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

3
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10
11
12 **Abstract**

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

23
24 Key-words: safety, effectiveness, quality, radiotherapy

27 **1. Introduction**

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

35

36 *1.1 Quality in radiotherapy : effective treatment and patient safety*

37

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

46 The advantages of this treatment modality include a good effectiveness (40% of cured patients
47 have had a radiotherapy), the conservatory aspect of the treatment (no surgery), and a good
48 cost/effectiveness ratio (in France, cancer treatments cost 12 billions euros per year, including
49 0,9 billions of euros for radiotherapy) (Le Bourgeois, 2006).

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

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

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

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

65

66 **1.2 Radiotherapy care providers : the role of medical physicists**

67

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

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

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

92 Even though scientific and technological progress has contributed to improving healthcare in
93 terms of clinical effectiveness, the gains for patient health are accompanied by the presence of
94 new risks for patient safety (ANAES, 2003; Carayon, et al., 2006). Indeed, medical physicists
95 have access to highly effective techniques, which meet the requirements of the medical
96 prescription, but which present certain risks, especially regarding the difficulties the
97 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.

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

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

110

111 **2. Method**

112

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

122 types of representations (Mollo & Falzon, 2004).

123

124 **2.1 Sample**

125

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

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

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

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

141 In all, 14 subjects, (7 women + 7 men) from five different centers participated in the study.
142 The subjects had between two and thirty years of experience in the profession. The
143 distribution of the subjects according to the centers is presented in Table 1. Each subject dealt
144 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

145 **Table 1 : Study sample**

146

147 **2.2 Procedure**

148

149 **2.2.1 Selection of treatment plans**

150 The selection of the treatment plans was made possible with the help of a medical physicist

151 from the A sample. The following were chosen:

152 - 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.

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

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

167 2.2.2 *Validation phase*

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

174 2.2.3 *Follow-up allo-confrontation interviews*

175 The interview instruction was presented orally to the physicists individually. The first part of
176 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

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

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

206

207 **3. Results**

208

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

213 **3.1 *Searching for a solution : effectiveness and safety criteria***

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

217 **3.1.1 *Effectiveness***

218 For the subjects, the “effectiveness” of the treatment means the attainment of optimal
219 dosimetrics, in other words, the maximum success of the treatment from a clinical standpoint.

220 A treatment is effective when the best distribution of the dose has been attained i.e., at least
221 95% of the prescribed dose is delivered within the target volume and a minimum amount is
222 delivered in surrounding organs, known as “organs at risk”. The effective solution is thus the

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

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

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

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

235

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

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

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

243

244 3.1.2 Safety

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

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

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

253 This has two consequences:

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

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

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

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

270

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

274

275 3.2 *Effectiveness-safety trade-offs*

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

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

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

286

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

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

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

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

296

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

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

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

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

310

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

317

318

319 **3.3 Prevention strategies designed to guarantee quality care in radiotherapy**

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

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

327

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

331

332 **3.3.1 Avoiding the risks**

333 Once the virtual design for an optimal solution has been produced, the criteria that the
334 subjects most often refer to are those that take into account the sources of risk in
335 implementing the solution. The aim of verifying these criteria is to ensure that a virtual
336 design for an optimal solution will still be optimal in a real situation. Indeed, physicists
337 reduce the factors that could lead to errors at the source - i.e. the virtual planning stage –
338 either by avoiding the use of “high-risk” work stations (ones that have an overload of patients,
339 old machines or new radiographer) for complicated treatments, or by limiting the complexity
340 of certain parameters of radiation. In addition, physicists can try to improve the comfort of
341 the patient in order to keep them from moving in a way that would compromise the correct
342 delivery of the dose to the prescribed volume. Thus, the physicists check the conformity of at
343 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

391

Table 2 : Risk prevention strategies

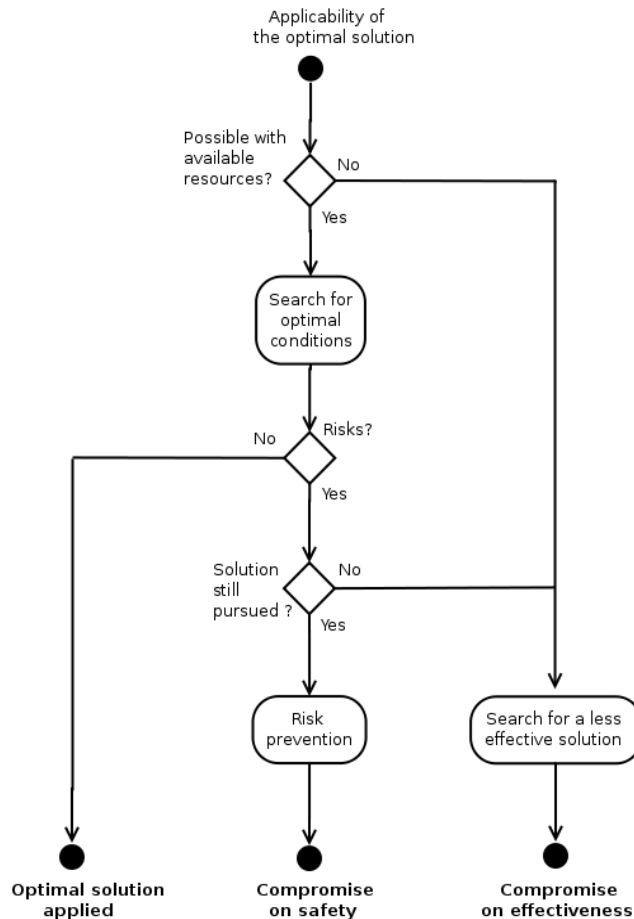
392

393 **4. Discussion**

394

395 ***4.1 Strategies for maximum performance***

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



399
400 **Figure 1 : Diagram of the applicability of an ideal solution**
401

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

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

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

418 *4.2 Errors, effectiveness and safety*

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

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

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

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

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

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

433

434 *4.3 Informal safety practices that should be encouraged*

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

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

447

448 ***4.4 Limits of the study***

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

458

459 **5. Conclusions**

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

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

481 Adverse outcomes are too frequently attributed to those who provide radiotherapy. Contrary
482 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

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

487

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