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FAILURE RATES AND DOWNTIME OF MULTI-LEAF COLLIMATORS IN INDONESIA

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Abstract

One of the greatest barriers to cancer treatment in Low and Middle-Income Countries (LMICs) is the access to Radiotherapy Linear Accelerators (LINACs). Not only are the LINACs complex, the harsh environment of LMICs cause frequent breakdowns resulting in downtimes ranging from days to months. Recent research has identified a disparity between LMICs and High Income Countries (HICs) and determined the Multi-Leaf Collimator (MLC) as a component needing re-evaluation. The MLC causes over 30% of the problems in RT LINACs, but the modes of failure and quantify the extent of the damage done are yet to be quantified. Using data from across Indonesia, we show the pathways to failure of RT Machines and frequency of breakdowns over time. A component of the MLC needs to be replaced every 9.98 faults per 1000 patients treated and the MLC itself breaks down on average every 36±1.8 days. When comparing the downtime by leaf width, the data shows 5 mm leaves contribute 18.27±6.5% to all breakdowns while 10 mm makes up 15.87±4.3%. These results outline the need to reassess the current generation of RT LINACs and ultimately work towards guiding future designs to be robust enough for all environments.

INTRODUCTION

Radiation therapy and radio surgery comprise a significant portion of cancer treatment all throughout the world with a high effectiveness [1–3]. With 40% of all successfully treated cancer cases involving radiotherapy and 60% - 80% of cases using it in conjunction with chemotherapy and surgery, it has become a mainstay of cancer treatment [1, 4]. However, recent studies into the quality of cancer care in sub-Saharan Africa has shown our current generation of radiotherapy LINACs are neither designed nor effectively utilised in developing nations [5–7].

The severe lack of radiotherapy LINACs in developing nations means they are particularly vulnerable in case one breaks [6]. Often, due to maintenance costs, Low-and-Middle Income Countries (LMICs) will not have a functioning LINAC in the hospital when one is in repair forcing patients to travel large distances for treatment or miss out altogether. Many of the faults are linked to inconsistent power supply and insufficient preventative maintenance, along with inaccessible spare parts and inadequate expertise [8].

A global collaboration dedicated to Smart Technologies to Extend Lives with Linear Accelerator (STELLA) has begun to address the shortcomings by developing robust alternatives. Their research into the state of radiotherapy care in LMICs have found LINACs breaking down for longer and more frequently than their HIC counterparts [8, 9]. One of the components currently under scrutiny is the Multi-Leaf Collimator (MLC), which breaks down as frequently in LMICs as in HICs [8, 10, 11]. The extent to which this component is problematics is yet to be adequately reported. Though the MLC is necessary for beam shaping and dose delivery, its current complexity in leaf width and number of leaves must be re-evaluated.

The research outlined in this paper will motivate the need for an improvement in the current generation of radiotherapy LINACs, especially in LMICs by analysing and comparing the breakdown and fault data of MLCs from hospitals across Indonesia.

MULTI-LEAF COLLIMATOR

The Multi-Leaf Collimator in a LINAC is positioned after the bremsstrahlung target to collimate outgoing x-rays to the shape and size of the tumour. It is comprised of two sets of jaws with motor driven tungsten leaves that can move in real-time as the LINAC gantry rotates about the patient. Figure 1 depicts a schematic diagram of the MLC in operation.

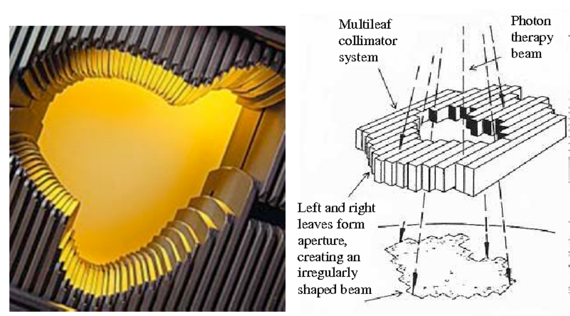

Figure 1: Multi-Leaf Collimator Photograph (left) and schematic depicting an MLC's function (right).

Some of the characteristics that define an MLC include the number of leaves, the width of the leafs (not always constant across the length of the MLC), the field size, the leaf length and speed, the shape of the leaf end (e.g. round, square) and the source to collimator distance.

FAULT ANALYSIS

The MLCs used in this study are from the Indonesian RT LINAC study [12]. They vary in vendor: {Varian, Elekta, Siemens}; number of leaves: {58, 80, 120, 160}, and; leaf

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width: {5 mm, 10 mm}. All MLCs have a field size of 40 mm×40 mm and machines with no MLC have been left out of the analysis.

Failure Modes

Faults encountered by the MLCs were categorised by the method used to rectify the fault: {Reset, Replace, Repair, Calibrate}. The frequency was normalised per 1000 patients treated. Since not all the data provided was able to be categorised, due to inconsistent data keeping, error bars were generated to account for the uncategorised faults resolutions [12]. A more rigorous system for record keeping and logging of faults would improve future studies, as LMICs don't tend to have accurate records of breakdown data, especially for minor faults.

From Fig. 2, the most common method to resolve a fault involves replacing components. The normalised value is 9.98 faults requiring a replacement per 1000 patients treated. The other resolutions values are 3.00, 2.20 and 1.84 faults per 1000 patients treated for Reset, Repair and Calibrate respectively. A majority of the components needing replacement are the leaves, T-Nuts and leaf motors.

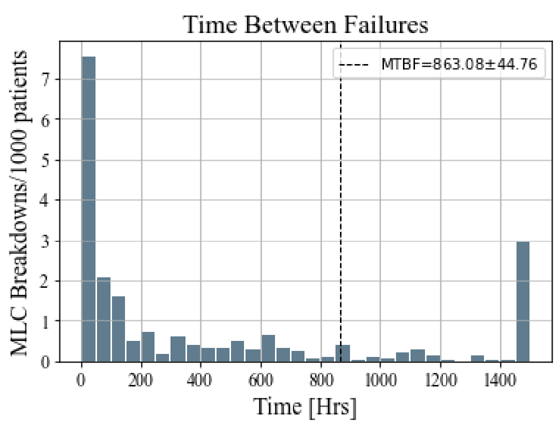

Figure 2: Histogram showing the most common methods for fixing failures across all MLCs in the Indonesian data set normalised to the number of patients treated. The error bars are generated from uncategorised data points.

A majority of the faults in the MLC are mechanical, rather than electrical or board related. This is because, of all the subsystems in a LINAC, the MLC has the most moving parts, with at minimum 58 independently moving leaves, each with their own motor.

Reliability

In engineering reliability analysis, the parameter Mean Time Between Failure (MTBF) is used to quantify and study faults [13]. The MBTF measures the average time between the resolution of one fault and the reporting of a subsequent one and is defined as:

$$MTBF = \int_0^{\infty} R(t)dt = \int_0^{\infty} tf(t)dt, \quad (1)$$

where $R(t)$ is called the reliability function and the expected value of the probability to failure function, $f(t)$. This function is applied to a machine's 'useful life', which is the period between installation after early failures and before the machine becomes worn out and eventually decommissioned [13, 14]. It is during this period that the machine has an approximately constant failure rate, λ, and $f(t) = \lambda e^{-\lambda t}$.

The MTBF for the MLC in through Indonesian LINACs is 863.08±44.76 hours as shown in Fig. 3. This means between the resolution of one MLC related issue, another will be reported approximately 36±1.8 days later.

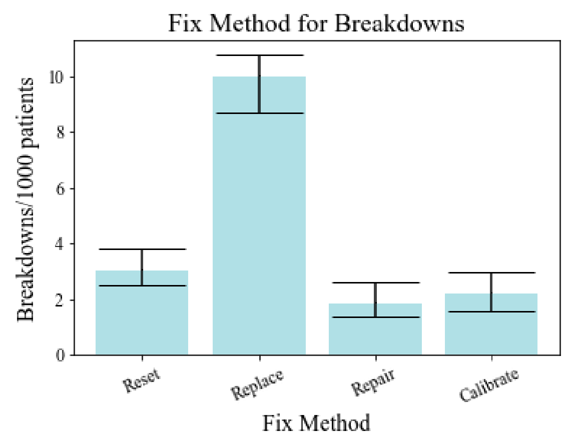

Figure 3: Histogram showing the time between failures for the MLC. The MTBF is indicated by the dotted line. The overflow bin is 1500 hrs.

The failure rate of MLCs and probability density function of time to failure through Indonesia is then given by,

$$\lambda = \frac{1}{MTBF} = 0.0278 \text{ day}^{-1}, \quad (2)$$

$$f(t) = \lambda e^{-\lambda t} = 0.0278 e^{-0.0278t}. \quad (3)$$

Determining the useful life of a machine and the early failures/wear out is not simple when some components of the machine get replaced entirely which others get simply repaired or recalibrated. As such, this result alone does not provide a complete picture of the state of radiotherapy in Indonesia.

The MTBF is heavily skewed towards times less than 200 hrs. Taking the median, we can see a more representative reflection of the Times Between Failures. The median time between the resolution of one faults and the recording of another is 110.29 hrs, which is almost 90% lower than the MTBF.

Leaf Width

The current understanding of the MLC has determined thinner leaf widths provide a high level of target coverage and sufficient sparing of vital organs [15–18]. There are some cases where the quality of dose is up to a clinically acceptable standard regardless of leaf width and in general, when a tumour is sufficiently large, the difference between leaf thickness is negligible [17–20].

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Though thinner leaves provide better quality of treatment, the question as to whether the added complexity of the MLC causes it to break down more still remains. If wider leaves are up to a clinically acceptable standard and are more reliable and robust, then the alternative is clear.

Table 1 takes the percentage contribution to LINAC downtime due to the MLC, averaged by leaf width. On average, 10 mm leaf MLCs contribute less to a LINAC's downtime. However, the spread of the data is too sparse to draw any conclusive results. It does, however, suggests that fewer leaves cause fewer breakdowns, which is expected, since fewer leaves means fewer pathways to failure. How fewer and wider leaves will effect the quality of treatment is not covered in this work and remains an area for future investigation.

Table 1: Percentage of Total Downtime Due to MLC

Leaf Width [mm]	Average	No. of LINACs
5	18.27±6.5%	8
10	15.87±4.3%	7

The 5 mm leaf widths include MLCs with 5 mm central leaves and 10 mm outer leaves and the 10 mm set includes MLCs with 10 mm central leaves and 65 mm outer leaves.

CONCLUSIONS AND OUTLOOK

The shortcomings of the MLC have been documented and there is an ever growing area of research dedicated to improving the MLC and its many faults [8, 21, 22]. The results above collectively aim to quantify the time and resources lost due to maintenance and repairs of the MLC. They show 9.98 faults per 1000 patients treated need a component replaced and the median time between MLC failures is 110.29 hrs.

Future designs of the MLC should consider internal log-keeping, if fault recording methods do not improve though LMICs. There is preliminary evidence to suggest wider leaves might decrease breakdown frequency, as 5 mm leaf widths cause 18.27±6.5% of breakdowns while 10 mm only make up 15.87±4.3%, however more statistics are needed to draw anything conclusive.

REFERENCES

[1] Targeting Cancer, https://www.targetingcancer.com.au/what-is-radiation-therapy/.

[2] G. Delaney, S. Jacob, C. Featherstone, and M. Barton, "The role of radiotherapy in cancer treatment", *Cancer*, vol. 104, no. 6, pp. 1129-1137, 2005. doi:10.1002/cncr.21324

[3] B. Zachariah, L. Balducci, G. V. Venkattaramanabalaji, L. Casey, H. M. Greenberg, and J. A. Del Regato, "Radiotherapy for cancer patients aged 80 and older: A study of effectiveness and side effects", *International Journal of Radiation Oncology, Biology, Physics*, vol. 39, no. 5, pp. 1125- 1129, 1997. doi:10.1016/S0360-3016(97)00552-X

[4] S. Harding, S. Hodder, D. Courtney, and P. Bryson, "Impact of perioperative hyperbaric oxygen therapy on the quality of life of maxillofacial patients who undergo surgery in irradiated fields", *International Journal of Oral and Maxillofacial Surgery*, vol. 37, no. 7, pp. 617-624, 2008. doi:10.1016/j.ijom.2008.04.004

[5] E. Rosenblatt *et al.*, "Radiotherapy utilization in developing countries: An iaea study", *Radiotherapy and Oncology*, vol. 128, no. 3, pp. 400-405, 2018. doi:10.1016/j.radonc.2018.05.014

[6] D. Pistenmaa and N. Coleman, "Developing medical linacs for challenging regions", https://cerncourier.com/a/developing-medical-linacs-for-challenging-regions/.

[7] H. Reichenvater and L. dos S. Matias, "Is africa a "graveyard" for linear accelerators", *Clinical Oncology*, vol. 28, no. 12, pp. e179-e183, 2016. doi:10.1016/j.clon.2016.08.010

[8] L. M. Wroe *et al.*, "Comparative analysis of radiotherapy LINAC downtime and failure modes in the UK, Nigeria and Botswana", *Clinical Oncology*, vol. 32, no. 4, pp. e111-e118, 2020. doi:10.1016/j.clon.2019.10.010

[9] O. Balogun, D. Rodin, W. Ngwa, S. Grover, and J. Longo, "Challenges and prospects for providing radiation oncology services in africa", *Seminars in Radiation Oncology*, vol. 27, no. 2, pp. 184-188, 2017. doi:10.1016/j.semradonc.2016.11.011

[10] T. Kron, private communication, Fev. 2020.

[11] A. M. Wojtasik, M. Bolt, C. H. Clark, A. Nisbet, and T. Chen, "Multivariate log file analysis for multi-leaf collimator failure prediction in radiotherapy delivery", *Physics and Imaging in Radiation Oncology*, vol. 15, pp. 72-76, 2020. doi:10.1016/j.phro.2020.07.011

[12] G. S. Peiris, S. A. Pawiro, M. F. Kasim, and S. L. Sheehy, "Failure modes and downtime of radiotherapy linear accelerators and multi-leaf collimators in indonesia", 2021. arXiv:2105.08906

[13] S. Speaks, "Reliability and mtbf overview", http://www.vicorpower.com/documents/quality/Rel_MTBF.pdf

[14] J. Lienig and H. Bruemmer, "Reliability Analysis", in *Fundamentals of Electronic Systems Design*, Switzerland: Springer, Cham, 2017, pp. 45-73.

[15] Z. Abisheva, S. R. Floyd, and J. K. Salama, "The effect of mlc leaf width in single-isocenter multi-target radiosurgery with volumetric modulated arc therapy", *Journal of radiosurgery and SBRT*, vol. 6, no. 12, pp. 131-138, 2019. PMCID:PMC6774495

[16] A. Serna, V. Puchades, F. Mata, D. Ramos, and M. Alcaraz, "Influence of multi-leaf collimator leaf width in radiosurgery via volumetric modulated arc therapy and 3d dynamic conformal arc therapy", *Physica Medica*, vol. 31, no. 3, pp. 293-296, 2015. doi:10.1016/j.ejmp.2015.01.011

[17] J. Y. Jin, F. F. Yin, S. Ryu, M. Ajlouni, and J. H. Kim, "Dosimetric study using different leaf-width mlcs for treatment planning of dynamic conformal arcs and intensity-modulated radiosurgery", *Medical Physics*, vol. 32, no. 2, pp. 405-411, 2005. doi:10.1118/1.1842911

[18] S. Yoganathan, K. Mani, K. Maria Das, A. Agarwal, and S. Kumar, "Dosimetric effect of multileaf collimator leaf width in intensity-modulated radiotherapy delivery techniques for small- and large-volume targets", *Journal of Medical Physics*, vol. 36, no. 2, pp. 72-77, 2011. doi:10.4103/0971-6203.79690

ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB415

[19] F. J. Height, T. Kron, D. Willis, and B. H. Chua, "Impact of mlc leaf width on the quality of the dose distribution in partial breast irradiation", *Medical Dosimetry*, vol. 37, no. 1, pp. 37-41, 2012. doi:10.1016/j.meddos.2010.12.011

[20] J. B. Fiveash *et al.*, "Effect of multileaf collimator leaf width on physical dose distributions in the treatment of cns and head and neck neoplasms with intensity modulated radiation therapy", *Medical Physics*, vol. 29, no. 6, pp. 1116-1119, 2002. doi:10.1118/1.1481515

[21] M. Oliver, I. Gagne, K. Bush, S. Zavgorodni, W. Ansbacher, and W. Beckham, "Clinical significance of multi-leaf collimator positional errors for volumetric modulated arc therapy", *Radiotherapy and Oncology*, vol. 97, no. 3, pp. 554-560, 2010. doi:10.1016/j.radonc.2010.06.013

[22] C. E. Agnew, S. Esteve, G. Whitten, and W. Little, "Reducing treatment machine downtime with a preventative mlc maintenance procedure", *Physica Medica*, vol. 85, pp. 1-7, 2021. doi:10.1016/j.ejmp.2021.04.012