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Research article

Process mining to optimize palliative patient flow in a high-volume radiotherapy department

L. Placidi [a,b], L. Boldrini [a,b], J. Lenkowicz [a,*], S. Manfrida [a], R. Gatta [c], A. Damiani [b], S. Chiesa [a], F. Ciellini [a], V. Valentini [a,b]

[a] Fondazione Policlinico Universitario A. Gemelli IRCCS, Roma, Italy
[b] Istituto di Radiologia, Università Cattolica del Sacro Cuore, Roma, Italy
[c] Dipartimento di Scienze Cliniche e Sperimentali dell'Università degli Studi di Brescia, Brescia, Italy

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ABSTRACT

Introduction: In radiotherapy, palliative patients are often suboptimal managed and patients experience long waiting times. Event-logs (recorded local files) of palliative patients, could provide a continuative decision-making system by means of shared guidelines to improve patient flow. Based on an event-log analysis, we aimed to accurately understand how to successively optimize patient flow in palliative care.
Methods: A process mining methodology was applied on palliative patient flow in a high-volume radiotherapy department. Five hundred palliative radiation treatment plans of patients with bone and brain metastases were included in the study, corresponding to 290 patients treated in our department in 2018. Event-logs and the relative attributes were extracted and organized. A process discovery algorithm was applied to describe the real process model, which produced the event-log. Finally, conformance checking was performed to analyze how the acquired event-log database works in a predefined theoretical process model.
Results: Based on the process discovery algorithm, 53 (10%) plans had a dose prescription of 8 Gy, 249 (49.8%) plans had a dose prescription of 20 Gy and 159 (31.8%) plans had a dose prescription of 30 Gy. The remaining 39 (7.8%) plans had different dose prescriptions. Considering a median value, conformance checking demonstrated that event-logs work in the theoretical model.
Conclusions: The obtained results partially validate and support the palliative patient care guideline implemented in our department. Process mining can be used to provide new insights, which facilitate the improvement of existing palliative patient care flows.

Introduction

Pain caused by bone metastases, which often represent the first evidence of disseminated disease, is the most common symptom requiring treatment in cancer patients [1]. Nearly three quarters of patients, with end-stage disease, will eventually need pain management [2]. Primary aim of palliative care is to increase the quality of the remaining life by reducing pain and preventing possible complications, which improves social functioning as well as mobility [3].

Brain metastases occur in 20–40% of patients with systemic cancer [4], who can present additionally seizures, focal neurology, or symptoms of intracranial hypertension. The response rate to radiotherapy for bone metastases is high [5] and the time-frame for symptomatic improvement is measured in weeks [6–8]. Prognostic indices help to tailor treatment options [9,10]; for example, whole brain (WB) radiotherapy can be offered to patients with extensive cerebral disease and good performance status [11]. Palliative radiotherapy for brain metastases stabilizes neurological symptoms in about half of the patients [12], even if associated with toxicity [13] and with less clear overall survival [14].

Radiotherapy is a cost-effective and time-efficient intervention, associated with a low toxicity profile and can be effective with doses ranging from 8 to 30 Gy in 1 to 10 fractions. Since 24% of the patients receive palliative radiotherapy within 30 days prior to death [15], additional tools are required to identifying patients benefiting from short treatment courses or alternative interventions and to optimize patient flow.

* Corresponding author.
E-mail address: jacopo.lenkowicz@gmail.com (J. Lenkowicz).

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Beyond survival estimates, factors influencing palliative radiotherapy fractionation include: patients' performance status; age; comorbidities and transportation capabilities; tumor factors such as number, location, and behavior of lesions; radiotherapy toxicity risks, taking into account any previous radiotherapy to the same anatomic site as well as other potential combined toxicities caused by other treatment modalities [16,17]. Other relevant factors are the presence of symptoms, concomitant therapies, like chemotherapy, and management settings. Furthermore, palliative patients may be referred to radiotherapy departments from different care environments (e.g. general practitioners, general hospitals, acute care facilities, long-term hospitals or community hospitals); the management of specific care needs results in a wide range of personalized patient flows, which may significantly slow down treatment procedures hampering the overall palliative care quality.

The complete understanding and governance of the actual clinical pathways could highlight patient flow pitfalls, not only those related with patient specific variables but also with other processes, like patient mobility, process sub-step duration time, logistic issues and data entering/usability.

Process mining is a method [18], which can provide new means to discover, monitor and improve processes in a variety of contexts, like healthcare [19]. Process mining in healthcare aims to automatically identify accurate models of patient care processes, extracting real-word data or, more precisely, data of event-logs, which are local file recordings readily available in hospital data storage and management systems. The assumption is that it is possible to sequentially record events so as to each event refers to an activity and particular case. Event-logs may store additional information (defined as "attributes") about events such as the resource timestamp of an activity or other data elements recorded with the event. Event-logs can be used to perform three process mining types using dedicated methods for process discovery, conformance checking and process enhancement.

This innovative patient flow management approach allows effective process improvement or re-organization, which can subsequently provide an online and continuative decision-making system to support the optimization of the palliative patient flow, which is an important factor not only from an individual point of view, but also from an organizational and health care systems perspective.

In this study, process discovery and conformance checking—part of process mining—has been performed with the aim to understand how to optimize patient flow in a high-volume palliative radiotherapy setting.

Materials and methods

Process mining

In this study, we used pMineR [20], a free R library applying a process mining method, which exploits Markov Models. Specifically, process discovery and conformance checking methods were applied in this study (Fig. 1).

Event-log generation

The first 500 palliative treatment plans of patients with bone and brain metastases delivered in our radiotherapy department in 2018 were included in this retrospective analysis to test the proposed methodology. Patients were treated on 4 different linear accelerators.

Based on the radiotherapy treatment planning system (TPS) (Eclipse, Varian Medical Systems, Palo Alto, CA, USA), scripting application programming interface (API) has been used to automatically create an output file with the event-log and the relative attributes of several workflow and treatment parameters for each plan.

Other workflow parameters, like the date of the first consultation, prescription and follow-up medical examination performed by the radiation oncologist (RO) with the relative clinical descriptive parameters (such as visual analogical scale), were automatically extracted from the internal radiotherapy department oncology information system (SpeedRo, KBMS, Italy).

The selection of the previously logs have been discussed in a multidisciplinary team, consisting of RO, medical physicist, radiotherapy technologists and nurses.

Process discovery

Given a set of real-world data, process discovery algorithm implemented in pMineR calculates the real process model using a graphical representation or a chosen compatible formalism, which analyzes and simplifies patient workflows disclosing descriptive stats from event-logs. Process discovery algorithm represents an estimator describing what is actually happening in the organization. In this study, the process discovery algorithm automatically identified and extracted specific events from the event-log data and then described the transition probability from one event to another by a first-order Markov Model. As preliminary investigation, the process discovery algorithm has been performed taking into account a specific subgroup of events of palliative patient workflows, described in table 1.

Process discovery can be considered successful if it manages to describe the considered event-log as input data with granularity and accuracy.

Conformance checking

The next step is conformance checking analysis, which aims to measure how an event-log data set works in a theoretical process model, with a possible double goal: to understand how good the theoretical process model is and to verify if an event-log is valid in the proposed theoretical process model.

The input of conformance checking is the created theoretical process model and the event-log set, which produces a statistical output able to explain how the two inputs fit each other.

The pMineR implements a specific conformance checking tool able to work with an internal formalism to represent work-flow-like diagrams and schemes close to the language adopted by physicians. Such formalism is defined as "pseudo-work-flow" (PWF).

Given an event-log, the pMineR engine reads the list of events and tests if one or more "triggers" can be fired for each event. A trigger is an item composed by two main sections: condition and effects. The condition analyses elements of the read event-logs. If the condition applies, the effects listed in the subsequent section are executed. Using this approach, statuses are automatically updated while events are sequentially processed from the first to the last.

Conformance checking has been validated on a theoretical process model proposed by RO experts in palliative care. Two different conformance checking analysis were performed. In the first conformance checking analysis, 3 different triggers (T), based on dose levels – 8 Gy (T01), 20 Gy (T02) and of 30 Gy (T03) – were set. Other 3 consecutive triggers were set to verify the number of plans went through from the treatment dose level prescription event (Prescription_Visit) to the event associated to the delivery of the first treatment fraction (Treatment_Fraction_Date_Time): for patients with a prescription of 8 Gy (T04), with a prescription of 20 Gy (T05) and for patients with a prescription of 30 Gy (T06). The second CCA described the maximum range of time between

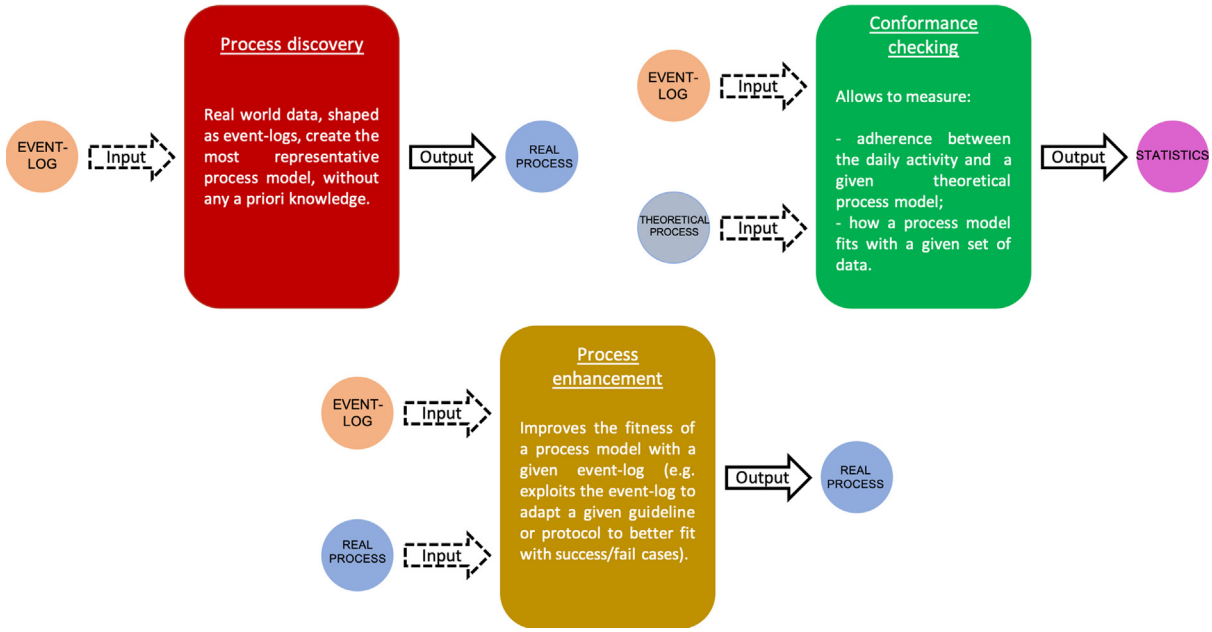

Fig. 1. The three main types of process mining: discovery, conformance checking and process enhancement. For processes, inputs and outputs are summarized.

Table 1
Event logs included in the process discovery algorithm. Each event has been itemized (left column) and then described (right column).

Event log item name	Event log description
Patient_Creation_Date_in_TPS	date and time when the patient file, which contains all patient information, is created in the TPS
Prescription_Visit	date and time when the RO prescribe the treatment dose level and the fractions scheme
Image_Creation_Date_in_TPS	date and time when a planning CT is acquired. During this event a CT is acquired to provide an electron density map allowing the dose calculation during the planning procedures
Course_Creation_Date_in_TPS	date and time when the whole treatment course is created. The course is a "container" of one or more radiotherapy treatment plans that will be delivered simultaneously or in a limited time span
Plan_Creation_Date_in_TPS	date and time when one plan is created. In this step, all the required procedures of planning are performed: beam setup, energy selection, dose calculation algorithm selection, dose distribution optimization and calculation, etc.
Planning_Approval_Data	date and time when, once the plan is completed, the attending RO approves the plan based to the chosen guideline to proceed with treatment delivery
Treatment_Approval_Date	date and time when the attending RO approves the treatment delivery; this event generally coincides with the delivery of the first treatment fraction
Treatment_Fractions_Date_Time	date and time of each treatment fraction delivery

the previously described events (treatment dose level prescription and first treatment fraction delivery).

In particular, for treatment plans with a dose prescription of 8 Gy, maximum time of 3 days, for 20 Gy of 10 days and for 30 Gy of 15 days were defined, respectively.

Results

The first 500 palliative treatment plans in 2018 delivered in our radiotherapy department, corresponding to 290 patients, have been included in this study. In particular, 438 bone metastasis treatment plans and 62 WB metastasis treatment plans were delivered.

Three different dose prescription levels were investigated: 8 Gy, 20 Gy and 30 Gy.

Based on the 500 plans considered in this study, 51 (10.2%) treatment plans had a dose prescription of 8 Gy, 249 (49.8%) plans of 20 Gy and 159 (31.8%) plans of 30 Gy. The remaining 41 (8.2%) treatment plans had different dose prescriptions. Considering the 290 patients included in the study, 33.2% of them already received a previous curative or palliative radiotherapy treatment. Moreover, 55.4% of the analyzed 290 patients received only one palliative treatment.

Results are summarized in Fig. 2.

Process discovery results are summarized in Fig. 3, for bone, WB and all metastasis treatment plans.

As reported in the figure, no differences were demonstrated confronting the three groups in terms of workflow process.

The workflow is generally straight from the creation of the treatment course (Course_Creation_Date_in_TPS) to the end of the workflow, except for number of treatment plans proceeding in the last step. This is probably due to the fact that 84%, for the All group in example, of the delivered treatment plans contain more than one treatment fraction: therefore, the treatment plans have passed thought the event assigned to the single treatment fraction delivery (Treatment_Fraction_Date_Time) for a number of times equal to the number of treatment fractions. Subsequently, 16% of treatment plans have progressed directly to the end of the evaluated workflow, since the plan's fraction number is one.

The flow of the treatment plans prior to the creation of the treatment is more complex, proving the non-linearity and variability of palliative treatment workflows.

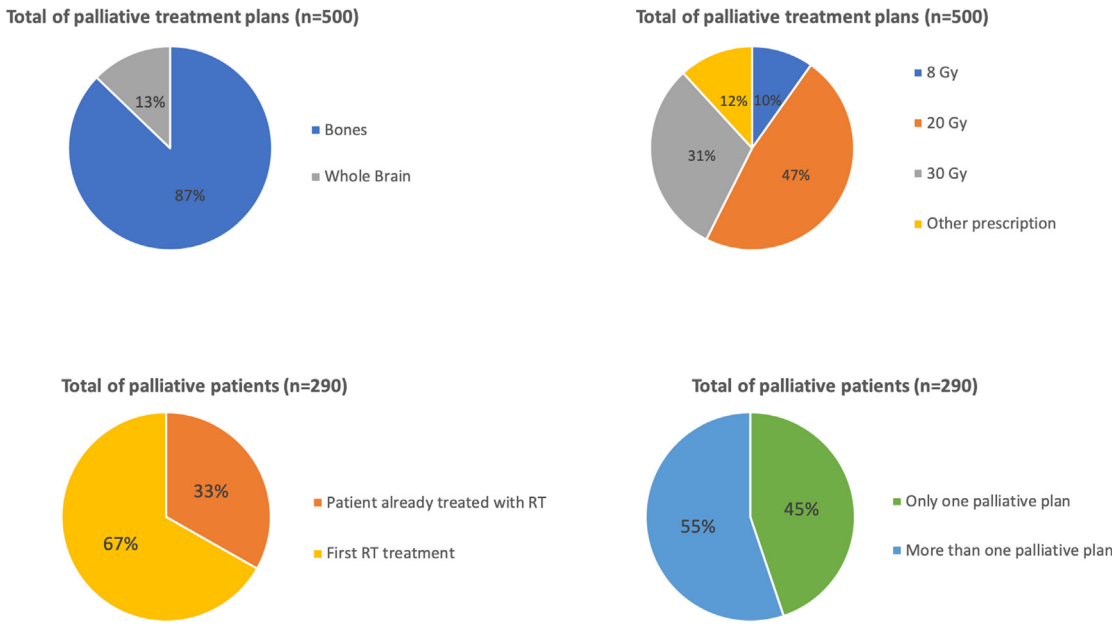

Fig. 2. Statistics of the palliative patients and treatment plans included in the study: bone and WB metastasis treatment plans, dose prescription of the palliative plans, number of patients already treated with radiotherapy and number of patients with more than one palliative plan.

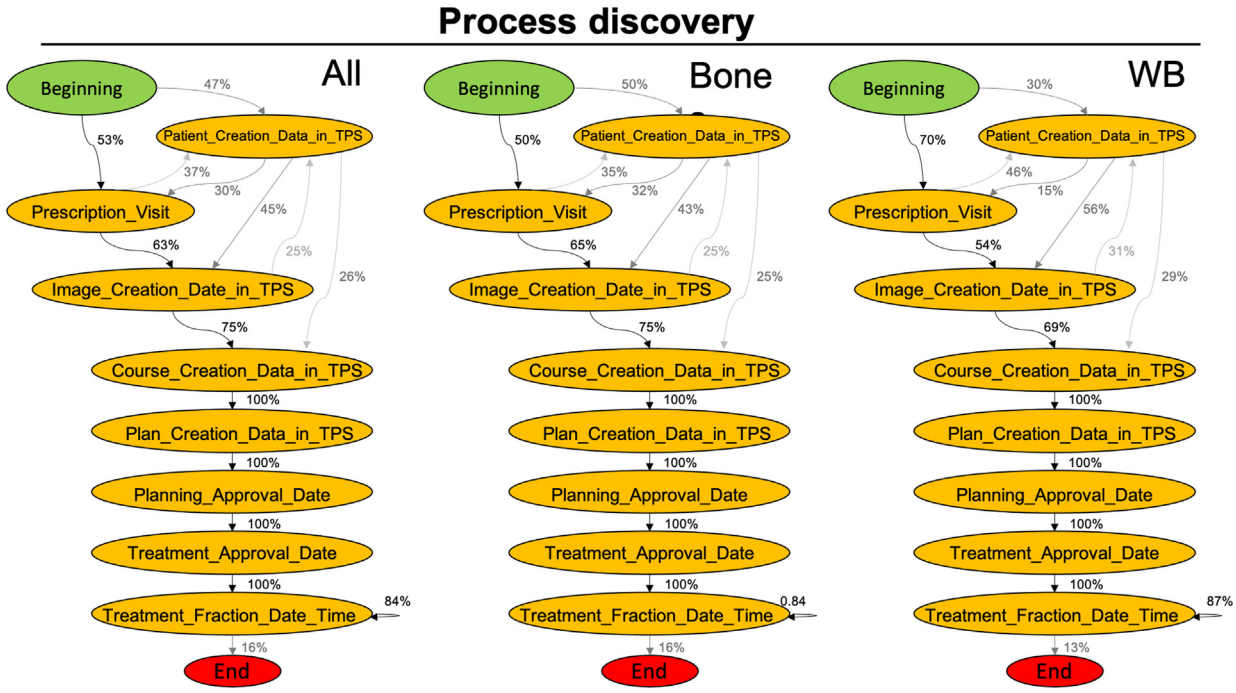

Fig.3. Process discovery analysis for all, bones and whole WB metastasis treatment plans. The percentage of treatment plans passing from one event to another are indicated alongside the corresponding arrow.

Considering all metastatic treatment plans, the first event for 53% of them was the dose level prescription and for the remaining 47% the creation of the patient in the TPS, where patient data general information is entered. This first path distinction is due to the fact that a relevant number of the considered patients (47%) had been already treated in our department and were therefore previously registered in the TPS database.

In 37% of the cases patient data was entered as the step following the prescription visit were dose level and fractionation scheme is assigned, while the other 63% of the cases, images required for treatment planning (planning CT) were acquired highlighting once more a significant number of patients that have been already entered in the TPS and have therefore received already a radiotherapy treatment. Consequently, in the 75% of the cases treatment course creation in the TPS was completed as the step following the acquisition of planning CT images, while the remaining 25% there was the need to first entered the patient data in the TPS.

On the other main arm of the workflow, after the filling of the patient data information in the TPS, for 45% of the patients, a planning CT was acquired and the relative images were imported in the

TPS, for 30% of the cases the RO completed the treatment dose level and fractionation scheme prescription and for the remaining 26% cases, treatment course was straightly created in the TPS.

Some consecutive workflow processes, especially cyclical ones, are partially hidden, since the PDA results (Fig. 3) show only the first connection between events corresponding to the first-order Markov Model analysis, which describes the transition from the first state to the second, computing only the transition probability from one state to the other. The hidden workflow processes have been not visualized to provide an easier understanding of Fig. 3 that would have been even more hard to follow.

The workflow processes for the bones and WB metastases group are similar; the only remarkable distinction is the different percentage of cases going through the first evaluated event. Concerning the bones group, half of the cases have as first event of the workflow the dose level and fractionation scheme prescription. Whereas, for the WB metastases group, in the 70% of the cases the RO prescribed the dose level and fractionation scheme as first event of the workflow, while in the remaining 30%, patient data was entered in the TPS.

Conformance checking analysis results are described in Fig. 4: 41 out of 500 plans showed a dose prescription different from 8, 20 or 30 Gy, as shown in T01, T02 and T03 considering the bone and WB metastases group separately.

Concerning the bone metastasis patients, 406 out 438 plans had a dose prescription of 8, 20 or 30 Gy. All the 51 plans with a prescription dose of 8 Gy, single fraction, run through the complete workflow untill treatment delivery. This is not the case for the plans with 20 Gy and 30 Gy prescriptions: 4 and 1 plans (with a dose prescription of 20 Gy and 30 Gy rispectively), were not delivered.

Regarding the WB group, all the 53 plans with a prescription of 20 Gy (34 plans) and 30 Gy (19 plans) went through the whole workflow until the treatment delivery.

The results related conformance checking of the temporal range between the prescription visit and the first radiotherapy treatment fraction, are shown in Fig. 5.

Table 2 lists the minimum, median, mean and maximum number of days from dose level and fractionation scheme prescription (Prescription_Visit) to first radiotherapy fraction delivery (Treatment_Fraction_Date_Time) event. These values should be compared with the reference daily clinical practice values (column PWF_ref) provided by the RO to respect the theoretical process model. Maximum values out of range were observed in patients with unexpected complications (i.e. fractures, toxicities related to other oncological treatments, patient's decision). The percentages of the treatment plans that failed to be in accordance with the reference daily clinical practice values (PWF-ref) were for the bones group 54.9%, 34.1% and 17.3% respectively for the 8 Gy, 20 Gy and 30 Gy dose level prescription. Concerning the WB group, the percentages were 8.8% and 15.8% respectively for the 20 Gy and 30 Gy dose level prescription.

Discussion

The actual palliative radiotherapy patient flow in our department was revealed during process discovery, demonstrating that some relevant steps are not always in agreement with the proposed PWF. This kind of information is essential to understand and further improve the management of palliative patients in our department.

The process discovery clearly shows where palliative patient flow is more straightforward and where it is more complex, in terms of different possible series of events, as shown in Fig. 3. Based on the total number of prescribed doses and services available, palliative patients pass parts of the patient flow multiple times.

The conformance checking analysis revealed that the majority of treatment plans run through the given PWF model, even though some exceptions exist, which are useful to further improve patient flow. Results obtained during conformance checking are extremely useful and necessary to proceed with the process enhancement step: the given PWF model can be adapted to better fit success and failure cases observed during the conformance checking analysis into the process.

The process mining methods presented can be employed in any radiotherapy department, regardless of its dimension, technologies and number of patients. A first implication of this study is the prospective merging of the entire department data information system to standardize at best data entry, which simplifies data

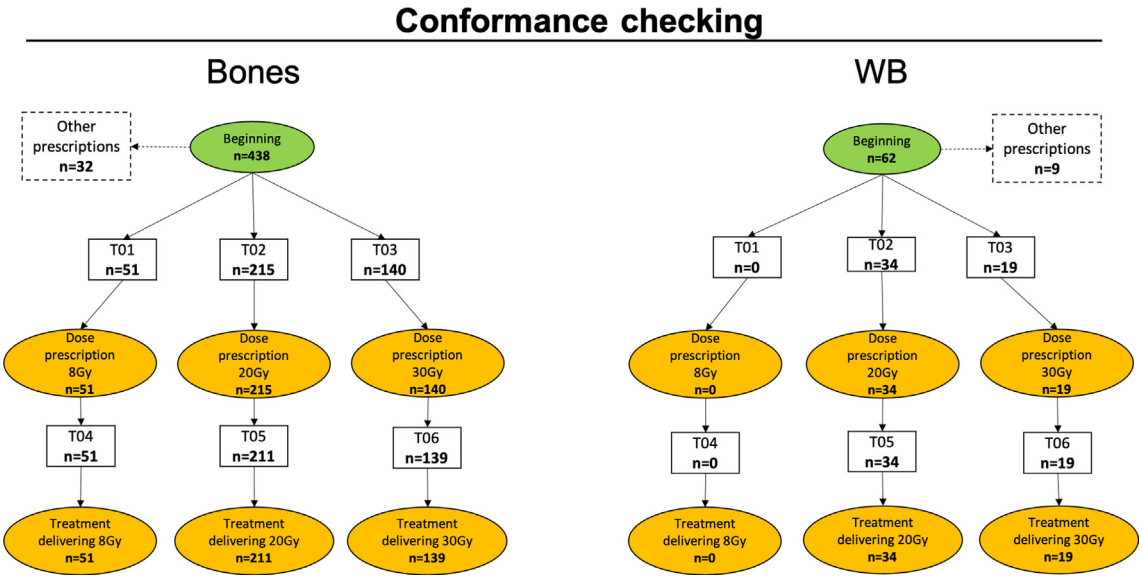

Fig.4. Conformance checking analysis for bone and WB metastasis treatment plans. Triggers are shown in the white square and display the number of plans that apply successfully the trigger's condition.

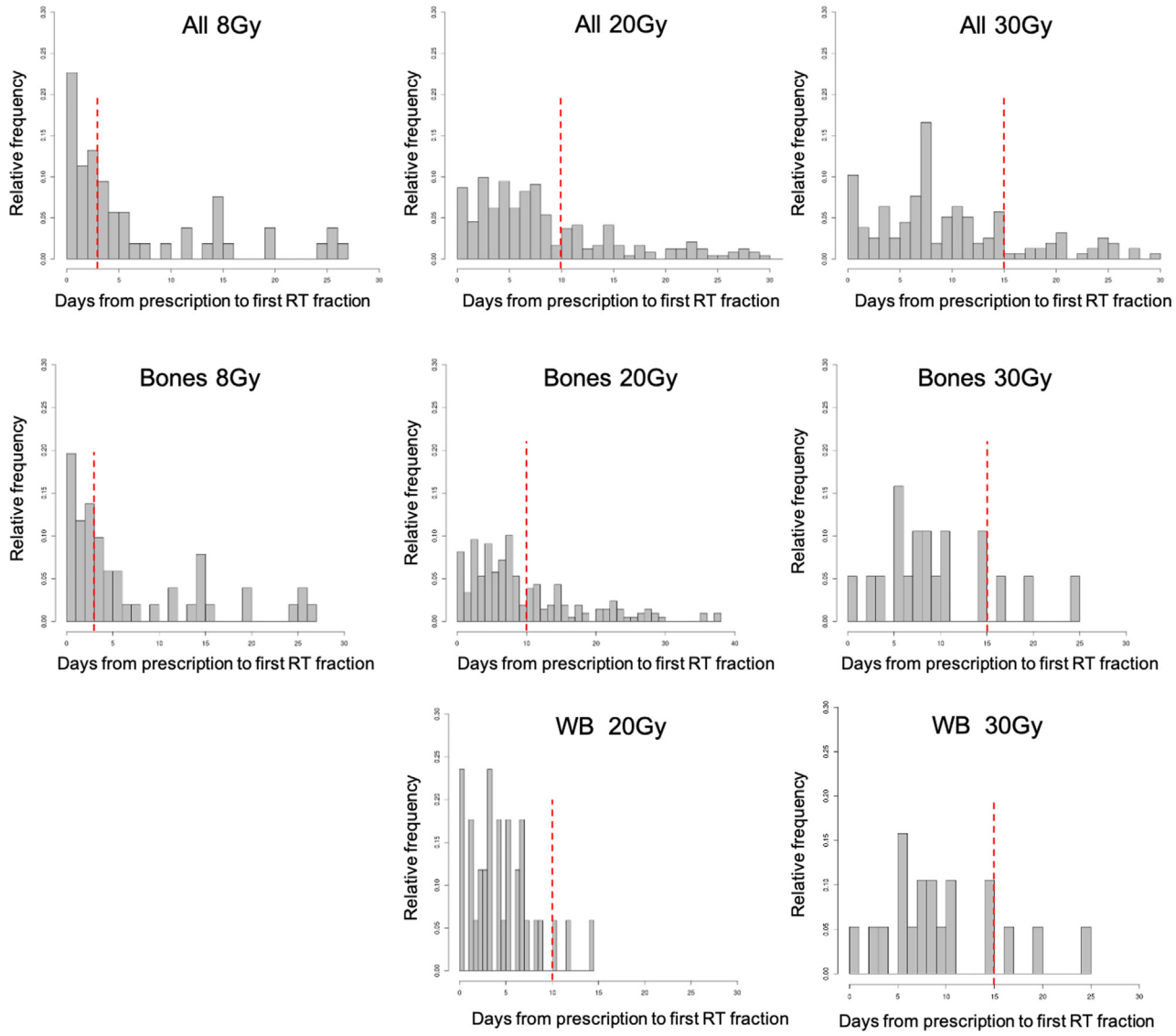

Fig.5. Histogram of days from the dose prescription to the first radiotherapy treatment fraction. Red dotted lines show the maximum numbers of days defined by the RO in the PWF model. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2
Minimum, median, mean and maximum days from dose prescription ("Prescription_Visit") to first radiotherapy treatment fraction ("Treatment_Fraction_Date_Time") for the bone, WB metastases group and for all patients.

		Days from prescription to first radiotherapy fraction			
	PWF_ref (days)	min (days)	median (days)	mean (days)	max (days)
All (N = 500)					
8 Gy	3	0.03	3.31	6.57	26.26
20 Gy	10	0.01	6.70	8.65	37.02
30 Gy	15	0.03	7.90	9.54	29.11
Bone (n = 438)					
8 Gy	3	0.28	3.31	6.81	26.26
20 Gy	10	0.01	7.03	9.32	37.02
30 Gy	15	0.09	8.24	9.47	24.46
WB (n = 62)					
8 Gy	3	–	–	–	–
20 Gy	10	0.04	4.18	4.57	14.26
30 Gy	15	0.09	8.24	9.47	24.46

minimum (min), maximum (max); the reference daily clinical practice values provided by the RO in the PWF model are reported in the column PWF_ref. Since no WB metastasis patient was treated with 8 Gy, related columns are empty.

extraction. An interesting prospective is to fully integrate process mining methods with electronic health records to create a "watchdog" software system, which automatically identifies cases at risk leaving the expected treatment paths. Therefore, we plan to develop an online decision-making system, to support physicians in online tracking to manage the palliative patient flow.

Some studies have already demonstrated that process mining can be of added value in oncology [21,22]. As far as we know, this is the first study where process mining is applied to real world palliative patient care flows in a high-volume radiotherapy department.

The proposed methodology of process discovery and conformance checking has been applied only to palliative patients' event-logs, but the analysis can be more extended. This could allow to increase the granularity of the considered event-log by the process discovery algorithm, as well as the timespan of the entire event-log, including events before the RO dose level and fractionation scheme prescription and after the end of the treatment.

Another relevant strength of the proposed method is represented by the results derived from the conformance checking analysis: this is a powerful tool to control and manage palliative patient's workflow based on specific guidelines, introducing warnings if a deviation from the guideline occurs during the expected palliative care path. In particular, the percentage of the treatment plans that failed to be in accordance with the given PWF highlights that, especially for the bones group with a dose prescription of 8 Gy, improvements could be achieved and outliers could be reduced to better fit the real workflow to the proposed PWF.

Amongst our limitations, the number of plans/patients enrolled in this retrospective study is limited and the event-log generation is related to a data entering system that could be improved.

Data extraction has been performed from two different databases (TPS and SpeedRo), requiring an additional effort to merge datasets in a unique event-log list, which underlines the need to limit data entry systems in clinical practice to maximize data actionability and potential sources of error in data codification.

Moreover, we encountered problems when including in the process discovery algorithm all the attributes related to the pretreatment and follow-up visits, or other information like the presence of any concomitant treatments (for example chemotherapy) that could have impacted the treatment timeline. This is related to the fact that automatic extraction of attributes was impractical, because the current absence of specific events did not allow any association. For this reason, clinical descriptive parameters, such visual analogical scale values, as well as the symptomatology of the patient, were not possible to be considered for the process discovery algorithm. In most of the cases, a standardize procedure is absent to fill in the mentioned attributes as they are often included as a free text. This very common scenario represents a real obstacle affecting efficiency of process mining methods by compromising the automation of the event-log generation. A possible workaround could be employing text mining [23] to discover knowledge from textual data. Physicians use often words that contain useful information, not captured elsewhere. Hence, text mining converts text into a numeric form that allows its use for analysis.

Based on these results, we are already changing our clinical practice, to better improve the quality of the logs file dataset, enhancing and standardizing data entry, in particular in the pretreatment and follow-up visits.

Our future aim is, once data entry will be improved and standardized not only for the considered logs, but also for many more, to perform process enhancement that will allow to improve the connection between clinical guidelines and the resulting flow through the chain of the events. This will result in a continuative decision-making system supporting the proposed PWF model to optimize our palliative patient flow.

The proposed process mining approach can be easily translated to any radiotherapy department, regardless its dimension, technologies and number of patients to exploit the huge amount of data available in order to optimize the workflow first and possibly improve the radiotherapy treatment.

Conclusion

Process mining was found to be a powerful method to describe and monitor palliative patients flow in a high-volume radiotherapy department. The obtained preliminary results of this study identified required changes in terms of patient flow defining relevant event attributes.

Palliative patients could benefit significantly of this approach, not only in the optimization of the treatment itself following the clinical guideline, but also taking advantages of logistics concerning the entire previous and subsequent events of the treatment. Process mining can be used to provide new insights, which facilitate the improvement of existing palliative patient care flows.

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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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Ethics and data protection approvals.

Ethics approval All procedures performed in this study were in accordance with the ethical standards of the institutional Italian committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent to participate and for publication. Informed consent for radiotherapy, data and publication entry was obtained from all individual participants included in the study. However, this retrospective study has involved fully anonymized data according with the RGDP n. 2016/679.

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