**Producing effective treatment, enhancing safety:
medical physicists' strategies to ensure quality in radiotherapy**

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Abstract

The purpose of this article is to understand the way in which medical physicists take into account treatment effectiveness and safety when selecting a treatment plan, with respect to the medical prescription and the technical, human and organizational resources available. Data-gathering was based on the allo-confrontation method: 14 medical physicists from five different treatment centers commented on real treatment plans that had been drawn up by their colleagues. Results show that medical physicists have two means at their disposal to control treatment effectiveness and safety: risk avoidance and risk reduction. Risk avoidance is achieved when conceiving the solution. Risk reduction occurs after the design of the plan and consists in accompanying and assisting the radiographers at the work station where the treatment is carried out.

Key-words: safety, effectiveness, quality, radiotherapy

1. Introduction

The US Institute of Medicine reports « Crossing the Quality Chasm » (2001) describes the following dimensions of quality in health care: (1) Safety, (2) Effectiveness, (3) Patient centeredness, (4) Timeliness, (5) Efficiency and (6) Equity (Berwick, 2002). This research has considered dimensions 1 and 2, treatment safety and effectiveness. The goal is to investigate physicists' strategies when a possible conflict between these two dimensions arrives. In this text, « quality » refers to the respect of these two dimensions in radiotherapy treatment.

1.1 *Quality in radiotherapy : effective treatment and patient safety*

Every year in France, about 180 000 patients suffering from cancer pathologies are treated by radiotherapy. Radiotherapy is a medical technique that consists of irradiating a tumor by means of a beam of ionizing irradiation. The objective of radiotherapy is to reduce the volume of the tumor by optimizing the concentration of the prescribed dose within the tumor itself and minimize irradiation of surrounding healthy tissues (Le Bourgeois, 2006). In practice, this is carried out through sessions in which fractions of the total dose are administered using various techniques which determine the shape of the radiation beams and the parameters of the machines used in the treatment.

The advantages of this treatment modality include a good effectiveness (40% of cured patients have had a radiotherapy), the conservatory aspect of the treatment (no surgery), and a good cost/effectiveness ratio (in France, cancer treatments cost 12 billions euros per year, including 0,9 billions of euros for radiotherapy) (Le Bourgeois, 2006).

Although radiotherapy contributes in a large way to the cure of cancer, it nevertheless presents

risks that can have important consequences for the patient's health, as recent accidents that have occurred round the globe have shown (CIPR, 2003; Cook, Nemeth, & Dekker, 2008; Nascimento, 2009; SFRO, 2008). Exposure in radiotherapy is considered to be accidental if there is a wide discrepancy between the prescribed parameters for radiation and the actual treatment (dose/volume) administered to the patient. The difference can be due to overdosage (the dose administered is higher than the one prescribed) or underdosage (the dose administered is lower than the one prescribed): both must be avoided (CIPR, 2003).

Patient safety in radiotherapy has become a public issue in France following the radiotherapy accident which occurred in Epinal in 2005. The investigation report states that, between 1989 and 2005, 4 900 patients experienced an overdosage of 7% caused by a calculation error. This accident is considered to have affected more patients than any other (Peiffert, Simon, & Eschwege, 2007).

The publicity given to this accident has led to increased quality requirements in radiotherapy: on top of clinical effectiveness, radiotherapy has to be safe.

1.2 Radiotherapy care providers : the role of medical physicists

In France, the preparation of treatment plans in radiotherapy requires four types of professionals: radiation oncologists, medical physicists, dosimetrists and radiographers. The radiation oncologist is responsible for prescribing the treatment (method and total amount of radiation). Radiographers simulate patient positioning and fashion immobilization devices at the simulation work station. Following this phase, a medical physicist and a dosimetrist work together to design the treatment plan (beam distribution, dose fractionation). This plan is assessed by the radiation oncologist. On the basis of this plan, radiographers define the real

conditions for positioning the patient. These last modifications are then checked by a medical physicist. Finally, radiographers administer the actual treatment.

It should be noted that the physicists contribute to the radiotherapy treatment chain at a point situated between the physician's prescription for treatment and the administration of the treatment by the radiographers. On the one hand, they must design a treatment plan that conforms to the constraints determined by medical protocol and/or the physician in charge of the patient. This phase is carried out virtually: using dedicated software, the physicist tests various combinations of beams (angular position, intensity, use of filtering devices, etc.), and checks the resulting distribution of the dose. This "virtual phase" results in a "treatment plan"¹, which, after validation by the physician, will be implemented by the radiographers. On the other hand, they must make sure that the treatment plan actually can be carried out in real situations – according to the material and human resources that are available – and in safe conditions, i.e., conditions that allow the radiographers to control the risks involved in administering the treatment. The physicists' objectives are thus to guarantee the effectiveness of the treatment (and therefore the health of the patient), by means of a treatment plan which complies with the medical prescription, and to ensure patient safety by minimizing the risks, if any, in implementing this plan.

Even though scientific and technological progress has contributed to improving healthcare in terms of clinical effectiveness, the gains for patient health are accompanied by the presence of new risks for patient safety (ANAES, 2003; Carayon, et al., 2006). Indeed, medical physicists have access to highly effective techniques, which meet the requirements of the medical prescription, but which present certain risks, especially regarding the difficulties the radiographers encounter in executing the treatment. These situations may lead to conflicts

¹ A treatment plan determining the quantity and the placement of the radiation beams, the distribution of the beam dose, the positioning of the patient and the accessories to be used.

between treatment effectiveness and safety. In some cases a treatment may be very effective from a clinical point of view, but very risky to carry out. If the risks of implementation are reduced, the opposite situation may arise: the treatment will carry fewer risks, but will also be less effective at the clinical level. At some point a decision must be taken to reach the best compromise between effectiveness and safety.

The conflict between effectiveness and safety is not particular to radiotherapy. Various authors have identified such a conflict and described the way in which it is managed in other situations (Caroly & Weill-Fassina, 2004; Gomes, Woods, Carvalho, Huber, & Borges, 2009; Toupin, 2008). The goal of this study is to understand the way in which medical physicists take into account treatment effectiveness and safety when selecting a treatment plan, with respect to the medical prescription and to the available technical, human and organizational resources.

2. Method

The data-collecting method that was used at this stage consisted of presenting real treatment plans to medical physicists using an interview method known as “allo-confrontation”. Allo-confrontation involves asking the subjects to comment on traces of their colleagues’ activities. (Mollo & Falzon, 2004). Such traces can be a video-recording, a plan produced as a solution to a problem, a transcript of a dialogue, etc. In this case the traces were the treatment plans which were provided in paper format. This method is applicable to this study: confronting subjects with an activity they practice but which is performed by someone else, without the latter being present, allows participants to explain their representations about real cases. Additionally, this method help subjects to develop their knowledge by getting aware of other

types of representations (Mollo & Falzon, 2004).

2.1 Sample

We contacted 40 medical physicists attached to radiotherapy centers in the Paris area. For comparative purposes, we chose subjects in centers of differing legal status (Centre de Lutte Contre le Cancer - CLCC, public and private establishments) and differing resources (cutting edge or conventional). Table 1 presents the 5 establishments where the study was conducted. It is to be noted that:

- the two CLCCs are major French research and treatment centers, which possess top-level equipment and a large staff; all observed centers have a record and verify system.

- the three other establishments are smaller-scale hospitals, located in Paris or its vicinity, with good but less diverse equipment and a smaller staff. However, they should not at all be considered as second-class establishments.

The reason for choosing these two categories of establishments is not based on an hypothetical difference in safety or effectiveness, but on the hypothesis that optimal solutions (i.e. safe and effective decisions) are resource-dependent. Resources may be human, technical, organizational.

In all, 14 subjects, (7 women + 7 men) from five different centers participated in the study. The subjects had between two and thirty years of experience in the profession. The distribution of the subjects according to the centers is presented in Table 1. Each subject dealt with the two treatment plans, in the same order.

<i>Center</i>	<i>Status</i>	<i>Number of accelerators</i>	<i>Available means</i>	<i>Medical physicists</i>
A	Specialized Cancer Center (CLCC)	7	Classic	5
			Conformational	
			IMRT ²	
			Tomotherapy	
B	Private establishment	3	Classic	2
			Conformational	
C	CLCC	6	Classic	2
			Conformational	
			IMRT	
D	Public establishment	3	Classic	2
			Conformational	
E	Public establishment	2	Classic	3
			Conformational	
<i>Total</i>				14

Table 1 : Study sample

2.2 Procedure

2.2.1 Selection of treatment plans

The selection of the treatment plans was made possible with the help of a medical physicist from the A sample. The following were chosen:

- one case classified as simple, following a protocol : the medical prescription was

² The technique known as IMRT (Intensity Modulated Radiotherapy Treatment) delivers a standard dose, but also allows for a variation in the intensity of the dose emitted inside each beam. It is thus possible to increase the total prescribed dose, as it will be more concentrated in the target volume, compared with a classic or conformational technique.

respected and optimized, and the implementation did not present any particular risks ; This case concerns a treatment plan for a prostate tumor. The total dose prescribed is 80 Gray distributed in 40 fractions (2 Gray per session, five coplanar beams).

- one case classified as complex, not following a protocol: in order to find an optimal solution for the medical prescription, certain decisions were made. However, this treatment solution, very effective in its virtual version, might create difficulties for the actual implementation of the treatment. The deliverance of the dose may be quite long: this can lead to undesirable movements of the patient on the table (which are a risk for both effectiveness and safety) or to delays at the workstation (which are a source of planning disorganization and stress to radiographers, and ultimately a risk for both effectiveness and safety); these difficulties could be taken into account at another stage. This case concerns a treatment plan for a brain tumor. The treatment is delivered in two sessions: at first the dose prescribed is 24 Gray distributed in 15 fractions (1.6 Gray/session, five non-coplanar beams), then the dose prescribed is 16 Gray distributed in 10 fractions (1.6 Gray/session, six non-coplanar beams).

2.2.2 *Validation phase*

The experimental procedure was validated with the collaboration of a second medical physicist on site A (not the same one who helped us to select the two treatment plans). The validation phase involved presenting the two treatment plans to this second physicist under the same conditions as those were be used for the actual experiment. This allowed us to estimate the physicist's comprehension of the treatment plans presented and to evaluate the time needed for allo-confrontation interviews.

2.2.3 *Follow-up allo-confrontation interviews*

The interview instruction was presented orally to the physicists individually. The first part of the instruction was a review of the research project and its objectives. The instruction itself

177 required the subjects to comment on the two treatment plans. Instructions were as follows:

178 *“I am going to show you two treatment plans drawn up by other professionals. I would like*
179 *you to comment on the choices made by these professionals. What interests us is the logic*
180 *behind these proposals. In dosimetry it is normal to have several different possible solutions.*
181 *The issue is not to evaluate their quality. I would just like you to comment on the choices*
182 *made by your colleagues and to tell me how they resemble or differ from what you would do*
183 *yourself and why you choose to do what you do. I will present one case to you, then the other.*
184 *You can ask questions at any time.”*

185 The individual interviews lasted about 30 minutes and were conducted by the first author on
186 the physicists’ workstation. The data were collected between March and May, 2009. The
187 interviews were recorded, and then transcribed in full.

188

189 **2.3 Data analysis**

190 The transcription of the 14 interviews concerning the two proposed plans provided 28 verbal
191 transcripts (14 subjects x 2 treatment plans). A content analysis was performed manually.

192 Coding categories have been defined in relation to research needs. Five categories have been
193 set: i) criteria used to evaluate solutions ; ii) assessment of solution acceptability ; iii) criteria
194 of acceptability ; iv) proposed solutions; v) strategies aiming at reducing risks in
195 implementing the solution.

196 This paper considers the results regarding the first and the last criteria. Criteria used to
197 evaluate solutions concern factors like the number of beams, their relative intensity, the
198 distribution of the dose within the volume to be irradiated, the type of contention devices the
199 duration of the irradiation, the type of equipment, etc. Strategies aiming at reducing

difficulties in executing a solution may concern either ways to avoid risks (taking in account technical, human or organizational factors as well as patient comfort) or ways to assist radiographers (oral and written communication, actual presence in the irradiation workstation).

The data were analyzed qualitatively by coding the interview, and quantitatively by the frequency of appearance in a given category.

3. Results

In brief, results show that physicists tend to give prominence to the treatment effectiveness in the virtual phase and to consider safety next. But they also show that physicists use prevention strategies in order to avoid execution errors, in particular by taking into account difficulties radiographers may meet.

3.1 Searching for a solution : effectiveness and safety criteria

When analyzing the treatment plans, medical physicists indicated the criteria they used in order to design or evaluate a plan of treatment. Two criteria were identified: the effectiveness of the treatment and the safety of the treatment.

3.1.1 Effectiveness

For the subjects, the “effectiveness” of the treatment means the attainment of optimal dosimetrics, in other words, the maximum success of the treatment from a clinical standpoint. A treatment is effective when the best distribution of the dose has been attained i.e., at least 95% of the prescribed dose is delivered within the target volume and a minimum amount is delivered in surrounding organs, known as “organs at risk”. The effective solution is thus the

one that allows for better control of the tumor with minimum damage to the organs at risk. A first type of trade-off is made at this level. This trade-off takes into account several facts:

- the locally available machines. A solution may be judged theoretically ideal but practically inapplicable due to the absence of a specific technology in the physicist's facility.

- the technical limitations of the available machines. In all, 10 subjects expressed the idea that some solutions that are appealing during the design of the treatment plan (i.e. during the virtual phase) may not be feasible in reality, due to some physical characteristics of the machine. The solution originally planned, considered to be most effective, has to be adapted so that it can actually be carried out.

We have not got any x-ray transparent tables. We have a table and two iron bars. Everything that is done from behind, for example, hits against the iron bar, and so, in reality, we can't actually do it. P13, Center C

Effectiveness is a shared criterion: all of the 14 subjects mentioned the need to fulfill this objective when designing or evaluating a treatment plan.

I look at the dosimetric solution because my priority is for the patient to receive good treatment. That means the prescribed dose for the tumor – and I look at the organs at risk and the healthy tissue as well. P1, Center A

We are scientists, we look at the distribution of the dose, and we always try to find the ideal solution. P12, Center B

3.1.2 Safety

The safety criterion is associated with the implementation risks that a treatment plan may entail. The physicists must make sure that the effective dosimetric solution, as programmed

virtually, can be carried out in safe conditions, i.e. in conditions that allow radiographers to safely perform the treatment. A safe treatment is a treatment carrying fewer risks of mis-implementation at the time it is carried out at the work station. In this respect, safety and effectiveness are dimensions that extend to the implementation of a solution.

Eight subjects referred to the need to attain this objective when they design or evaluate a treatment plan.

This has two consequences:

- the mere availability of a technology is not sufficient to trigger its use. Medical physicists, physicians and radiographers need to be trained to its appropriate usage. Risks of inappropriate usage may prevent its actual use. Such sacrifice decisions, in which a sub-optimal treatment plan is preferred in order to achieve safety, have been observed, as shown in the quotation below.

We received the IMRT machine about 18 months ago. The software, however, has been available less than 12 months ago. We have had more and more patients and we haven't had time to develop the IMRT. Knowing the time needed by the IMRT, we will not be able to take as many patients. As a consequence, we devise beam arrangements which are simpler, but also safer for us. P6, Center E.

- solutions vary in their degree of complexity in the implementation stage. An effective treatment plan may be risky in terms of the required level of precision, of the number of factors to take into account, in the degree of constraint for the patient, etc.

We sometimes have a tendency to try to design a treatment that is perfect on a virtual level, but which will be difficult to execute at the workstation. That is something we must keep in mind. P4, Center D

Thus, a second type of trade-off appears. The good solution in radiotherapy is the one that provides an optimal answer to the medical stipulations (effectiveness) while minimizing risks of implementation (safety).

3.2 Effectiveness-safety trade-offs

Although the intent to find an optimally effective solution is clearly present amongst medical physicists, the solution is not always easy to implement. The quest for optimization thus becomes the object of a trade-off determined by two main conditions: the resources that the physicists have at their disposal and the technical feasibility of achieving the solution.

The quest for dosimetric effectiveness through innovative techniques is not always carried out without safety risks for the execution of the solution. According to some subjects, the more sophisticated the techniques involved in a solution, the more it will be prone to risks, despite the presence of automatic checks.

You can obtain super sophisticated doses, with 10 beams of radiation, non coplanar things, but the more sophisticated the things you do, the greater the risk of error. P7, Center A

In these situations, the ideal solution for a safe and effective treatment cannot be implemented:

- Either one reduces the risks in executing the solution, but then there is loss in effectiveness. This type of compromise is chosen by a few subjects (3/14) who, although aware of the loss in terms of treatment effectiveness, give priority to a gain in safety:

For my part, I prefer a very simple, old-fashioned treatment - something that was already being done 20 years ago, with a square field, and which is perhaps not optimal, but which I know has

stood the test of time - to something new and very sophisticated, but which is often not without its risks.. **P2, Center A.**

It is to be noted that physicist P2 is a young, well-trained professional who belongs to a center which possesses high-performance equipments. P2's preferences are thus not related to lack of training or to an acquired tendency to stick to old-fashioned techniques.

- ... or one maintains the effectiveness of the treatment, despite the increased risk of mis-implementation when the solution is carried out.

This last type of compromise is favored by the majority of the subjects (11/14). It involves accepting certain risks, which need to be taken into account when implementing the solution, in exchange for the certitude of the clinical effectiveness of the treatment.

If we can do something that is optimal and it is possible to implement it, even if it is going to be difficult, we do it. At least in the cases I've seen up to now, that's what we have always done. For the moment, it is more the effectiveness of the treatment that is important, even if it is longer and more complicated at the work station. We prefer to spend more time on it, as long as it is for the good of the patient. **P11, Center B.**

Nevertheless, the analysis of the data indicated that strategies were employed by physicists to enhance effectiveness and safety of treatments. Actually, physicists have some means of control at their disposal in order to deal with the risks. These involve anticipating the difficulties of execution which the radiographers may encounter and setting up strategies to prevent risks, thus allowing them to control the optimal effectiveness and safety of the treatments. The next section presents these risk prevention strategies.

3.3 *Prevention strategies designed to guarantee quality care in radiotherapy*

When medical physicists consider the solution to be risk-prone, they anticipate the risks. The subjects were unanimous in mentioning strategies aimed at facilitating the work carried out by the radiographers at the end of the treatment chain, and thus to reduce the risk of mis-implementation.

On paper, you can be under an illusion of precision. Obviously, on paper the cuts don't move, the patient doesn't breathe, all is well. But in reality, this is not the case, and that has to be taken into account. P7, Center A

To do this, they use of two main types of prevention strategies that allow them to act upon the criteria for the safety of the treatment in order to approach the desired optimal effectiveness: avoiding the risks and assisting the radiographers (see Table 2).

3.3.1 *Avoiding the risks*

Once the virtual design for an optimal solution has been produced, the criteria that the subjects most often refer to are those that take into account the sources of risk in implementing the solution. The aim of verifying these criteria is to ensure that a virtual design for an optimal solution will still be optimal in a real situation. Indeed, physicists reduce the factors that could lead to errors at the source - i.e. the virtual planning stage – either by avoiding the use of “high-risk” work stations (ones that have an overload of patients, old machines or new radiographer) for complicated treatments, or by limiting the complexity of certain parameters of radiation. In addition, physicists can try to improve the comfort of the patient in order to keep them from moving in a way that would compromise the correct delivery of the dose to the prescribed volume. Thus, the physicists check the conformity of at least three sources of risk: the technical factors, the human and organizational factors, and the

344 patient.

345 *We will try to limit the variety of filters because that is a regular source of error: a 30° filter*
346 *instead of a 45° filter, and so forth, that sort of thing. Sometimes we say to ourselves: instead of*
347 *having 5 beams we will try to stay with 4 and adjust other elements. Because you have to go into*
348 *the room every time, you have to change the shields. And the precision in positioning the shields*
349 *is not as good as it could be with multileaf collimator (a pair of independent blades used to define*
350 *a beam with a complicated shape). P4, Center D*

351

352 Half of the physicists mentioned that they adjust certain radiation parameters to avoid
353 “confusing” the radiographer or to facilitate their work. The means used are designed
354 especially to reduce the time involved in manipulation and to minimize errors commitment.

355 *For example, for positioning the patient backwards or forwards on the table, we try never to put*
356 *2.38 cm, we put 2.5 cm. We will round off to half a centimeter so that radiographers won't make a*
357 *mistake. P2, Center A*

358

359 Along with these strategies, other strategies are destined to help the radiographers carry out
360 the treatments safely and effectively. They are listed below.

361

362 3.3.2 *Assisting the radiographers*

363 The strategies for assisting the radiographers include not only oral and/or written transmission
364 of solution designs, but also the presence of physicists or dosimetrists by the operator's side
365 when the solution is first implemented. These strategies aim to control the sources of risk that
366 were not already taken into account during the virtual conception.

367

368 The oral and/or written transmission of solution designs

369 In all, 13 of the 14 physicists mentioned that when a solution is complicated or unusual, the
370 routine instructions for implementing the treatment that are provided in the file are re-
371 enforced, and any possible changes are indicated. This is a way of anticipating certain
372 difficulties that the radiographers could encounter during a treatment session.

373 *For the complicated cases, I go see the radiographers and I say to them “Look, I’ve planned a*
374 *treatment where there are only oblique beams, so it’s complicated”. But I tell them why: “Because*
375 *of the way the target is, I can’t treat it with a classic technique, so I prefer to warn you that you are*
376 *going to have a bit of trouble, but it is for the good of the patient”. P10, Center E*

377

378 Presence during the first implementation of a complicated solution

379 For the non-standard cases, giving instructions alone is not sufficient to reduce the risks
380 involved in carrying out a complicated solution. As a matter of fact, nine of the 14 subjects
381 mentioned that one of the ways to reduce the complexity of a solution was to be present for
382 the first implementation, that is, to be present in the x-ray room with the radiographers, in
383 order to better control the risks.

384 *I have to admit that I find it hard to change a technique without going and showing them, without*
385 *going and seeing it with them [the radiographers], and being aware of their difficulties too,*
386 *because, if you are not right there, you don’t see it. P6, Center E*

387

388 The identified risk prevention strategies used by medical physicists and discussed previously
389 are presented in Table 2.

390

ENHANCING PATIENT SAFETY	Avoiding risks	Accounting for technical factors (n=8)	Type of machine	Avoid sending complicated treatments to old work stations
				Limit the complexity of manually controlled radiation parameters
			Radiation parameters	Adjust certain risk-prone parameters despite presence of automatic controls
			Quality and type of contention	Take into account to determine length of session
		Taking human and organizational factors into account (n=6)	Radiographers' experience	Avoid sending a complicated treatment to a work station where the radiographers are novices
			Workload at the station	Avoid sending a complicated treatment to a work station where there is an overload of patients
			Quantity of complicated cases per day	Avoid sending a complicated treatment to a work station where there is a large number of complicated treatments per day
		Taking patient comfort into account (n=6)	Position difficult to maintain/Patient suffering from pain/Children	Avoid positions that are difficult to maintain for a long period, especially for patients suffering from pain or for children
		Assisting	Oral or written	Warning messages indicating a non standard treatment

	Radiographers	transmission	Instructions indicating a call for help
		(n=13)	Instructions for positioning
		Presence of the medical physics team (n=9)	Oral instructions, verification of the reproducibility of the simulated positioning

Table 2 : Risk prevention strategies

4. Discussion

4.1 Strategies for maximum performance

The diagram shown in Figure 1 summarizes the main findings from the study, i.e. the applicability of an ideal solution and the possible compromises with regard to this ideal solution.

Figure 1 : Diagram of the applicability of an ideal solution

We should note in this Figure that, in the absence of resources, the search for a compromise is not a matter of choice for the medical physicists. They are obliged to abandon the quest for an ideal solution and to be content with a solution consisting of a satisfactory compromise. If the ideal solution is possible with the available resources, the physicists will seek to achieve optimal effectiveness with this solution. Thus, the optimal solution is always a local one: it is resource-dependent. In the presence of risks, the majority of physicists will pursue the quest of maximum effectiveness, because they have a certain number of strategies allowing them to take action to prevent risks. Nevertheless, even though they take a calculated risk, it is a risk all the same. This implies a certain degree of compromise on safety, and confirms the presence of a very specific characteristic of the medical profession, i.e., the quest for optimal

performance in terms of treatment effectiveness (Amalberti, Auroy, Berwick, & Barach, 2005; Woods, 2006).

We have seen that a minority of subjects will not take this risk (3/14). This decision may be due to an absence of the resources necessary for ensuring the safety of a risk-prone optimal effective solution. Some subjects will therefore prefer to compromise on effectiveness and return to a safer, more classic solution.

4.2 Errors, effectiveness and safety

The notion of error does not have the same meaning when considering the two criteria and when considering the trade-off between the two criteria.

- In the effectiveness context, an error is a treatment plan that fails to optimally distribute the dose according to the standard (95% in the prescribed zone, as little irradiation as possible in the organs at risk).

- In the safety context, an error is an inaccurate implementation of the treatment plan: failure to set a protection device, wrong duration of the irradiation, wrong positioning of the patient, etc.

- In the effectiveness/safety trade-off, an error can be :

- o either the choice of a treatment plan that may lead to safety errors when these potential errors are not foreseen and protected by prevention barriers devised by the physicist (dangerous trade-off);

- o or the choice of a treatment plan that is perfectly safe but suboptimal in terms of effectiveness (ineffective trade-off).

4.3 Informal safety practices that should be encouraged

The physicists' strategies reveal that they take into account their colleagues' activities when

carrying out their own activities. This constitutes a guarantee of cooperation in the interest of safety (Manser, 2009). The physicists' objective is to make sure that the virtual optimal solution will be optimal in real situations. However, this activity remains "invisible" inside the organization, and therefore, unrecognized, even though it is costly in terms of time: time for implementing the risk reduction strategies, and time for being present to assist the radiographers. Thus, as soon as the organization has a sufficient number of physicists available, it must calculate the amount of time that can be allotted to this type of safety work. An awareness of the work other people carry out in the interest of enhancing safety must also be shared by all the actors involved, including during the period of their initial training, in order to maintain a common level of awareness about the importance of the work of the whole group for the work of each individual.

4.4 Limits of the study

In order to investigate the compromises under study, a semi-experimental method was used, which exclusively focused on the medical physicists' point of view. It would have been useful to observe conversations between physicists and physicians when discussing compromises for difficult solutions. This would have allowed us not only to analyze the content of the different exchanges and compare the differences between various physicist-physician teams, but also to study the same physicist in relation to the different physicians he/she is dealing with. These limits could be taken into account in a study of the points of view of the physicians and of physician-physicist teams when conflicts arise between the effectiveness and the safety of a treatment.

5. Conclusions

In cases of conflict between the effectiveness and the safety of a solution, the majority of the physicists give priority to effectiveness, achieved by means of a treatment plan. In designing this solution, the ease of execution for the radiographers is not a factor that is taken into consideration. Safety is handled in a second step, by facilitating or assisting the implementation of the treatment. In particular, the results show the important role of oral and written transmissions, and of the presence of a physicist/dosimetrist at the radiation workstation when complicated treatments are administered. These strategies are shared by the majority of physicists and are a sign of a strong culture of effectiveness, based on the optimization of medical protocols and associated with a culture of safety, founded on the prevention of risks at the workstation. The former is prescribed by the formal rules of radiation, while the latter is not formalized and belongs to the realm of practical knowledge about the radiographers' situations, organization and work.

Thus, obtaining patient safety via risk management, as it is implemented by medical physicists in radiotherapy, is much like that observed by Amalberti (1998) when he developed the concept of ecological safety. In this perspective, risk management undergoes a metacognitive evaluation³ that gives the operators the sense that they master the situation. During this evaluation, they take into account the objective risks that are attached to the consequences of errors, and the internal risks, i.e. the consequences of not being up to the task (Amalberti, 1998). This allows them to target maximum performance, that is to say the production of effective treatments, while at the same time providing barriers for controlling the previously identified risks.

Adverse outcomes are too frequently attributed to those who provide radiotherapy. Contrary to this, the findings of this study indicate consistent concern for and efforts to enhance patient

³ The Oxford Dictionary of Psychology (2003) defines metacognition as knowledge and beliefs about one's own cognitive processes (cognition about cognition). In our case, a metacognitive evaluation allows subjects to assess their awareness of the management of risks and their ability to adapt to challenges that occur during this process through effective strategies

safety while providing effective treatment by those who plan and implement radiotherapy. Thus, when an adverse outcome occurs, rather than automatically blaming the technician, others possible contributing factors, such as the design of the radiotherapy device, are candidates for consideration.

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References

- Amalberti, R. (1998). *Gestion dynamique des erreurs et contrôle de processus*. Paper presented at the au XXXIIIème congrès de la SELF, "Temps et travail", Paris.
- Amalberti, R., Auroy, Y., Berwick, D., & Barach, P. (2005). Five System Barriers to Achieving Ultrasafe Health Care. *Annals of Internal Medicine*, 142, 756-764.
- ANAES. (2003). *Principes méthodologiques pour la gestion des risques en établissement de santé*: Rapport de l'Agence Nationale d'Accréditation et d'Evaluation.
- Berwick, D. M. (2002). A User's Manual For The IOM's 'Quality Chasm' Report. Patients' experiences should be the fundamental source of the definition of "quality. *Health affairs*, 21(3).
- Carayon, P., Schoofs Hundt, A., Karsh, B.-T., Gurses, A. P., Alvarado, C. J., Smith, M., et al. (2006). Work system design for patient safety: the SEIPS model. *Qual Saf Health Care*, 15, 50-58.
- Caroly, S., & Weill-Fassina, A. (2004). Evolutions des régulations de situations critiques au cours de la vie professionnelle dans les relations de service. *Le travail humain*, 67(4), 305-332.
- CIPR. (2003). *Prévention des expositions accidentelles chez les patients recevant une radiothérapie* (Vol. Publication 86): EDP Sciences.
- Cook, R., Nemeth, C., & Dekker, S. (2008). What went wrong at the Beaston Oncology Center? In E. Hollnagel, C. Nemeth & S. Dekker (Eds.), *Resilience Engineering Perspectives : Remaining Sensitive to the Possibility of Failure* (Vol. 1). Aldershot, England: Ashgate Studies in Resilience Engineering.

- Gomes, J. O., Woods, D. D., Carvalho, P. V. R., Huber, G. J., & Borges, M. R. S. (2009). Resilience and brittleness in the offshore helicopter transportation system: The identification of constraints and sacrifice decisions in pilots' work. *Reliability Engineering & System Safety*, 94(2), 311-319.
- Le Bourgeois, J. P. (2006). Place de la radiothérapie dans la stratégie thérapeutique des cancers. In J. J. Mazeron, A. Maugis, C. Barret & F. Mornex (Eds.), *Techniques d'irradiation des cancers : la radiothérapie conformationnelle*. (pp. 13-19). Paris: Ed. Maloine.
- Manser, T. (2009). Teamwork and patient safety in dynamic domains of healthcare: a review of the literature. *Acta Anaesthesiologica Scand*, 53, 143-151.
- Mollo, V., & Falzon, P. (2004). Auto- and allo-confrontation as tools for reflective activities. *Applied Ergonomics*, 35(6), 531-540.
- Nascimento, A. (2009). *Produire la santé, produire la sécurité. Développer une culture collective de sécurité en radiothérapie*. Unpublished Thèse de Doctorat en Ergonomie, Conservatoire National des Arts et Métiers, Paris.
- Nascimento, A., & Falzon, P. (2009). Produire la santé, produire la sécurité : récupérations et compromis dans le risque des manipulatrices en radiothérapie. *Activités* 6(2), 3-23. <http://www.activites.org/v26n22/v26n22.pdf>.
- Peiffert, D., Simon, J. M., & Eschwege, F. (2007). L'accident d'Épinal : passé, présent, avenir. *Cancer/Radiothérapie*, 11(6-7), 309-312.
- SFRO. (2008). Guide des procédures de radiothérapie externe 2007. *Cancer/Radiothérapie*, 12(3-4), 143-313.
- Toupin, C. (2008). *Expérience et redéfinition de la tâche dans le travail des infirmières de nuit : Une recherche menée dans des unités de pneumologie*. Unpublished Thèse d'Ergonomie, Cnam, Paris.
- Woods, D. D. (2006). Essential characteristics of resilience. In E. Hollnagel, Woods D. D. & Leveson N. (Eds.), *Resilience engineering: Concepts and precepts* (pp. 21 - 33). Aldershot, UK Ashgate.