



Article Type: Point Counterpoint

## POINT/COUNTERPOINT

*Suggestions for topics suitable for these Point/Counterpoint debates should be addressed to Jing Cai, The Hong Kong Polytechnic University, Hong Kong: [jing.cai@polyu.edu.hk](mailto:jing.cai@polyu.edu.hk), and/or Habib Zaidi, Geneva University Hospital, Geneva, Switzerland: [habib.zaidi@hcuge.ch](mailto:habib.zaidi@hcuge.ch). Persons participating in Point/Counterpoint discussions are selected for their knowledge and communicative skill. Their positions for or against a proposition may or may not reflect their personal opinions or the positions of their employers.*

## **In modern linacs monitor units should be defined in water at 10 cm depth rather than at $d_{\max}$**

Frank Van den Heuvel, Ph.D.

*Department of Oncology, University of Oxford, Oxford, UK OX3 7DQ*

*(Tel: +44 1865-225-834; E-mail: [frank.vandenheuvel@oncology.ox.ac.uk](mailto:frank.vandenheuvel@oncology.ox.ac.uk))*

Qiuwen Wu, Ph.D.

*Department of Radiation Oncology, Duke University, Durham, North Carolina 27710*

*(Tel: 919-613-6727; E-mail: [qiuwen.wu@duke.edu](mailto:qiuwen.wu@duke.edu))*

Jing Cai, Ph.D., Moderator

This article has been accepted for publication and undergone full peer review but has not been through the copyediting, typesetting, pagination and proofreading process, which may lead to differences between this version and the Version of Record. Please cite this article as doi: 10.1002/mp.13015

This article is protected by copyright. All rights reserved.

Accepted Article

## OVERVIEW

Thanks to the widely adopted guidelines such as AAPM TG-51<sup>1</sup> and IAEA TRS-398<sup>2</sup>, linac calibration has become more consistent and accurate around the globe than previously. Modern linac photon beams are often calibrated in water at 10 cm depth, and configured such that 1 monitor unit (MU) corresponds to 1 cGy at the depth of maximum dose, ( $d_{\max}$ ). However, such configuration is not without limitations. Some think it is unnecessarily complex and prone to errors, and believe that defining MU at 10 cm is more appropriate. Others think that change of MU definition can cause confusion and possibly serious consequences without any real benefit. This is the premise debated in this month's Point/Counterpoint.

Arguing for the Proposition is Frank Van den Heuvel, Ph.D. Dr. Van den Heuvel has been an Associate Professor and senior research scientist at the University of Oxford since 2014. He also holds an honorary appointment at the Oxford University Hospitals NHS Trust where he acts as the Director of Radiation Therapy Medical Physics. Dr. Van den Heuvel obtained his B.S. in Physics degree from the University of Antwerp, Belgium in 1987. He was awarded a Ph.D. in Physics from the University of Brussels in 1994, where he also took the directorship of the radiotherapy physics department. In 1996 he moved to Wayne State University in Detroit Michigan to become an Associate Professor. In 2005 he moved back to Europe to join the University of Leuven as a Director and Professor of Medical Physics. In 2012 he was elected Fellow of the AAPM.

Arguing against the proposition is Qiuwen Wu, Ph.D. Dr. Wu obtained his Ph.D. in Experimental Particle Physics from Columbia University in New York city in 1994, and subsequently worked at Memorial Sloan-Kettering Cancer Center in New York, NY, Virginia Commonwealth University in Richmond, VA, and William Beaumont Hospital in Royal Oak, MI. Dr. Wu is currently a Professor in the Department of Radiation Oncology at Duke University, Durham, NC. He is certified in Therapeutic Radiological Physics by the American Board of Radiology, is a Fellow of the AAPM, and is a member of the Board of Editors of the Journal of Applied Clinical Medical Physics. He has made original contributions to intensity modulated radiation therapy (IMRT) optimization and clinical implementation, radiobiological modelling, image guided radiation therapy (IGRT) and quality assurance techniques. Dr. Wu's clinical interests include prostate cancer and head and neck cancer.

**FOR THE PROPOSITION: Frank Van den Heuvel, Ph.D.**

### **Opening Statement**

The question whether to determine the conversion of measured dose to number of Monitor Units (MU) in the conditions of beam calibration or something else is akin to asking whether one should eat a soft-boiled egg starting with cracking the pointy end (small endian) or the more rounded end (big endian).<sup>3</sup> The end result is still an eaten egg.

In essence, one determines a number that provides the ratio between a measured dose and the MUs to achieve this. Any number used will result in an internally consistent framework which generates correct and accurate treatments. There are a few restrictions as the accelerator needs to be working within safe parameters and large values provide coarse dose choices (some newer machines can deliver fractions of MUs though).

In the case of definition at  $d_{\max}$  the way the aforementioned number is determined is rigorously prescribed (*maximum-method*).

First, an accurate calibration using a traceable ionization chamber is performed. Over the years many protocols have been provided to measure this in the most accurate way. They have fancy names: TRS-398, TRS-277, TG-21, TG-51, DIN-6800, THX-1138, HPA-1964, HPA-1983, NCS-2000 and many, many more. Most of them define a measurement depth of at least 5 cm. The newer protocols (TRS-398 and TG-51) stipulate an isocentric position of the ionization chamber, providing a very accurate measurement in conditions relevant to a modern (isocentric) treatment.

The *maximum-method* now asks us to relate that measurement to the dose delivered by a 10x10 cm<sup>2</sup> field delivered to a water phantom with surface at a distance of 100 cm from the source and in a point at distance from that surface which corresponds to the maximum amount of dose delivered by that beam in relation to the depth of the ionization chamber. Relating this to dose delivered in the calibration conditions to the *maximum-method* point. Depending on how the rest of the commissioning methodology is performed that can be relatively simple (tissue phantom ratio (TPR)-commissioning) or have triple Wile E. Coyote status (percent depth dose (PDD)-based commissioning) and was provided in a package delivered by ACME Inc.<sup>4</sup> This last, admittedly facetious, remark becomes clear as we need to convert from PDD to TPR convention for which the formula below, with the notations from the original article by Jim Purdy,<sup>5</sup> is used.

$$TPR(d, f, S_d) = \frac{P\{d, f, S_d / [(f + d) / f]\}}{P\{d_r, f, S_d / [(f + d_r) / f]\}} \times \frac{B\{S_d / [(f + d) / f]\}}{B\{S_d / [(f + d_r) / f]\}} \times \left(\frac{f + d}{f + d_r}\right)^2$$

That is a lot of work and a lot of possible errors waiting to happen. As pointed out before, the number is arbitrary so errors in this do not matter too much. But then again why go through the trouble? The main problem is that this factor is different for every energy, machine, and manufacturer. If the number is used incorrectly (for instance a 6 MV number used for a 21 MV treatment), the consequences are dire. Better to use one single number for all machines and energies. An added advantage is that when the calibration conditions are chosen judiciously, the total number of MUs delivered will roughly equal the dose delivered divided by the number used.

As always: "Work hard, increase production, prevent accidents, and be happy." (George Lucas).

#### **AGAINST THE PROPOSITION: Qiuwen Wu, Ph.D.**

##### **Opening Statement**

Modern linacs photon beams are calibrated in water at 10 cm depth, based on AAPM TG-51<sup>4</sup> and IAEA TRS-398<sup>5</sup> recommendations, and these guidelines are adopted in most clinics worldwide. This is a significant achievement compared to previous practices – this is more accurate and consistent. However, other settings associated with the calibration were left alone and can vary from clinic to clinic, such as the equipment setup: either source-to-surface distance (SSD) = 100 cm, or source-to-axis distance (SAD) = 100 cm. In addition, most linacs, if not all, are also configured to have 1 MU corresponding to 1 cGy at  $d_{max}$ . This also defines the MU.

I oppose the change of the definition of the 1 cGy/MU at  $d_{max}$  to depth of 10 cm for the following reasons.

This change of MU definition is unnecessary, as it does not affect how the linac is calibrated, it is merely a scaling factor to the current definition, therefore does not provide any scientific benefits to how patients are treated with radiation. However, this will introduce additional difficulties to the professionals in the radiotherapy fields, and can cause more confusion among the team members, the linac manufacturers and treatment planning system (TPS) vendors. The foremost concern with the new definition is that the value of maximum dose is lost or hidden from the physicians or planners when they are performing a quick estimate of the patient dose;

we all know the maximum dose is an important metric when planning a radiation treatment. In contrary, in the current definition, the maximum dose is close to the MU value for static treatment. A similar concept of normalized percent depth dose ( $PDD_N$ ) was introduced in the AAPM TG-71 report<sup>6</sup> but was not widely adopted, probably for the same reason.

Secondly, this is not a small change, and can be more than 50% from the current definition, depending on the photon energies. Many related systems will need to be updated or recommissioned and professionals will need to be retrained and synchronized to the changes. Therefore, this will be a disruption at the minimum on the service we provide and can also be the cause of more serious consequences. Catastrophic errors occurred several years ago due to the misconnection between the linac calibration and TPS commission highlights the importance of such change of definition.<sup>7</sup>

Another concern is that the exact setup geometry is necessary for the definition to be complete. The current calibration guidelines do not enforce a uniform geometric setup: SSD or SAD,  $d_{max}$  or other depths because each one has its own merits. Of the more than 2400 institutions that Imaging and Radiation Oncology Core (IROC) has data for, 73% are based on 100 SSD at  $d_{max}$ , 25% on 100 SAD at  $d_{max}$ , and 2% on SAD at other depths.<sup>8</sup> The choice between SSD and SAD at  $d_{max}$  can mount up to a few percent differences in doses depending on the photon energy. However, if 10 cm depth is chosen instead of  $d_{max}$ , i.e., 1 cGy/MU at 10 cm depth, then the difference between SSD or SAD setup will be significant and one unified recommendation should be given. But the proposal stops short of this recommendation.

Therefore, I oppose the change of the MU definitions, because it is not necessary, does not bring new scientific benefits to the practice, and it is not complete. Such change will require the overhaul of many systems in this field, many professionals will also need to be re-trained and catastrophic results can be introduced if this change is not implemented carefully.

**Rebuttal: Frank Van den Heuvel, Ph.D.**

It is interesting to observe that, in this day and age of fake news and alternative facts, we find ourselves in a situation where both parties agree on the facts but in a very old fashioned way disagree on what the conclusions are from those facts. I presume this must be very confusing to the younger members of our audience.

Dr. Wu and myself both agree that the definition of what an MU is does not affect the linac calibration and that any number provides an internally consistent set of rules with which one can calculate the dose delivered to the patient.

We do differ on what to do next. I also agree with the fact that quick checks and the possibility to use common sense to guide an operator to detect potential errors could be valuable. Anything that triggers a closer look at a possible error warrants a chance. But his assumption that we can do this in the modern age with a calibration at  $d_{\max}$  is faulty. Indeed, nowadays all modern treatment machines (Tomotherapy, Halcyon, ViewRay, Elekta Uniq, and I am forgetting many of them) are not able to use a fixed source to skin distance. All treatments in those cases are isocentric, with the target positioned in, or close to, the isocenter. The proposal as outlined in the argument for the statement makes the easy inference from standard anatomical data straightforward, this independent from the type and make of the machine or energy used. Indeed all the machines mentioned before will have different SADs varying from 90 cm to 140 cm. It will not allow you to make the inference to within a few MUs, which is the goal.

The only thing Dr. Wu can argue is the fact that "we have always done it that way". The latter of course is not valid anymore as the environment has changed. As to the change in approach introducing chaos, the solution is easy. In the current situation one needs to keep track of all machines and their calibrations. In a scenario of moving over to the new methodology one only needs to do this with new installations. As soon as all machines are replaced one can stop keeping track of the MU and have a one-size-fits-all statement.

The same thing seems to be happening over and over again. We keep adding steps to our processes to react to individual events but lose sight of the whole process because we can only have incremental changes. This then results in a very complex process that becomes unwieldy and errors are introduced by the complexity of the processes and protocols, not in the least because the bureaucracy to deal with this complexity then becomes a goal in itself.

**Rebuttal: Qiuwen Wu, Ph.D.**

The main argument my opponent has for the change of MU definition is based on the misinterpretation of the calibration protocols. For example, TG-51 *does not* "stipulate an isocentric position of the ionization chamber". In fact, many clinics have their linacs calibrated at 100 cm SSD instead of 100 cm SAD. Doing so also eliminates "a lot of work and a lot of errors" that are involved in the PDD to TPR conversion. In his own words, "why go through the trouble?" It does

not have to be. With the same 100 cm SSD setup, the PDD can be measured and used to derive the beam quality parameter of the ion-chamber, and linac output calibration can be subsequently performed and no change in setup is needed. In fact, the concept of TPR is not needed during the calibration process at all; any possible mistakes associated with the conversion become irrelevant here. While most treatment plans are isocentric, this does not mean that the linac calibration and MU definition need to be.

The TPR and tissue maximum ratio (TMR) are useful concepts in treatment planning, especially in dose calculation algorithms based on empirical formulae during early years; they are less frequently used in model based dose calculation algorithms implemented in modern treatment planning systems. The mathematical formula of PDD to TPR conversion depicted by my opponent may be frighteningly complex to others, it is actually straight forward to many clinical physicists and is largely performed automatically during commissioning process by computer programs; and their roles largely diminished to secondary dose calculation checks. Since they are not necessary for the linac calibration or MU definition, they should not be included in the debate here.

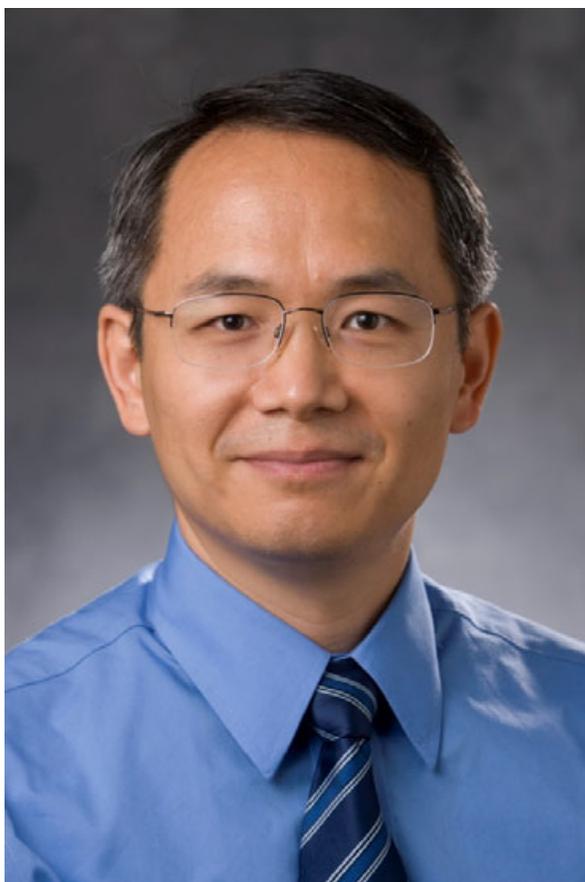
One advantage of the proposed new definition not directly stated by my opponent but implied is that the MU will be less sensitive to the photon energy, as  $1 \text{ cGy} = 1 \text{ MU}$  for all energies at 10 cm. So if wrong photon energy was planned or delivered to the patient, the magnitude of the error in dose distributions inside patient is less significant. However, this logic is very weak. One can argue that, if wrong energy is used, it is already mis-administration, no matter what the magnitude is.

In principle, both MU definitions are equivalent, and either one should work. We could have started, trained, and become used to either one. But since the  $d_{\text{max}}$  setup was the chosen one initially, it is now frivolous to switch to the other. Furthermore, a change of this large scale on many clinics would no doubt cause more headaches or mistakes since there is no down time allowed.

There is one more thing.<sup>9</sup> It may seem a trivial question how to crack a soft-boiled egg. But to do it quickly while maintaining its wholesomeness requires skills and experience. Sometimes it is better to crack the boiled egg at the middle, not the pointy end, not the rounded end.<sup>10</sup>

### **Conflicts of Interest**

Dr. Van den Heuvel and Dr. Wu have no relevant conflict of interest.



## References

1. Almond PR, Biggs PJ, Coursey BM, et al: AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams. *Med Phys*. 1999;26(9):1847-1870.
2. Andreo P, Burns DT, Hohlfeld K, et al: *Absorbed Dose Determination in External Beam Radiotherapy: An international Code of Practice for dosimetry based on standards of absorbed dose to water*. IAEA Technical Report Series No 398. Vienna 2000.
3. Swift J, Rawson CJ, Higgins I. *Gullivers travels*. Oxford, UK: Oxford University Press; 2008.
4. Johnson, J. The Physics of Roadrunner - Balloon Anvil, <https://youtu.be/e7K1Sgywkil>. Accessed April 24, 2018.
5. Purdy JA. Relationship between tissue-phantom ratio and percentage depth dose. *Med Phys*, 1977;4(1):66-67.
6. Gibbons JP, Antolak JA, Followill DS, et al: Monitor unit calculations for external photon and electron beams: Report of the AAPM Therapy Physics Committee Task Group No. 71. *Med Phys*. 2014;41(3):031501.
7. Bogdanich W. *As Technology Surges, Radiation Safeguards Lag*. The New York Times. 2010.
8. Kry SF. *IROC data on Linac calibration setup*. IROC Houston QA office. 2018.
9. Wikipedia. Stevenote. <https://en.wikipedia.org/wiki/Stevenote>. Accessed April 24, 2018.
10. CrazyRussianHacker. You've Been Peeling Hard-Boiled Eggs Wrong. <https://youtu.be/qLjCDNoRC-g>. Accessed April 24, 2018.