the workflow and chemotherapy protocols of adult Hematology/Oncology. As of 15 November 2007, the program was implemented throughout all adult Hematology/Oncology wards including the outpatient clinic. Before the implementation process, all user groups of the system including all hematologists/oncologists were trained, and tested for the proficiency of the system use. By the time of this study, the system

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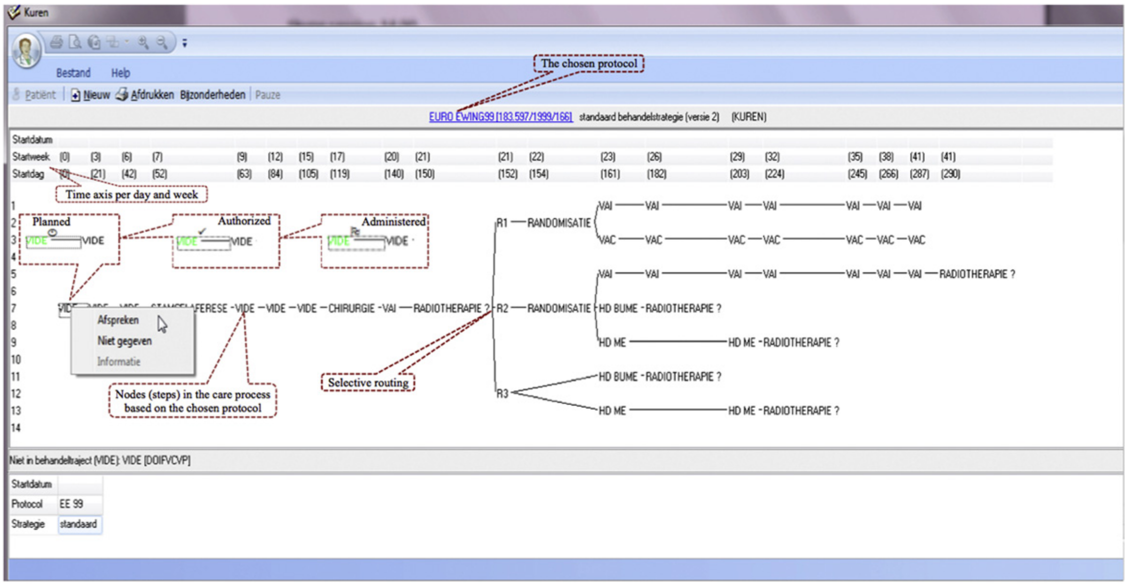

Fig. 2 – Physicians plan their patients' chemotherapy in an overview interface where the road map of a chosen protocol is depicted graphically.

was integrated into the hospital information system, laboratory information system and the hospital's electronic patient record (ELPADO®), but not into the existing computerized physician order entry (CPOE) system and the pharmacists information system (TgMed®).

Kuren was basically designed for Hematology/Oncology protocols and fully supports prescribing and administration of chemotherapy courses. Using protocols, the system combines and coordinates different disciplines' roles involved in the care process (including oncologists, residents, pharmacists, nurses, and secretaries). The system has different screens and different functionalities for different roles. Following choosing a protocol in the system, all necessary steps including the relevant chemotherapy courses are presented in the form of connected nodes spread over a timeline. Fig. 2 shows a series of connected steps to be taken in the care process according to a chosen protocol. Branching in this graph represents selective routing in a patient care plan considering the patient clinical condition and his/her para-clinical test results. By clicking on each chemotherapy course node, physicians can determine the exact doses of the course medications (by entering patients' biometric indexes), as well as the administration date and place within different windows of the system. The color of the node subsequently changes with a small clock sign above it, showing that the course was formulated and pending to be authorized by the physician. The pharmacist interface let her/him know what chemotherapy courses she/he is expected to prepare, allowing for better resource management. And an interface for nurses allows their pre-preparation and recording of chemotherapy administration data.

2.2.2. *The workflow process after the implementation*

The system mostly affected the workflow between the day care unit and the pharmacy department. The patient was admitted; his/her blood sample was taken for pre-ordered tests. He/She then had to wait until the physician invited him/her into the consulting room. The physician logged into the Kuren system and opened the patient's file. After observing the patient's lab values, being imported from the electronic patient record system, the physician invited the patient into the consulting room. On the overview interface of the system, the physician could easily check the patient's progress as well as the patient's previous history of treatments by clicking on the past steps on this interface (Fig. 2). The chemotherapy course could automatically be adjusted using the patient's biometric indexes recorded into the system. If there was no problem in lab values and physical examination, the physician could authorize an already formulated chemotherapy course to be administered. The clock sign above the course (on the overview interface) would then change into the tick mark. The pharmacy automatically received the prescription, entered its data into the TgMed® system for producing a preparation recipe. Using the system, human error was eliminated in dose calculation and it was not necessary for pharmacists to check the prescription for dose accuracy or missing data anymore. Thus, faxing back and forth of a problematic prescription was eliminated from the workflow process (Fig. 3). In the day care unit, a nurse could get printed details of the course administration after she entered the course's starting time into the system. When a nurse indicated in her interface that the course was administered, then the tick mark above the course on the overview interface changed into a flag.

2.3. *Study design*

In this study, we were looking for efficiency gains as a result of improved dose calculation, coordination, and streamlining the process associated with the implementation of the Kuren program. For this purpose, four workflow efficiency related external indicators were evaluated. These indicators are considered external performance indicators since their focus are on workflow itself rather than on

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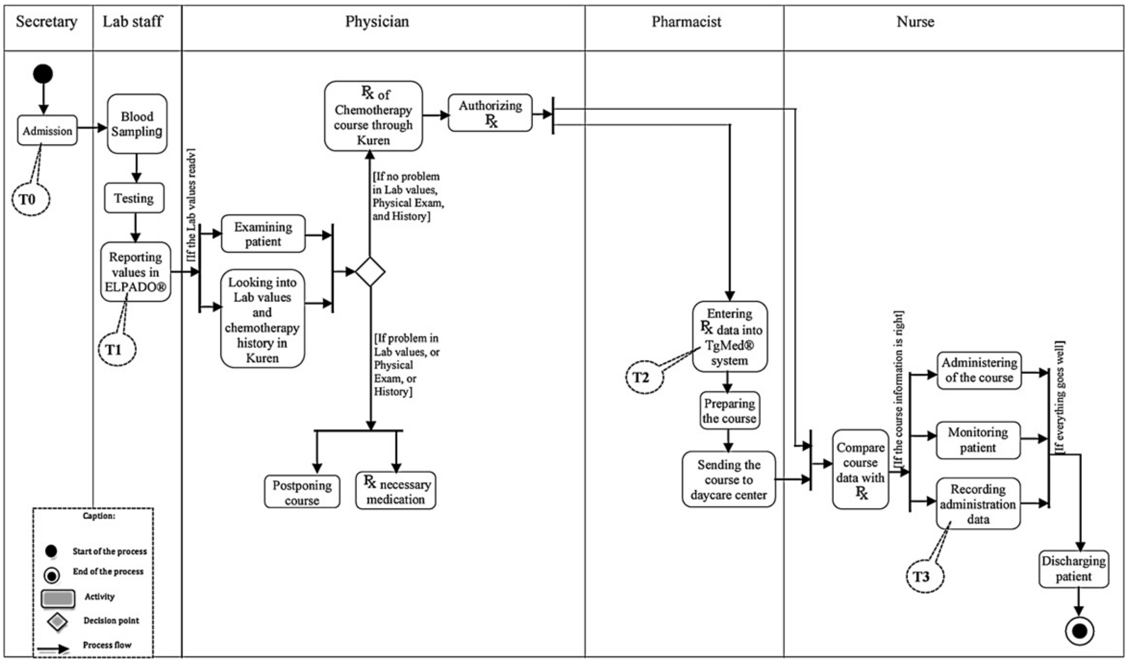

Fig. 3 – The chemotherapy workflow process following the implementation of Kuren. The workflow process was streamlined: the physicians' assistant role and activities related to communicating appropriate prescription data were omitted following the system implementation.

resources necessary to perform work process [19]. The main methodology was a before and after comparison of turn-around-times for the Paclitaxel–Carboplatin chemotherapy course. As complementary methods, moreover, we evaluated the chemotherapy-postponing rate, administration record-completion rate, and admission rate of day care unit before and after the implementation. The data was gathered by thorough examination of the paper-based records and log files of information systems retrospectively.

2.3.1. *Turn-around-time*

Medication turn-around-time has already been studied in evaluating the efficiency of the medication process following IT implementation. The turn-around time allows measuring the impact of health IT applications on the efficiency of patient care, both in inpatient and outpatient settings. The work that has been done so far has mainly focused on CPOE systems and inpatient settings [20–22]. This turn-around-time index can also be used to evaluate the outpatient chemotherapy process, which is a multi-step, multidisciplinary, and yet time-intensive process. Removing unnecessary sequencing and iteration of tasks throughout a process is expected to reduce the turn-around-time.

Paclitaxel–Carboplatin was a common combination of chemotherapy medications, amounting to 30% of all pre-implementation (84/247) and 24.5% of all post-implementation chemotherapy courses (79/324). The whole length of each cycle of this chemotherapy course consists of patient admission, preparation and visiting, plus the course administration time. The administration of this course comprises a 1-h premedication and a 3-h infusion of Paclitaxel followed by a 30-min infusion of Carboplatin. By measuring the overall and partial turn-around-times of the process, we can reflect upon the process efficiency before and after the implementation (Fig. 1). Four time records of the process were collected: T0 (patient admission time), T1 (the time Lab values were ready and uploaded to the ELPADO®), T2 (the time patient prescription data were entered into the TgMed®), and T3 (the recorded time for Paclitaxel administration). The overall turn-around-time was the interval between T0 and T3 (T0–T3). For detailed study, the overall turn-around-time was separated into three partial turn-around-times: T0–T1, T1–T2, and T2–T3.

2.3.2. *Postponing rate*

Delay in administration of chemotherapy courses in the day care unit could happen because of different reasons, but was frequently due to synchronization and coordination problems with the pharmacy department. Prescriptions, for example, were lost or neglected during the process of sending/receiving them through the fax machine. Preparing a chemotherapy course at the pharmacy department could take more time if additional communication with the day care unit was necessary to gather missing data from the chemotherapy prescriptions. However, in the busy day care unit, where limited resources including the chemotherapy beds and chairs were being tightly scheduled, there was small space for changing the day schedule if something went wrong in the process of course preparation. Thus postponing prescribed courses to another day was sometimes inevitable. Comparing the postponing rate of courses could provide us with additional information on the process efficiency change following the implementation of Kuren.

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Table 1 – Baseline characteristics of patients and chemotherapy process of the outpatient clinic.

	Pre-implementation ($N = 247$ patients)	Post-implementation ($N = 324$ patients)	*P* values	*T* values	*Z* values	95% confidence interval of the difference
Age* (mean years) (17–78)	59.23	54.77	.502	.672	–	−1.578, 3.218
Female (%)†	44.5 (110)	49.7 (161)	.222	–	−1.222	–
Ordered lab test* (mean)	20.85	18.64	.001	3.499	–	.972, 3.459
Prepared course* (mean)	14.1	15.6	.063	−1.862	–	−2.076, .055
Admitted patients* to day care unit per day (mean)	5	6.9	.000	−5.974	–	−2.551, −1.279
Postponed courses (%)†	36.4 (90)	18.8 (61)	.000	–	−4.723	–
Records with missing T3 (%)†	8.5 (21)	2.8 (9)	.002	–	−3.047	–

* Variables with normal distribution were tested with student *t*-test.
† Variables with skewed distribution were tested with non-parametric test.

2.3.3. *Record completion rate of administration time*

Improving the workflow process and reducing the need for continuous synchronization and coordination between different involved parties can reduce ad hoc communication and interruptions in nursing work. Nurses, as a result, can allocate more time on activities like record keeping. As an additional method of evaluating the process efficiency, we examined the chemotherapy administration time record completion rate (of T3) between all pre- and post-implementation courses. T3 was of our interest because it was an important time point in measuring the time needed for administering chemotherapy courses and it had to be recorded manually. Thus recording T3 could represent the quality of nurses' record keeping. Moreover, T3 was needed for measuring turn-around-time. Therefore, records' completion rate concerning T3 was defined as an indirect indicator of the chemotherapy process efficiency.

2.3.4. *Admission rate*

The level of service of an organization in a condition where the staff and other resources have not changed can be a good sign of workflow optimization [19]. The number of patients admitted per day during pre- and post-implementation study phases were compared as an extra indicator for evaluating the effect of the system on the workflow efficiency improvement.

3. Data acquisition and analysis

3.1. *Data collection*

Data was collected and refined for pre-implementation from 26/09/2007 till 30/11/2007 (49 working days) and for post-implementation from 1/10/2008 to 5/12/2008 (47 working days). T0 was collected from the hospital information system; T1 and T2 were extracted from log files of the laboratory and the pharmacy information systems. T3 for the pre-implementation group was extracted from paper-based course administration records of the patients' chart. For the post-implementation group, T3 was extracted from the paper-based administration forms. These forms were filled in by the nurses of the day care unit and scanned into the hospital information system. Other data items including demographic data and the number of admissions for each working day were collected either from the patients' chart or from the hospital information system.

Primarily, 571 sets of chemotherapy courses' records (247 for pre- and 324 for post-implementation periods) were evaluated to find out course postponing rate. The data set was then refined more by removing courses with missing T3, and in case data from different sources (from outpatient clinic, from the lab, and from the pharmacy department) could not be matched. The primary dataset for turn-around-time study included 109 and 118 Paclitaxel–Carboplatin chemotherapy courses. After excluding incomplete data sets, the ultimate dataset for measuring the turn-around-time included 84 and 79 records of Paclitaxel–Carboplatin for pre- and post-implementation periods respectively.

3.2. *Data analysis*

Mean and median were used as the central measures of data analysis. Means were used for evenly distributed data and medians for skewed data. The Student's *t*-test was used to detect a difference in mean data and the Mann–Whitney *U*-test was used to identify a difference in median data at an a priory .05 level of significance (Table 1). The chosen sets of Paclitaxel–Carboplatin for turn-around-time study amounted to 34% (84/247) of total pre-implementation and 24.4% (79/324) of total post-implementation chemotherapy courses administered in the day care unit. In order to evaluate the effect of other variables beside the implemented system on the overall and partial turn-around-times, a multivariate multiple regression model was used. Patients' age and gender, the average number of chemotherapy courses prepared per day by the pharmacy department (as an indicator of the pharmacy department workload), the average number of ordered lab tests per patient per day (as an indicator of a the lab workload) was included in the model (Table 2). The day care unit had limited resources and possibility for admitting patients with long care stays like Paclitaxel–Carboplatin. These courses were planned in advance and for each patient with Paclitaxel–Carboplatin, a specific time slot, a nursing staff, and a chemotherapy chair were allocated. Thus in a condition where there was no change in the resources and no possibility to parallelize steps of the process, we did not expect the workload of the outpatient clinic had an effect

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Table 2 – Results for Pillai's Trace of multivariate multiple regression.

	df	F value	P value
Age	4, 161	.661	.620
Gender	4, 161	1.757	.140
Number of courses prepared in the pharmacy department	4, 161	1.284	.279
Number lab tests requested form the lab	4, 161	.874	.481
Implementation of Kuren	4, 161	6.339	.000

on the turn-around-time of Paclitaxel–Carboplatin. Relation of the turn-around-times with the implemented system was evaluated for the chosen set of Paclitaxel–Carboplatin courses in pre- and post-implementation phases by Between-Subject Effects' test (Table 3). Wherever there were multiple comparison on the same data (sub)sets, the significance level of tests was corrected by the Bonferroni method in order to avoid a lot of spurious positives.

4. Results

The two pre- and post-implementation groups of the primary data set ($N = 571$) were not significantly different with respect to patients' age ($t(569) = .672$, $P = .502$), gender ($Z = -1.222$, $P = .222$), and the average number of chemotherapy courses prepared per day by the pharmacy department ($t(569) = -1.862$, $P = .063$). However, the average number of ordered lab tests per patient per day was significantly higher in the pre-implementation group ($t(569) = 3.499$, $P = .001$).

During the refining of the primary dataset, we also counted the number of chemotherapy courses that had been delayed and the number of courses without T3 being recorded in the patients' chart. There was a reduction of 17.6% of chemotherapy postponing ($Z = -4.723$, $P = .000$) and a reduction of 5.7% of records with missing T3 ($Z = -3.047$, $P = .002$) in the post-implementation group. Moreover, the level of service during post-implementation stage was increased and 1.9 more patients per working day were admitted to day care unit ($t(94) = -5.974$, $P = .000$) than in the pre-implementation group (Table 1).

In a multivariate multiple regression model, Kuren was significantly related to the overall turn-around-time (Pillai's Trace = 0.159, $F(4,161) = 7.613$, $P = .000$). However, there was no significant relation between the overall turn-around-time and the other included variables in the model (Table 2). Further, Between-Subject Effects' test with Bonferroni corrected α (.012) showed that the implemented system was significantly related to the overall turn-around-time (T0–T3) ($F(1,164) = 9.116$, $P = .003$) and the T1–T2 turn-around-time ($F(1,164) = 14.909$, $P = .000$). This means the effect of the system mainly came from its effect on the T1–T2 interval. Other partial turn-around-times were not related to the implemented system significantly ($P > .012$) (Table 3).

Comparing Paclitaxel–Carboplatin turn-around-times with Student's *t*-test showed that the overall turn-around-time was reduced by 18.9 min following the implementation of Kuren ($t(169) = 3.48$, $P = .001$). Partial turn-around-time of T1–T2 was reduced by 14.27 min ($t(169) = 3.715$, $P = .000$) following the implementation of Kuren (Table 4).

Table 3 – Between-Subject Effects' test (*Bonferroni corrected $\alpha = 0.013$).

	df	F value	P values*
T0–T1	1, 164	1.608	.207
T1–T2	1, 164	14.909	.000
T2–T3	1, 164	2.514	.115
T0–T3	1, 164	9.116	.003

5. Discussion

Analyzing the results of the study showed that the efficiency of the chemotherapy workflow process in the outpatient clinic was improved following the implementation of Kuren. We measured a significant reduction in the overall turn-around-time and in the T1–T2 partial turn-around-time of the Paclitaxel–Carboplatin chemotherapy. The overall improvement in the process turn-around time was mainly due to the time reduction in the period between T1 and T2. This improvement was expected because time-consuming steps in that part of the process were eliminated by Kuren implementation. Our study however did not find any significant difference at other partial turn-around-times. This can be interpreted that the system did not affect other parts of the process negatively. Moreover, we found a statistically significant reduction in the postponing rate, and a statistically significant increase in the record completion and admission rates following the implementation of the system. Thus, the measured improvements in the four external workflow performance indicators clearly demonstrate the positive impact of the implemented system on the chemotherapy process efficiency.

The positive impact of the Kuren program in this study can be explained by its help in reengineering the workflow process. With exact dose calculation, efficient communication, and better synchronization and coordination between the involved parties in each running episode of patient care there was no necessity of repeating tasks. The pre-preparation workload of physicians was reduced and finding patient information became easier; thus physicians had more time for managing their patients. Prescriptions were easier to read comparing to carbon copies of physicians' handwriting, and they were more complete, as the system did not allow incomplete prescriptions to proceed. The chemotherapy prescriptions did not contain any illegible information or wrong dose calculation which could lead to coordination problems and delay in the process flow by way of requiring clarification through interruptive face-to-face communication, phone calls, and/or faxing prescription back and forth. The system also made the necessary information more accessible to involved parties. Prescriptions were instantly delivered to nurses in the day care unit and to the pharmacy department. The unnecessary sequencing in the process steps was eliminated. Therefore, the system could cut off some extra steps for coordination and synchronization and could save time and extra efforts accordingly (Fig. 3).

The main dimensions of continuity of care are informational, relational, and managerial. These dimensions are

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Table 4 – Comparing overall turn-around-time and T1–T2 partial turn-around-time for Paclitaxel–Carboplatin chemotherapy courses in pre- and post-implementation of Kuren (*Bonferroni corrected $\alpha = .0125$).

	Mean time in pre group (min) (N = 75)	Mean time in post group (min) (N = 95)	P value*	Range (95% confidence interval of the difference)
T0–T3	156.15	137.25	.001	7.550, 27.679
T0–T1	39.51	44.88	.207	−10.182, 2.218
T1–T2	55.08	40.81	.000	6.490, 21.211
T2–T3	47.60	52.40	.322	−8.235, 2.721

closely tied to care coordination [5]. A care protocol works like a shared plan upon which all parties are agreed. Thus, by using a protocol, every party knows what to do, when, and how throughout the care process of a patient. It also helps care providers to coordinate and collaborate throughout patients' running care processes. The paper-based protocols however, have proved to be difficult to use, follow, and adhere to. One important aspect of the Kuren program, which brought efficiency benefits, was supporting work based on care protocols [23,24]. In order to offer quality chronic care, the involved parties need to coordinate across the care continuum too. Patient care records are of paramount importance in this regard. In the busy and interruption-driven work conditions of the day care unit, nurses had to perform many tasks, including follow-up of the ordered chemotherapy courses from the pharmacy department, educating patients, filling in electronic and paper based forms, and administrating and monitoring the chemotherapy courses. Previous studies have shown that care providers fail to record patient care information because of many interruptive interactions, e.g. phone calls and face-to-face communication that they have to perform to gather necessary information for their work [25]. Improving workflow processes and reducing the need for continuous synchronization and coordination between different involved parties in our study could reduce those ad hoc communications and interruptions. Nurses, as a result, could allocate more time on record keeping. The system could improve the documentation of the care processes and thus improved care providers coordination and collaboration across different patient care episodes.

Our results in this study correspond with previous studies on medication turn-around-time in the context of applying CPOE systems in some major medical units [21,22]. However, the magnitude of our results is not as big as those reported for CPOE systems. There could be several potential reasons that contribute to this difference. Firstly, chemotherapy is a complex and multi-step process, which requires more parties to coordinate and collaborate than other type of medication process within other units (e.g. in surgical services). Consequently it was difficult to produce huge improvements by implementing an IT system that mainly affected one specific step of the process. Secondly, in the outpatient setting the workflow process was already time-intensive and tightened. The Hematology/Oncology outpatient clinic of Erasmus MC had already implemented several improvement measures and the process turn-around-time was already shortened before the Kuren implementation. As a result, any marginal improvement in the process efficiency is valuable. The value of the findings becomes even more evident if the time saved in the chemotherapy process is multiplied by the number of patients being treated, for example, within a year. Less time-intensive units such as Hematology/Oncology inpatient settings are likely to reap more efficiency benefits from the implementation of the system. More efficiency benefits in our situation could moreover be realized if Kuren was fully integrated into the pharmacy information system. This could remove more time-consuming manual work steps from the process.

Our findings are in line with results of previous studies on applying IT systems in chemotherapy processes, though with different objectives or methods [26,27]. Most reviews centrally documented the reduction of chemotherapy errors, and inferred the improvements in communication between pharmacists, physicians and nurses as an additional benefit [14,28]. These positive results are proved by findings such as a rise of percentage of early medication administration out of small-sized samples, decrease in number of nurses involved in the process, or subjectively from verbalizations of patients' family concerning shortened lengths of stay for inpatient chemotherapy [6]. There are also studies reported on improving chemotherapy process efficiency and safety by performing organizational and workflow appropriations. One study reported more than 50% reduction of the time elapse between start of intravenous hydration and the start of chemotherapy in a simulated inpatient settings [29], and another study reported considerable improvements in the staff efficiency, bed utilization, and reducing overtime in outpatient settings [30]. However, the current study is one of the first to evaluate and document the impact of an IT application to improve outpatient chemotherapy processes efficiency objectively.

Putting the results into context demonstrates that Kuren did produce its positive impact on the workflow process efficiency by improving coordination between the care stakeholders and removing unnecessary sequencing and repetition of tasks. Positive impact of IT systems on similar clinical settings can therefore be expected if these systems provide similar process improvements. Workflow process improvement is especially valuable for conditions in which many parties are involved and as a result more coordination between them is required. Considering the fact that Kuren organized and coordinated patients' care using standard care protocols, it is more likely that similar positive effects can be gained with similar mechanisms in other institution too. It can also be envisioned that a system with such potentiality is able to produce positive efficiency effects on the workflow processes of other chronic disease's care where standard care protocols are also in use.

The study had a pre- and post-implementation design. This naturally controlled many confounders such as different patients, physicians, and nurses as opposed to those studies

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with a non-equivalent control hospital or simulation studies [13]. We chose almost the same periods of time for collecting data in the pre- and post-implementation phases in order to avoid the possible impact of season on patient load and chemotherapy types. Moreover, the post-Kuren data were collected one year after the system implementation, because in this time frame the users became proficient enough in using the system. It is also unlikely that the Hawthorne effect played any role here because our data were collected retrospectively [31]. During the study period, there were no changes in the outpatient clinic's organization such as changes in the management, staff, and organizational rules. We tried to include more samples to dilute the bias caused by disparities among different working physicians, pharmacists, or nurses, though this item could not be controlled as data were collected retrospectively. The effect of other possible confounding factors was examined in a multivariate multiple regression model. Several limitations should be stressed too. Potential limitations include firstly the inadequate measured time indicators. The chemotherapy process is a multi-step process and therefore the turn-around-time of each individual sub-process should be measured. Using the retrospective method, however, we could not find more recorded time indicators to be compared in pre and post stages. Moreover, the data was collected retrospectively, leaving room for potential confounding factors that are difficult to deal with. Manual chart and medication record review was vulnerable to errors. Some experts caution against relying on chart reviews because of possible inaccurate data recording by clinicians. In the chemotherapy administration, however, the accuracy of time registration is of critical importance for safety and effectiveness of chemotherapy medications and hence to be recorded precisely. Last but not least, in a highly organized process like protocol-based chemotherapy, any unilateral attempt to create order in one part of the process, for example by implementing Kuren, may accompany creating disorder in another part of it [17,18]. This emphasizes the importance of in-depth qualitative studies to gain deeper insight over the developments that have taken place following the implementation of Kuren. To have a more general overview on the system effects, it is necessary to define and measure some internal workflow performance indicators. These indicators are sensitive to resources and effort spent to achieve better external indicators such as reduced turn-around-time [19].

In conclusion, the results of this study confirm that IT systems that work based on care protocols allow more efficient patient care in chemotherapy settings. More importantly, the study shows IT systems that reduce the need for synchronous communication and synchronization between the stakeholders of a complex workflow process can help reengineering the process by removing unnecessary sequencing and repetitions of tasks and as a result improve workflow process efficiency.

Authors' contribution

HP, CG, and RB designed the study. HP, CG, RR, and AR contributed in data collection. The data was analyzed and interpreted by HP and CG. The other co-authors had the opportunity to comment on the statistical methods and analysis. HP and CG prepared the manuscript. HP, RB, RR, and AR contributed in revising and improving the manuscript.

Summary points

What was already known on the topic?

- Executing chemotherapy protocols is a complex, collaborative, and error prone process especially when the protocols have to be run for long period of time.
- Problems in synchronization and coordination of collaborative parties in this process are known as sources of inefficiencies and errors in the process.
- Information technology can offer many potentialities to improve the process, yet there has not been a study that demonstrates positive effect of a system on the process objectively.

What has this study added to our knowledge?

- This study demonstrates that information technology can improve the efficiency of complex and time-intensive processes such as outpatient chemotherapy.
- Such improvement in the process efficiency can mainly be deployed through improvements in coordination between the involved parties.
- Our study underscores that most of the benefits of IT applications in collaborative and shared care can be achieved if IT helps standardizing care processes between the involved parties for example through running standard care protocols.
- A protocol-based information system can improve workflow and help reengineering care process more efficiently.

Ethical concerns in the study

At Erasmus MC, ethical committee approval is only necessary for studies in which a behavioral changes of care providers is expected or in which patients are receiving other treatment than usual, both of which were not the case for our study.

Conflict of interest

The third author is the designer of the Kuren program. Nevertheless, the study presented in this paper has been free from any financial interest or commercial commitment on the system and the project. The results of the study represent merely the authors' scientific perspectives.

Acknowledgements

The authors would like to thank Dr. Jos Aarts, Dr. Poel Jansen, Prof. Dr. Bob Löwenberg, Dr. Heleen van der Sijs, and the manager of the outpatient clinic, Mrs. Erna Elfking and her colleagues, especially Mrs. Bokje Hoogland, and Mrs. Pateritia Matthijssen for their kind cooperation during this study.

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