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Motion management in radiation oncology

Dr Bertholet: Hello, everyone. I will start my presentation and thank you for joining this session. We will be talking about motion management in radiation oncology. And I'm a physicist so, this is more of a technical presentation. What I'd like to cover with you today is motion in radiation oncology. What type of motion do we need to manage in the first place? We will start with a brief overview of the different strategies and then, we'll go a little bit more into detail and for this, I will have to talk also about motion monitoring. And to finish, I'd like to go over the current status in the clinical practice. And feel free to ask questions at any time and we will address them at the end. So, in radiation oncology, there's a lot of motion we have to take into account and the timescale is very important because we would typically take a planning CT and maybe some supporting information from MR or a PET imaging. And the actual treatment will only start a week later and last for several weeks. And during all this time, there are quite some changes that happen in the anatomy. At the target level, the tumour that we want to hit with radiation or the organ at risk or healthy tissue level, the ones that we wanna spare. So, we typically categorize these changes in intrafraction changes and interfraction changes where the interfraction ones happen on a longer timescale and will have an impact from one fraction to the next or one day to the next. An intrafraction changes happen on a much shorter timescale and they already have an impact at the delivery of one single fraction of radiotherapy. So, this is all the kind of things we wanna take into account. Cardiac, breathing and peristalsis motion occur on the short timescale and are typically intrafraction changes. Organ fillings, such as bladder or rectum filling, it also does happen on the intrafraction timescale, but it will also have an impact depending on what's the baseline filling on one day or another. And then, patient will sometimes lose weight, or their body control will change with swelling and things like that due to the treatment itself and have an impact on the day-to-day changes. So, interfraction changes are something you can address with re-planning. Now, there's a lot of enthusiasm for a plan of the day and online re-planning, but today, we're really going to focus on those short-time changes that happen at the intrafraction scale and then it means we need to act very quickly. So, typical organ that moves during radiotherapy and one of the earlier ones that was studied is the prostate. And here, on the right side, you have four different patients. A shift in millimeter on the y-axis as a function of time in seconds. So, you already have a time resolved motion. With the blue line representing the lateral motion, so, in the right-left direction. And longitudinal is the green line. It's like the superior-inferior motion. And the red one is the vertical motion so, in the anterior-posterior direction. And quite a lot of patients will have some drift of the prostate motion. Sometimes, you have more transient motion or even respiratory-like motion in the prostate and sometimes, some more combination of drift and transient motion. This is typically due to gas passing through the prostate or through the rectum, sorry, or the patient relaxing their pelvic bone, pelvic muscles. And more recently, some researchers have found that there's also a rotation of the prostate and also, quite erratic and various types of motion. The lung is also moving. That's not very surprising giving the

breathing motion. And Seppenwoolde did a very nice study where she mapped the motion of about 20 tumours from 20 patients. On this sketch of the bronchi, you can see that the more caudal tumours close to the diaphragm tend to move more than the ones in the upper part of the lung or fixated on the bronchi. And other things she showed very clearly in this study is the hysteresis motion where a tumour takes a different path from inhale to exhale, than from exhale to inhale. And a bit more recently, Schmidt et al. did a similar study. This time, they decomposed this motion that they measured into a respiratory component and a cardiac component. That you can see in blue and in red, respectively. So, once again, quite a large motion, more so towards the lower parts against some hysteresis motion. And respiratory motion, mostly in the superior-inferior direction. While the cardiac motion is more in the anterior-posterior direction. I'd like to bring your attention to the scale here of about a centimeter. In radiation therapy, we're usually aiming in accuracy or targeting accuracy in the order of millimeter or even sub-millimeter. So, having a target that moves by several centimeters, it's really a concern. Just on the other side of the diaphragm, you have the liver. And this is a graph that shows for one patient, the motion or the position in the anterior-posterior direction as a function of the craniocaudal position. And the black clutch shows the motion during cone-beam CT so, that's just before treatment delivery. And you can see that there's a large amplitude in the craniocaudal direction. And this dot represents the mean mode, the mean position during this time. And already at the end of the treatment over the last field of radiotherapy, you can see that the respiratory motion is similar but there was a shift in this mean position. So, on top of the respiratory motion, you also have some drift motion and changes in the respiratory pattern. And some years ago, at the beginning of my PhD, I was looking also once again at the rotation of a constellation of three markers implanted in the liver and we could see that there was some rotational motion also, following a respiratory pattern. And then, in the abdomen, there's also a lot going on. There is respiratory motion as well. This is again, a little sketch similar to the one of the bronchi, but for a pancreas where you can see the motion of different tumours. And when you take a graph of the amplitude as a function of the frequency, so frequency analysis of the signal, you can decompose it into a respiratory signal and other signals that are not consistent with respiratory motion. So, this is what you can see here in this position as a function of time graph. And in this one that was playing before, let's see if I can get it again. You have the stomach that is moving. The first thing you can see is that this is an MR image so, it has a very nice soft tissue contrast. And we'll try to make it play again. Here. In this image, they have corrected for respiratory motion. So, they have kind of completely taken it out to only exhibit this pulsatile motion and the traveling wave that you have in the stomach due to peristalsis and gastrointestinal activity. And this is something we know happens but with more and more use of MR imaging in radiation oncology, we get to see this type of motion much more clearly nowadays. So, that would be for a summary of some of the motions we can see in radiation oncology. There are lots of organs that are moving and now, how can we actually address this motion? And margins are a big way to do that. Most of the examples, I will show you, are for respiratory motion because I think it's the main player, and at least for the margins, we have a pretty good system to account for this mostly periodic motion. So, I could probably give a 45-minute lecture on margins alone. I'm gonna try and give you an idea of the basic concepts, but this paper you can see here is really a reference when it comes to margin for respiratory motion. So, imagine you have a patient that is breathing, and you take a 40 CT. So, when you take a 40 CT, you bin the data that you get depending on the breathing phase of the patient and you reconstruct not only one volumetric image but 10 images also with a zero phase at the end exhale or inhale and then phases in between up to the other side of the breathing signal. And if we move this scale now to a simple sketch with maximum exhale up there and maximum inhale down there. If you take any random phase there or if you take just one 3D image, let's say that's where you see your tumour. It's somewhere between exhale and inhale but it doesn't correspond to any position really. So, one way you can do to ensure or at least increase the probability that you hit the target with your treatment beam is to apply some margins and there are some recipes to calculate these margins. So, this PTV margins. First thing I would like to point out is that these margins are actually aimed at integrating all sorts of uncertainties in the radiotherapy process and you can see motion or position changes as one type of uncertainty. So, the first component that we include is all the systematic errors. Typically, you can see that if

this is the time-weighted position of your tumour during a breathing cycle, there's already a systematic error by the fact that the image you're using doesn't correspond to this mean position. So, that's a big error, and it has a big weight on your PTV margin. And then, there are random components, and you can see the breathing motion as a random component of the motion, and it has a slightly lower influence on the margin. The last component is the penumbra because the beam doesn't stop very sharply at the edge of the field, but there's a bit of diffusion to the side. This could actually be a good thing when you're trying to hit a tumour that is moving within the beam. So, this is one type of margins you would maybe have to calculate if you take any kind of image. Another approach that is very often used in the clinic is the internal target volume, where you delineate your tumour in all of those phases, and you create this big envelope that encompasses the position of the tumour in all of the breathing phase. You can see there is still a PTV margin here in orange. This is for all those other types of uncertainties you have in the radiotherapy process. But basically, this is the same as if you say respiratory motion is a purely systematic component of the error. And the mid position concept is choosing your planning image, such that the anatomy as in this mean position, time-weighted position and then, you get rid of the systematic component, and you can include the respiratory motion as a random component of your margin and it's already quite a lot smaller than the first version. So, let's go to other types of motion mitigation. Here you have the margin concept. This is a pretty big ITV for a tumour that moves a lot. Here, you have a second graph with a tumour that moves a little less. This is with abdominal compression. This is used sometimes in the clinic where we use a plate or a belt to press on the abdomen so that we can reduce slightly the amplitude of the breathing. But the main problem with that is that you have very large margins and also, that whatever was the breathing cycle of your patient when you took the planning image, there's actually no guarantee that the breathing cycle would be similar during treatment delivery, so, your tumour might still move outside of this envelope. Other methods to mitigate motion that are active methods include three big families. There's breath-hold where you ask your patient to take a few deep breaths and then hold their breath and you can basically treat in a static position. Another solution is gating. If the patient is maybe not able to hold their breath, you can simply turn the beam on and off when the tumour is in the desired location, but this will make your treatment longer. This one is maybe the most intuitive. If the tumour moves, you just follow it with the beam. That sounds simple, but it's actually technically quite demanding. But with that, you can track any kind of motion. Breath-hold obviously only works for breathing motion, but tracking could help you track also the kind of erratic motion we saw in the prostate, for example. So, once again, you are reminded you can ask questions whenever you want. I would like to go a bit more in detail into the active mitigation technique. So, one of the things that makes this tracking quite complex is that if you wanna follow a tumour with the beam, well, you need to know where it is in real-time and all the time. So, that's what brings us now to the topic of motion monitoring and it really comes in any kind of flavor and a lot of flavor. You can use all sorts of imaging like x-ray imaging, MR, ultrasound, surface imaging, and you here have other systems like electromagnetic transponders or breathing surrogates, and some methods that combine those signals. You can broadly categorize motion monitoring methods into three families with dedicated systems. Often these systems have, they were really designed for motion monitoring and for motion mitigation. They give you everything in one platform, but they tend to be quite costly and not very widely available. There are some systems that you can use as add-ons to a conventional Linac. So, this is the kind of treatment machine you have in pretty much any hospital, and you just need to bring in this additional equipment, but it is still quite costly and it's often a machine specific. So, also less available. There are some techniques you can do on a standard Linac system alone and we will talk briefly about it towards the end. So, I wanna start by three specialized systems. So, this category of specialized machines that are made for motion monitoring and full motion mitigation, and they use a hybrid kV, so, x-ray, and optical monitoring. And the three of them have x-ray sources, either in the floor, here or in the ceiling, here or in a ring entry, here. And they also all have an optical monitoring system in the ceiling, so, the camera that you can see, here. So, let's start with the ExacTrac. Actually, this one can be used on any Linac, but you can see it's pretty bulky equipment in a room. The idea is that prior to treatment, you will monitor the breathing signal of the patient with the optical monitoring, and you can take some images

to set up your patient accurately. And you can define the gating level, which is like your reference at a gating window and that's when you want your beam to be turned on. So, during treatment, you can use just the breathing signal and turn the beam on and off when you are in this gating window. However, the breathing signal and the correlation between this optical signal and the tumour position can change over time. So, you might wanna acquire some images also at some given time points to verify that the correlation model is still valid and if not, you can stop the beam, reposition your patient, and then keep going. This is the CyberKnife system. It has a robotic arm to deliver the radiation and it can move in any direction to adapt to the position of the tumour. And the Vero system, which unfortunately, has been discontinued now. The Linac is mounted in the ring entry, and it's positioned on some gimbals so, it can tilt the position like this or pan like that to also adapt to a moving tumour. The principle is quite similar to the ExacTrac system. There's a phase just before treatment, where we take kV images and a breathing signal at the same time, but we built a mathematical model, an equation that can give you the internal target position as a function of the external position. And this is this XML position and this correlation model that will guide the tracking during treatment. And here, again, you can take images to verify and rebuild the model if needed, if the breathing signal has changed. So, before we move on to another type of specialized machine, I'd like to mention MLC tracking, because this is actually one of the nice possibilities you can have to do tracking on a conventional Linac. MLCs are multi-leaf collimated that give their shape to the treatment beam that can modulate intensity. You can see here, they're moving to modulate the intensity of the beam, but you can also see that there is an overall periodic motion. It's following a small marker here that you can probably not see very well. And this was proposed in the 2000 already to mitigate three-dimensional motion on a conventional system. So, with potentially a wide usability. And more recently, it's been used clinically for lung cancer patients. And there is really a lot of interest to implement MLC tracking clinically and safely. And I probably think that a lot of this interest has been also reignited by the MR-Linac. And, for example, on the unity MR-Linac the Linac by Elekta, MLC tracking has been proposed to do motion mitigation. At the moment, I think it's not commercially available, but I expect it will come very soon. Another thing that is nice with MLC-tracking that was also shown on an MR-Linac, but this is actually a research MR-Linac in Sydney, is that you can track the two tumours that move differently. So, here you have on a phantom, two apertures for two different targets. And pre-treatment, these targets are aligned. And on a next MR image, let's say they have moved in different directions. So, you can actually adapt the aperture to each target separately. This is one of the nice features of the MLC tracking. So, as I say, this is probably one of the favorite solutions for the Elekta MR-Linac but currently not clinically available. However, there is another MR-Linac platform, the ViewRay platform where you can nowadays already do gating, either in free breathing or in breath-hold. And here you can see, once again, the very nice soft tissue contrast offered by MR imaging and you can see tumours that are moving, sometimes stopping. And the green and blue contours show the tumour, and the red is the reference contour. So, you can turn the beam on and off depending on where the tumour is. And this is also a nice system because there's a video feedback to the patient. So, the patient can see their image and they can try make their treatment more efficient by breathing such that their tumour is inside the target region. So, now some of this add-on monitoring equipment and let's start with the respiratory surrogate. We've already talked about it for the CyberKnife and the Vero system that used respiratory surrogate. This little box can be positioned on the stomach on one of the commercially available Linacs and give you a breathing signal and you can do gating based on that. On the other platform, Elekta, you have a spiral meter that measures changes in the breathing volume. So, these are sometimes part of the conventional equipment, not on all platforms that are otherwise, low costs. One of the issues is that it's only a surrogate. It's only telling you where you are in your breathing phase, but it doesn't actually monitor the tumour position. Surface imaging is gaining in popularity. It's also external monitoring, but you can monitor an entire surface or let's say a surface of interest and it will not only give you a breathing signal, but it will give you a displacement with respect to a reference in translation and in rotation, and this is very popular for breath-hold and for gating, especially, for chest wall and breast cancer patients, and also for positioning for the RTTs, they really like it. You can potentially get rid of tattoos with a system like that. The electromagnetic transponder system is

essentially like a mini-GPS, but for your tumour. So, you would implant beacons inside the tumour that have a little circuit and then this antenna will excite the beacons and detect where they are in 3D. And you can do gating with the system in any kind of soft tissues, but it is specific to the Varian platform only. And the last one I wanna mention is ultrasound imaging. This one is specific to the Elekta platform and it's only for prostate. We have a robotic probe that can hold the ultrasound probe to take ultrasound imaging and do gating as well. So, I said we would mention briefly solutions on conventional Linac and briefly, mainly because at the moment, they are mostly the work of research groups, and these are not yet or not fully-integrated in clinical product or clinically available product. But this is a conventional Linac and when the beam comes out here, you have actually an MV image that you can deploy here to image the beam exiting the patient, and you have a kV system to take x-ray perpendicular to the beam. And like I said, the respiratory sensor is integrated on the Varian platform, but otherwise, rather low cost and easy to implement solution. So, with this kV imaging, either alone or combined with the respiratory sensor or the MV imaging, you can get real-time 3D motion monitoring. And all these methods that you have here, COSMIK, KIM, MV/kV or sequential Stereo imaging have been implemented clinically and they've been used on patients and in real time. Sometimes, together with motion mitigation or with dose reconstruction. So, they're very, very close to a clinical use. So, I'm looking forward to reading your questions later. Before we move on to that, let's have a quick look at clinical practice because we've seen, there are lots of techniques for motion monitoring and for motion mitigation. Some of them are quite costly and more or less available. So, we were really interested with a group from ESTRO in knowing a little bit more if centers are actually using motion monitoring. We were focusing exclusively on respiratory motion management, so, no prostate here, and active mitigation so, with gating, breath-hold or tracking. And we were also very interested in knowing if there were wishes to change or increase the use of motion mitigation and what were the barriers to implementation or increased use. We got 200 responses from 41 countries, and I'll go through some of the main results with you. The main treatment side was actually breast cancer. I didn't really mention it before. In breast cancer, there is some respiratory motion but there is also evidence of clinical benefits in inspiration breath-hold, because you not only freeze the breathing motion, but you also bring your target further away from the heart, which is a very radio sensitive organ, and breast cancer patient are sometimes quite fit and able to hold their breath for long enough to deliver treatment. And in fact, 56% of the centers we surveyed were using motion mitigation for breast cancer patients. The monitoring was done with respiratory surrogates or with surface imaging. And although there is quite a good evidence and it's rather simple technique for breast cancer patients, it's only just over half of our respondents. The next treatment sites were lung, liver and pancreas. We saw before there's quite a lot of respiratory motion in these sites and there is a trend in moving towards SBRT or hypofractionation with a higher dose per fraction and longer fraction times. So, we need even higher accuracy in these cases. And for these sites, 32%, 22% and 15% of the respondents use gating for lung, liver and pancreas, respectively. Again, the monitoring was very often provided just by us, a breathing surrogate. But we had four institutions that already had access to an MR-Linacs. So, one of those images I showed you before where they can gate treatment. And tracking was performed in 10, eight, and 5% of the centers. All of them were using CyberKnife, except one for lung and this is this clinical trial I showed you for eMOLST tracking on a lung cancer patient. So, this number, you can see is already quite low. Of all our respondents, 40% had plans to implement motion monitoring for a new treatment site in the next two years. So, we can really expect some big changes soon. When we asked them to rank the barriers to implementation and give one to the most important or eight to the least important and gray means not relevant, we saw two types of barriers that really popped out and it's equipment and financial resources and human resources. First one is not very surprising because we've seen all these brilliant machines and additional equipment, but not every department can afford that. And human resources, well, I guess they're a problem for many things, but when you wanna include or introduce a new technique, you also need to go through the quality assurance of it. So, in summary, if motion mitigation is done at all, it's done with gating and with a respiratory surrogate mostly. But there is a lot of interest to implement motion mitigation, especially, for breast and lung cancer patients. The main limitations on material and human resources but it's a very fast evolving field and I bet to similar

study in a couple of years will give more encouraging results. So, as a last message, we've seen that there's a lot of organs that move during radiotherapy delivery. The order of magnitude we had was about centimeters and think about the fact that radiotherapy is a very accurate technique. We are aiming for some millimeter accuracy and delivery. Margins are a very widely used method to mitigate motion but when the motion is irregular or changing from day-to-day, it really meets its limit. With active methods, so far, we need specialized equipment but it's very promising to compensate for irregular motion and to reduce the margins and therefore, the irradiation to healthy organs. And that's why there's a lot of interest for it and the main limits are still human and material resources. So, thank you very much for your attention and I'm looking forward to your questions.

Prof Franco: So, thank you very much, Jenny, for this very interesting talk. So, we'll be more than happy to start the discussion and to have your questions or whatever you feel is needed. So, feel free to ask question. We will be more than happy to take it. Otherwise, we can start a little bit of discussion, Jenny. I was kind of interested and intrigued by the fact that you mentioned at the very beginning when you talk about margins, which is basically the easiest way we can use to deal with margins or at least the one that was first introduced and where we basically use a probabilistic approach, and we try to mitigate the uncertainties that are linked to the delivery of our treatment by adding margins. And we tend to think that mostly, and partially it's true, but maybe, it's not the whole truth, that these margins are required to take into account geometrical uncertainties and set up errors mostly, which tend to be responsible for the uncertainties from one fraction to the other and also from organ motion, which has, of course, which has an impact in between the fraction and within the same fraction. But this is not all the uncertainties that are connected and are present during the radiotherapy process. There are a lot of other uncertainties that starts from the very beginning, from the simulation room, during the decision to select and define a target volume and others that are more related to the planning, to the delivery, so, I would want to have a take on you. So, how far can we push ourselves to shrink the margins and is there a limit, is there a threshold and what are the uncertainty that may mostly impact this margin that we need to use?

Dr Bertholet: Yeah, the margins is really a big concept and I think it's something that is really here to stay for a long time for better or for worse. But there's a lot of uncertainties that go into this margins' recipe, this big sigma for systematic uncertainty and the small sigma for random uncertainties, they really can contain a lot of types of uncertainties. And again, the ones that make the biggest contribution to a margin or the big sigma, the systematic errors. So, of course, when you take the image and you select one phase or if your patient was really just in a different kind of anatomy that day, this error will have an impact on the treatment for the whole time. One other error that is often actually dominating on these margins is contouring uncertainties and that's where really you, as clinician, have an important role to play. So, some of the studies around margins were also focusing on how you can train to make consistent contours. By peer reviewing your contours with your colleagues, for example, and this can reduce a lot already the uncertainty and the margin don't go around it. So, you can easily take the margin concept and say, oh, I'm calculating a margin component for motion or for this or that. But in clinical practice, you need to consider a whole lot more of uncertainties. Some smaller uncertainties, but that would be very systematic are also in calibration of the machine; this theoretically all goes into a margin concept. So, of course, if you think about it, that would add up to very, very large margin if you put all of it together. I think it's actually difficult to really take all of that into account. And these margins' recipes, they are also supposed to be for specific populations and normally, each center would have to estimate the error for a certain population of patient and calculate the appropriate margins. They can be different in every direction, larger in the superior-inferior direction to account for respiratory motion or things like that.

Prof Franco: Yeah, I think this is a good measure. So, there is, let's say, a general recipe, but I think that what you mentioned is important that every center needs to try to measure at least or estimate at the best possibility their margins in order to be able to provide a reliable and precise delivery.

Dr Bertholet: And also, we need to remember that these margins, they were designed for conventional fractionation at 2 Gy per fraction. So, in this case, you can actually consider that set up errors are random because they're different every day but if you move towards hypofractionation with only 3 fractions, if your patient is not set up right on one day, it has a much more important weight on the error budget at the end. So, you have also a margins' recipes that account for the number of fractions and the fact that an error that happens at 1 fraction doesn't really have so much of a random character anymore.

Prof Franco: That's good, that's a good point. And does it also have to do something with the type of radiation you use? So, is it the same for protons, for particles or others, I mean, do you need to manage differently?

Dr Bertholet: Yeah, you definitely do, I think. I don't really know of any real adaptation of this margin-concept for proton or at least not for pencil-beam scanning where you really scan the tumour with a very small beam. So, here, your errors of respiratory motion have a completely different impact. A lot more of this interplay effect, like we say, where you're scanning a tumour and you try to hit it here, but it depends, sometimes it's here, sometimes it's not so, maybe, you deliver a lot of dose in some parts and little dose in others, but maybe, very simply already. Remember, there was one of the sigma that was accounting for the penumbra. So, the beam is not like a knife that cuts through the tissue, and it has a wider penumbra. So, a wider diffusion at the edge, if you like. For example, in the lung tissue then in another tissue. So, you would already use a different recipe if you are looking at lung cancer or something in the abdomen, for example.

Prof Franco: Yeah, and also the fact that with protons and the particles in general, the robustness of the delivery then is much more sensitive to changes in the density of tissue, so, things like the motion could be even more impactful than with protons.

Dr Bertholet: Yup.

Prof Franco: That's interesting. So, Jenny, I think, I mean, I had one of the messages I got from your presentation, I don't know maybe I'm wrong but let me know if I am. There's not a general recipe for managing motion. I mean, there's, of course, different body size that have different component of the motion. There's different ways to imaging those regions of the bodies and there's different tools to do it, let's say. But let's say I'm opening a new clinic and I want to set up a program that is reliable in terms of planning delivery and in terms of managing the motion. What would be your advises? So, what do you think is really important to be able to do reliable delivery and to reasonably take into account also for the motion components?

Dr Bertholet: That's a very interesting question and one that is asked, there's no silver bullet that will work on everything and we need to remember that there are some patients we just wanna treat without motion mitigation. It's not an issue everywhere. So, I think there are very little centers that or people would be reluctant to, let's say, buy a CyberKnife or maybe an MR-Linac and have nothing else in their department because I think we still have, let's say, a main working horse, the conventional CRM-Linac. Also, for, you know, to be to palliative treatments in our clinics every day and it's faster to deliver on the CyberKnife. You need to use a small beam and it can easily take a very long time to deliver one treatment fraction. And the MR-Linac is I think a very promising machine but not all patients really wanna get into an MRI and there are some contraindications as well. And at the moment, I think, the main argument for an MR-Linac is to be able to do online re-planning, so, plan of the day for more slow changes. I think that having something like MLC tracking or already gating on the ViewRay system is a huge added value. But yeah, if I had all the money in the world, I think I would get an MR-Linac and I'm looking forward to seeing the new progress there. I didn't go too much into detail, but with the CyberKnife system, you can maybe track certain lung tumours that are big enough and that are not too close to the spine, but otherwise, with most of these methods or non-MR techniques, you need to implant fiducial markers. And I think this a bit of also, I would say, cultural difference there. In some countries, people are quite reluctant in implanting markers. In others, they just do it and they're not too worried, but this is also, of course, a disadvantage. And another advantage of something like

the MR-Linac or soft tissue imaging, I don't know if ultrasound will really make it, I think there's also hope for ultrasound imaging, is that you not only see the tumour or really good surrogate for the tumour position, but at some point, you're gonna wanna look at the organs at risks as well. So, let's say following a tumour with the beam is probably a good idea, as long as it doesn't get too close to a sensitive organ.

Prof Franco: And together with the fact that, of course, there's radio protection advantages, of course, in not using x-ray sources to image the patient.

Dr Bertholet: Of course, yeah, yeah.

Prof Franco: Yeah. I'm just thinking, do you think like Flash, would change our, this is like a random question, but, I mean, Flash is still there, it's still experimental, still investigational, or we don't even know if will be made a pass but there are still like trials ongoing and the rationale, of course, is to, let's say, decrease the toxicity profile by augmenting the dose, right? But that's kind of a little bit, this way of delivery the radiation a bit changes our perception and the importance, let's say, of motion, but, of course, if you are able to deliver so fast, your radiation dose you don't really need to care about the motion, right? At least the intrafraction motion. Maybe you need to...

Dr Bertholet: Yeah. All you need to care about it even more because when you shoot, you can't miss anymore. But it's true, of course, if you deliver your treatment in less than a second, then, you don't really need to care about this cyclic motion, about this drift motion. But I don't think if we use Flash, I don't think we will just treat the general area and count on the biology to save the healthy tissues. So, we will need some targeting accuracy because then you're allowed no mistakes, basically. But yeah, I think it will bring another sort of problem in the very fast imaging and yeah. Delivery in a Flash, everything in a flash.

Prof Franco: So, one thing was interesting, Jenny, is that you let us know and let us see in the survey, the POP-RT survey that you did on the adaptation, the use of adaptation, that's one of the most important constraints that people have is financial resources, but also, human resources and general organization, the general feet of the techniques and approaches to mitigate the motion into like a general running of a daily clinical practice. So, since these resources might be an issue, do you think there's room for automation in the management of organ motion? There's a lot of interest, of course, in automation of the old processes in the working environment, in radiation oncology. There's a lot of, of course, things going on in segmentation, in planning, is it also there in organ motion in management, the automation of the process?

Dr Bertholet: Yes. And you cannot avoid it at all because you need to do the whole process in under a second if you wanna manage respiratory motion on the MR-Linac. You saw this contour that was moving in real time. It means the auto-contouring has to be that fast to contour a tumour in an image 4-image per second or so and then, it needs to send a very quick signal to the Linac to either gate the beam or to adapt the position of the MLC and this means that automation is really important all the way for all sorts of things, also, when you calculate the internal position based on the surrogate or something like that. I think automation it's already there. If you do a motion mitigation, there is already automation there for sure. But you can probably also make it easier in terms of the workflow, setting up the patient and setting up those levels and all that. Everything that you can help in this regard would really be useful I thin

Prof Franco: Yeah, I think, I'm sure that some of the parts are like by definition automated, but I was more thinking about the general workflow of the process, right? Like trying to minimize, let's say, the time of a personnel at the machine or the need to do manual quality checks or something.

Dr Bertholet: Yeah. I was gonna say quality check in QA, because I think there's a bit of uncertainty on the user side too, you know. Did I place this equipment correctly as the patient moving or anything? So, if you have any kind of surveillance on the patient on you are monitoring itself to ensure that you're doing it right. I mean, simply something those external surrogates that are widely use in the practice. What I didn't report

here is that in some centers, they also acquire x-ray images during treatment but currently, there isn't really any tool to automatically detect, say, the edge of the chest or even the diaphragm dome or even any kind of surrogate that you could see maybe on images or fiducial markers. And if you had that, that would turn red when this correlation model is not valid anymore. I think it would help tremendously already.

Prof Franco: It would be like a better idea of the, let's say, the spatial framework where tumour is moving. That'd be good. So, thank you. Thank you very much, Jenny. I think if there is not any further questions, I think we can like close the session. So, I thank you, Jenny for the very educational and interesting talk with quite intriguing topics. So, thank you very much and I thank you everyone for joining and for listening.

Dr Bertholet: Thank you.

Prof Franco: Bye-bye.

Dr Bertholet: Bye.