1 Title:

Adept Medical STARTable: Scatter Radiation Shielding Grid Format Methodology

2 Background:

Adept Medical STARTable Shield is embedded with 0.5mm Lead (Pb), offering protection from scatter radiation for operators. To verify this, testing was carried out to measure the product's effectiveness in a controlled environment, by simulating scatter radiation exposure to operators and measuring x-ray dose around a gridded pattern.

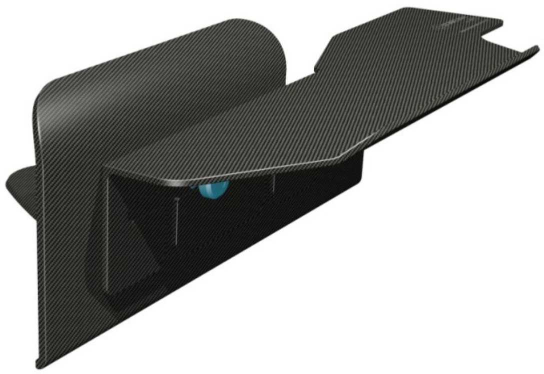

Figure 1 - Adept Medical STARTable

3 Scope:

The aim of this test is to measure the level of scatter radiation with and without the STARTable over multiple gridded points, providing a comparison in the amount of scatter radiation protection the STARTable offers to operators. The methodology is designed to examine the impact of the STARTable on the amount of scatter radiation present at the position occupied by the clinican, without any other radiation protection present.

4 Method:

The testing was conducted at Auckland District Health Board Interventional Cardiology Laboratory's on a Siemens Artis Imaging Table. The measurements were recorded by Brian Lunt, Medical Physicist.

A radiographic human torso phantom was used to simulate a patient on the table and provides the primary source of radiation to the clinician and staff via scatter.

Below is an image of the STARTable showing dimensions of the vertical portion containing the 0.5mm Lead.

Further details listed below are constant test parameters that were consistent in all measurements. In addition to these, the intensifier height, beam intensity, beam quality (automatic) and gantry tilt (independent variable) were changed.

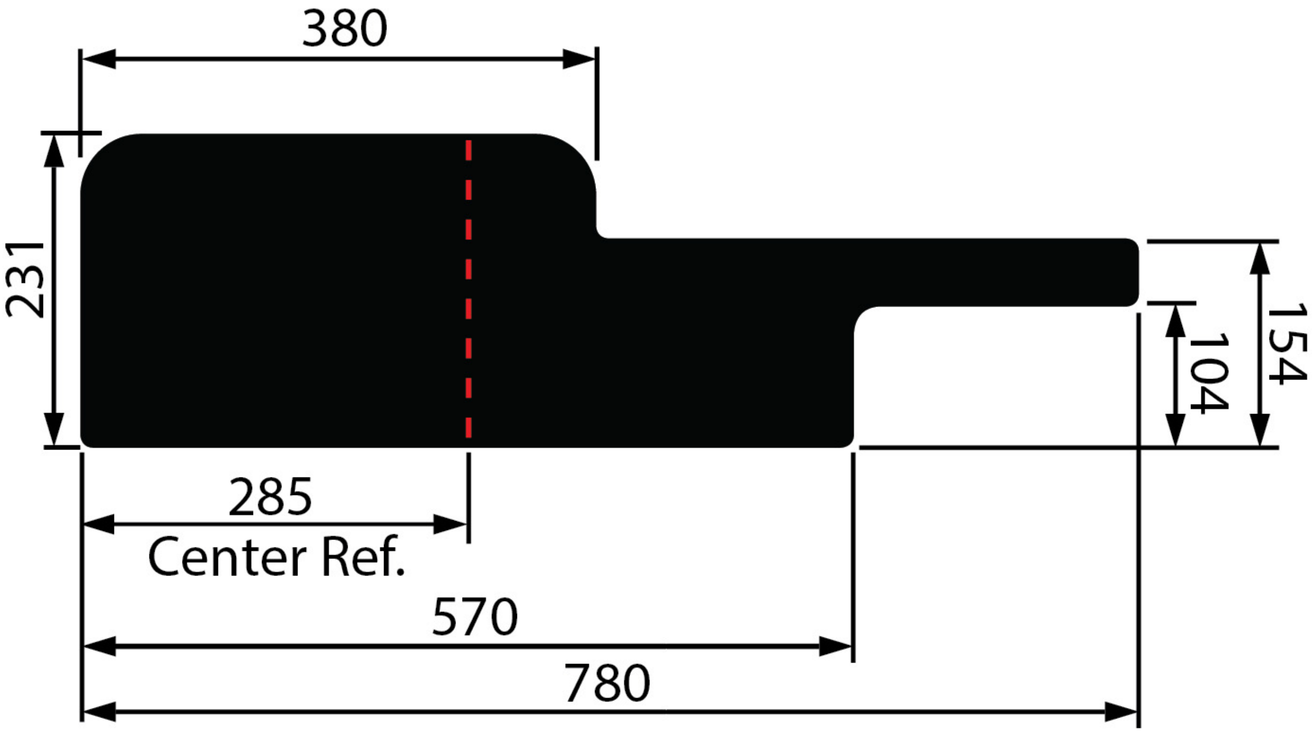

Figure 2 - Dimensions of the STARTable

Table 1 - Constant parameters during the testing of the STARTable

Technique	
Scatter Source	Rando Human Torso Phantom
C-Arm Model	Siemens Artis Q-Zen
Digital Procedure Selection	Coronaries/ HDR CARE Minus
Beam Quality (KVp)	80±5
Image Table Width at Shield	45 cm
Image Table Height	90 cm
Source Image Distance	100 cm
Exposure Time	10 Seconds
Frames / second	15
Air Gap	15 cm
Scatter Mode	Integrate
Camera Field of View	20cm
Dosimeter Model	Unfors Xi

The digital procedure selection determines the output parameters such as beam quality and intensity. These changes automatically depending on the angle of the C-Arm, and the average values were recorded and are displayed in Table 2.

Table 2 - C-Arm average parameters

Parameters	Zero-Tilt	Extreme Angulation
Entry Dose (mGy/mm)	6	20
Pulse Width (ms)	3.2	4.2
Copper Filtration (Cu mm)	0.2	0.1
Tube Voltage (kVp)	76.8	81
Tube Current (mA)	152.4	208

The Human phantom was placed centrally to the Imaging Table with the X-Ray camera centralised to this on both X and Y axes. The STARTable was positioned at the side of the table, to the patient's right. It was aligned to the centre of the phantom and X-Ray camera.

The Dosimeter was placed at differing heights from the centre reference at 20 cm intervals about a grid and always 65 cm out from centre of the Imaging Table. Figure 3 shows the set up in the lab; the STARTable is sitting against the far side of the phantom, and the dosimeter measurement grid is shown on the piece of paper further behind that. Position A is located at the right side of the image (cranial), and position E at the left side (caudal). The distancing between points is as labelled in Table 3.

Figure 3 - Photograph of the testing setup

Table 3 - Testing grid distances. Positions 1-6 indicate height off the group, while A-E are centred about the midpoint of the STARTable's bulk.

Position		A	B	C	D	E
	Distance	-40 cm	-20 cm	0 cm	20 cm	40 cm
1	50 cm					
2	70 cm					
3	90 cm					
4	110 cm					
5	130 cm					
6	150 cm					

The first test was performed with no gantry tilt (LAO 0º / CRAN 0º).

This view gave the minimal amount of scatter radiation due to the angle with which the beam hits the phantom and self-absorption by the phantom

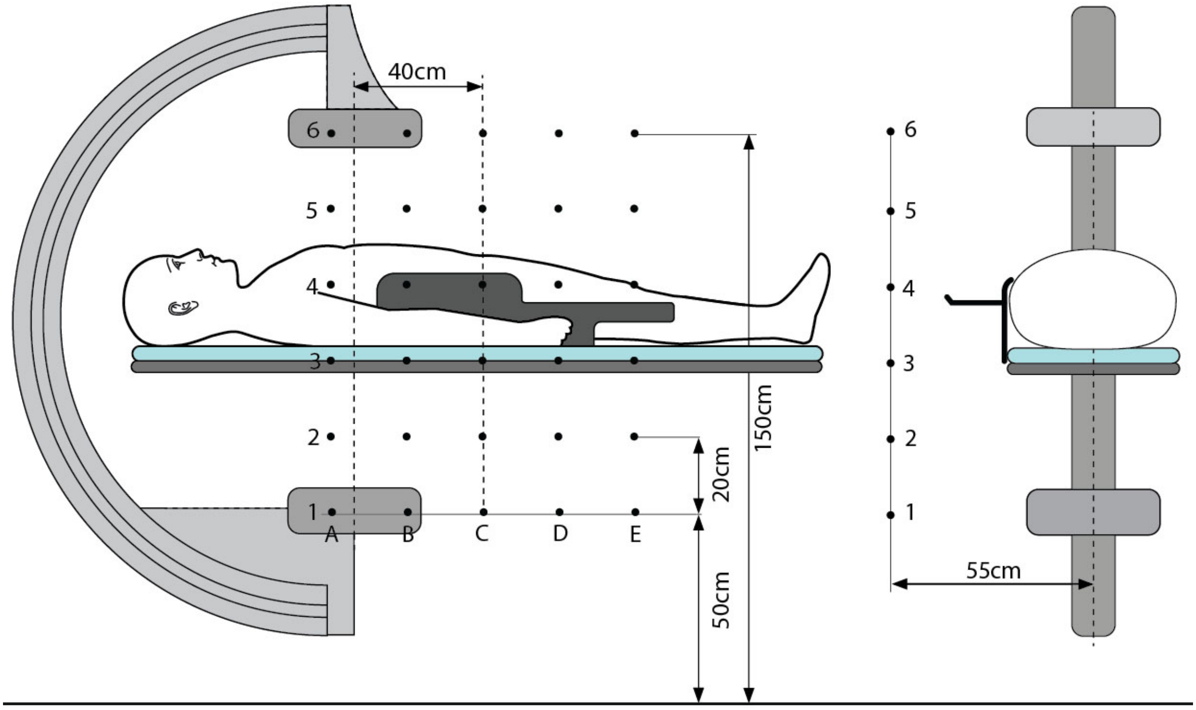

Figure 4 - Side and head-on views of the LAO 0 / CRAN 0 setup

The second test was performed with extreme gantry tilt (LAO 34° / CRAN 20°).

This is an extreme case of angulation, which causes a different scatter pattern off the phantom and onto the radiologist. Generally, the amount of radiation is much larger in this orientation. For the two different rotations of the C-Arm, the amount of radiation is very different. This is due to the different degrees of absorption of x-ray scatter by the phantom at the operator standing positions. As such, the two different orientations cannot be directly compared.

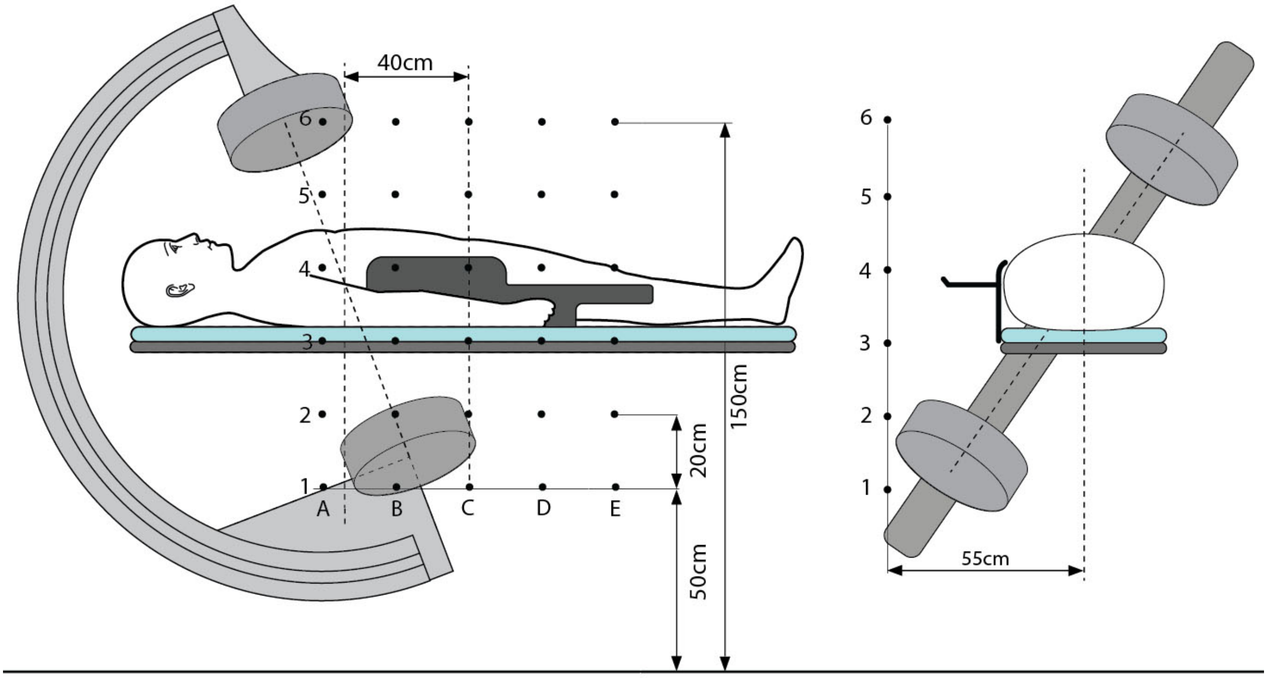

Figure 5 - Side and head-on views of the LAO 34 / CRAN 20 setup

As visible in Figure 4 and Figure 5, in both tests the grid is positioned in the same location relative to the Operating Table.

5 Results:

Gantry Tilt 0º

Table 4 below summarises the percentage reduction for 0º gantry tilt

Table 4 - Percentage reductions of radiation for zero tilt (units in %)

	A	B	C	D	E
1	3.5	-4.1	-7.3	-6.8	3.9
2	-4.4	4.6	0.8	4.2	2.4
3	-6.5	50.0	44.8	44.4	60.0
4	-7.8	61.2	65.5	76.6	70.8
5	5.3	62.7	78.6	89.7	78.6
6	7.8	36.7	48.6	64.8	-307.1

Note that the negative readings are not physically viable, as lead absorbs radiation and will not be a source of further scatter at the energy level of X-Rays. Instead, the negative values may arise from a combination of factors. These include:

- Misplacement of the dosimeter
- Random fluctuations in output radiation
- Randomness of the scatter patterns
- Human error in reading the dosimeter levels
- Incorrect angulation of the dosimeter

Small negative readings are common due to fluctuation and should average out to near zero with multiple measurements (Table 4Table 5, 1C, 3A etc.). Highly negative readings may be treated as outliers, with the assumption of an incorrectly positioned dosimeter or other errors in measurement. These outliers need to be ignored. However, the large negative readings may also be attributable to the fluctuation radiation (Table 4, 6E). In either case where random fluctuation causes the negative percentage change, it is viable to zero all negative values (all values are positive), as shown in Table 5.

Table 5 - Adjusted percentage reductions of radiation for zero-tilt (units in %)

	A	B	C	D	E
1	3.5	0.0	0.0	0.0	3.9
2	0.0	4.6	0.8	4.2	2.4
3	0.0	50.0	44.8	44.4	60.0
4	0.0	61.2	65.5	76.6	70.8
5	5.3	62.7	78.6	89.7	78.6
6	7.8	36.7	48.6	64.8	0.0

It is now important to consider the absolute differences of attenuation. The above analysis of the data is given in percentage; the relative magnitude is good for comparisons with a narrow range of different values, or for making initial analyses with a single general scale. It is also important to examine the true attenuation values to quantify the amount of protection supplied to the clinician. A large percentage difference with a small radiation value can account for a negligible effect on a clinician.

Table 6 - Exposure values without the STARTable (nGY/sec)

	A	B	C	D	E
1	141	146	109	74	51
2	159	174	119	72	41
3	124	146	96	54	30
4	102	116	84	47	24
5	75	75	56	35	21
6	51	49	37	25	14

Table 7 - Exposure values with the STARTable (nGY/sec)

	A	B	C	D	E
1	136	152	117	79	49
2	166	166	118	69	40
3	132	73	53	30	12
4	110	45	29	11	7
5	71	28	12	3.6	4.5
6	47	31	19	8.8	57

Table 8 - Change in exposure with and without the STARTable (nGy/sec)

	A	B	C	D	E
1	5.0	-6.0	-8.0	-5.0	2.0
2	-7.0	8.0	1.0	3.0	1.0
3	-8.0	73.0	43.0	24.0	18.0
4	-8.0	71.0	55.0	36.0	17.0
5	4.0	47.0	44.0	31.4	16.5
6	4.0	18.0	18.0	16.2	-43.0

The above tables show the resultant exposure values (nGy/sec) for each position. Note that from Table 8, the small percentage changes of 1C and 3A are associated with small exposure changes. The large percentage change of position 6E also has indications of being negligible. Although the percentage change is over 300% with the shield, the new value is within the same order of magnitude (from 14 to 57), and the absolute change is 43 nGy/sec. At such a small value (x 10^{-9}) this value is negligible and likely attributable to random fluctuation, possibly with some measurement error.

To examine the overall effects of the STARTable, the results have been condensed into averages along the vertical plane and along the horizontal plane. These are displayed in Table 9 and Table 10.

Despite the large negative value at position 6E being partially attributable to random fluctuation, it does make a large difference to the corresponding row and column averages at that location. Table 11 shows the effect of excluding 6E from the averaging. The removal of the value from the averaging completely increases the row by 7.9% and the column by 7.2%. Extrapolation of both of these would indicate 6E should have been around 70%, which would have caused a higher average in both directions.

Table 9 – Height (row) averages at zero gantry tilt (measured in %)

Position	Row Average	Average with Zeroed Negatives
1	-2.1	1.5
2	1.5	2.4
3	38.6	39.8
4	53.3	54.8
5	63.0	63.0
6	-29.8	31.6

Table 10 – Width (column) averages at zero gantry tilt (measured in %)

Position	Column Average	Average with Zeroed Negatives
A	-0.3	2.8
B	35.2	35.9
C	38.5	39.7
D	45.5	46.6
E	-15.2	36.0

Table 11 – Comparison of percentage averaged when including and excluding the outlying value of 6E

Position	Average Without 6E	Average With 6E
6	39.5	31.6
E	43.2	36.0

These results show that in both the vertical and the horizontal direction, there are significant differences in averages. Through the different heights, there is almost no attenuation at 50 and 70 cm (positions 1 and 2) which are in the area underneath the patient couch – as the STARTable does not cover this area, it makes sense that there is no attenuation change. Along the length of the patient, the most cranial column has little attenuation, which aligns with the asymmetrical nature of the STARTable. Figure 2 shows the dimensions of the STARTable – the cranial end should receive also no attenuation.

Throughout the vertical averages, the attenuation increases until 130 cm, and drops at 150 cm. However, this includes the ignored 6E value, which, if recorded correctly, may have increased the value of the row overall. The highest attenuation is 63% at a height of 130 cm, or position 5.

Apart from position A, the horizontal averages are very similar, with a range of 10.7%. The maximum is 46.6% attenuation at position D. Again, position E may have had a higher average if not for the outlier 6E.

Though the averages were taken across whole rows, it is important to note that these are subject to averaging and that it does not describe the overall radiation to the clinician well. A clinician is less likely to stand towards the patient's head. The general radiation protection that a clinician would receive is taken from column D, as the clinician will commonly stand in a more caudal location from the radial entry point.

Overall, the maximum reduction in radiation occurs at 5D with an 89.9% reduction. The largest magnitude reduction occurs at position B3, with 73 nGy/sec. The data of the graph in Figure 7 can be used to gain an overview of the realistic changes in clinician radiation, as it provides a comparison between the dose magnitude with shielded and unshielded measurements. The zeroed percentage change data is shown graphically in Figure 6 below; it shows, quite obviously, the areas where the STARTable has a large effect on the dose to the clinician.

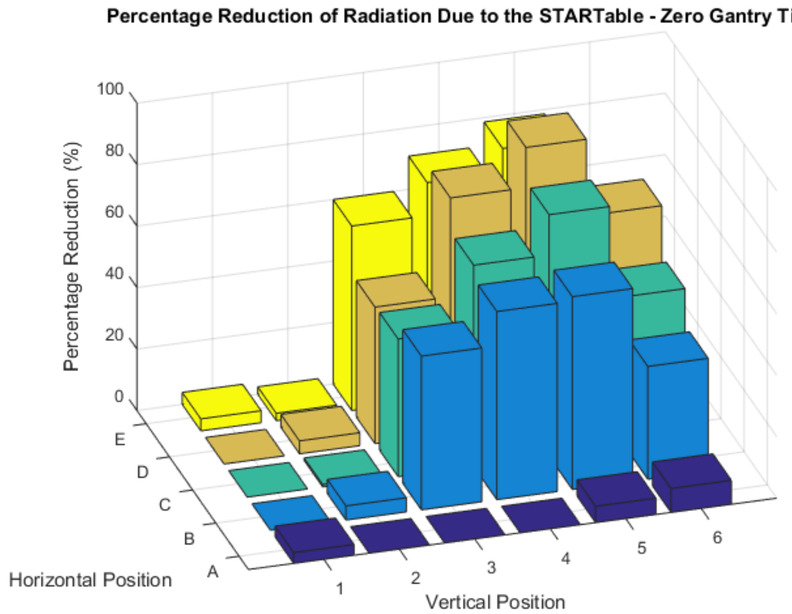

Figure 6 – Bar chart of percentage reduction of radiation at zero gantry tilt

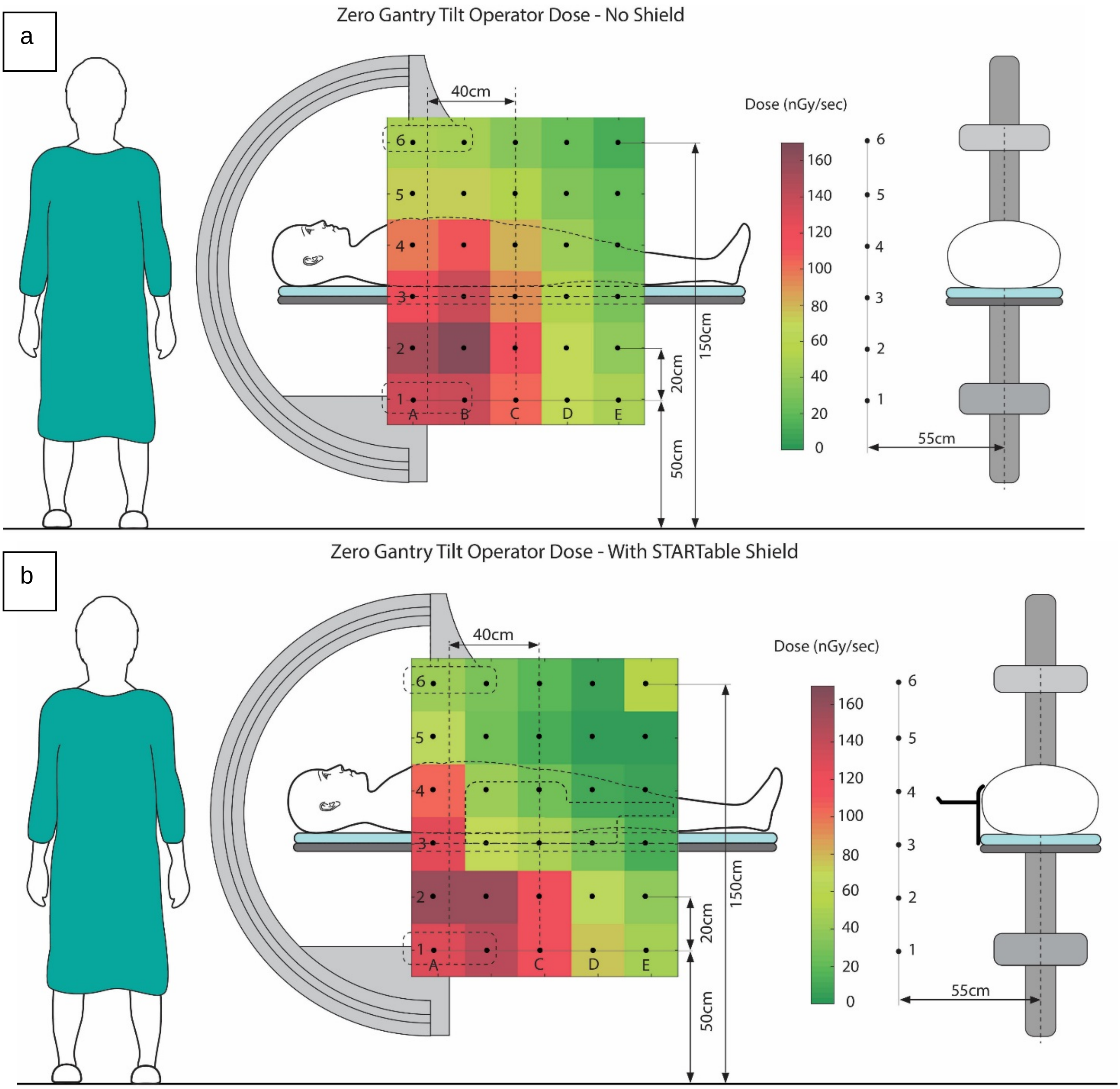

Figure 7 – Colourmap comparisons of dose to the operator, with and without the STARTable, at zero-tilt

It is evident from both Figure 6 and Figure 7 that the addition of the shield greatly reduces the dose to the operator in the region above the operating table. Nevertheless, despite the large amount of attenuation which is visible through Figure 6 above the operating table and to the right of position A, Figure 7 aligns with Table 8 in indicating that there are some sections where the attenuation from the STARTable is altering a dose which is already small. More significant reductions in dose are visible in the more extreme C-arm tilting angles.

LAO 34 / CRAN 20

Below are the results of radiation as a percentage change with and without the STARTable; much as above, the graphs include the relative results and the results where all values are positive.

Table 12 - Percentage reductions of radiation for an orientation of LAO 34 / CRAN 20 (units in %)

	A	B	C	D	E
1	-2.1	-7.1	92.2	-196.6	-260.0
2	-9.9	3.2	22.4	18.5	14.2
3	-9.6	17.4	47.9	55.7	68.8
4	-12.4	47.3	78.2	86.5	88.8
5	-2.2	44.2	71.0	75.7	75.2
6	2.5	40.5	56.5	63.9	64.4

Table 13 - Adjusted percentage reductions of radiation for an orientation of LAO 34 / CRAN 20 (units in %)

	A	B	C	D	E
1	0.0	0.0	92.2	0.0	0.0
2	0.0	3.2	22.4	18.5	14.2
3	0.0	17.4	47.9	55.7	68.8
4	0.0	47.3	78.2	86.5	88.8
5	0.0	44.2	71.0	75.7	75.2
6	2.5	40.5	56.5	63.9	64.4

Much like the values with zero angulation, there are regions of very large negative percentage changes throughout the grid. Positions 1D and 1E have -196.6% and -260.0% changes respectively. Table 14 and Table 15 show the magnitude rather than percentage of these changes.

Table 14 - Magnitude of dose at an extreme orientation with no STARTable (nGy/sec)

	A	B	C	D	E
1	429	70	45	2.9	20
2	485	716	643	286	219
3	550	718	595	316	192
4	466	596	500	304	170
5	357	394	345	230	137
6	242	237	209	158	104

Table 15 - Absolute differences between no radiation protection and the STARTable (nGy/sec)

	A	B	C	D	E
1	-9.0	-5.0	41.5	-5.7	-52.0
2	-48.0	23.0	144.0	53.0	31.0
3	-53.0	125.0	285.0	176.0	132.0

4	-58.0	282.0	391.0	263.0	151.0
5	-8.0	174.0	245.0	174.0	103.0
6	6.0	96.0	118.0	101.0	67.0

Both 1D and 1E have very low measured values. Position 1D is the difference between 2.9 and 8.6 nGy/sec, and position 1E is the difference between 20 and 72 nGy/sec. There are similar values in the positions in A – these may all be somewhat attributable to fluctuations, which justifies their zeroed values.

Though it does not have the largest percentage difference at 78.2% attenuation, 4C has the largest reduction in absolute value with 391 nGy/sec. The largest percentage difference is found at 1C, though the absolute value change is 41.5 nGy/sec.

The trends in attenuation are displayed in Table 16 and Table 17 below. These summarise the different averages across the height and width of an operator's body.

Table 16 - Height (row) averages at an orientation of LAO 34 / CRAN 20 (measurements in %)

Position	Row Average	Zeroed Negatives
1	-74.7	18.4
2	9.7	11.7
3	36.0	38.0
4	57.7	60.2
5	52.8	53.2
6	45.6	45.6

Table 17 - Width (column) averages at an orientation of LAO 34 / CRAN 20 (measurements in %)

Position	Column Average	Zeroed Negatives
A	-5.6	0.4
B	24.2	25.4
C	61.4	61.4
D	17.3	50.1
E	8.6	51.9

In Table 16 and Table 17 there are insights to the average attenuation levels over the whole STARTable. The maximum attenuation average for the extreme angle case occurs at position 4, 110 cm, with a reduction of 60.2%. Below the operator table there is a small amount of attenuation. Above the operating table, the attenuation ranges from 38.0% to the maximum, giving a larger range of 22.2%.

In the horizontal locations, there is almost no attenuation along position A, similar to the zero-tilt example. There is also only a small amount of attenuation (25.4%) at position B. Position C has the highest attenuation, with 61.4%, and D and E receive similar, high amounts of attenuation. Across these three more caudal positions, there is a range of 11.3%.

The results are demonstrated in Figure 8, showing the percentage reductions to the grid, while the colourmap of Figure 9 describes the changes in the raw values due to the shield.

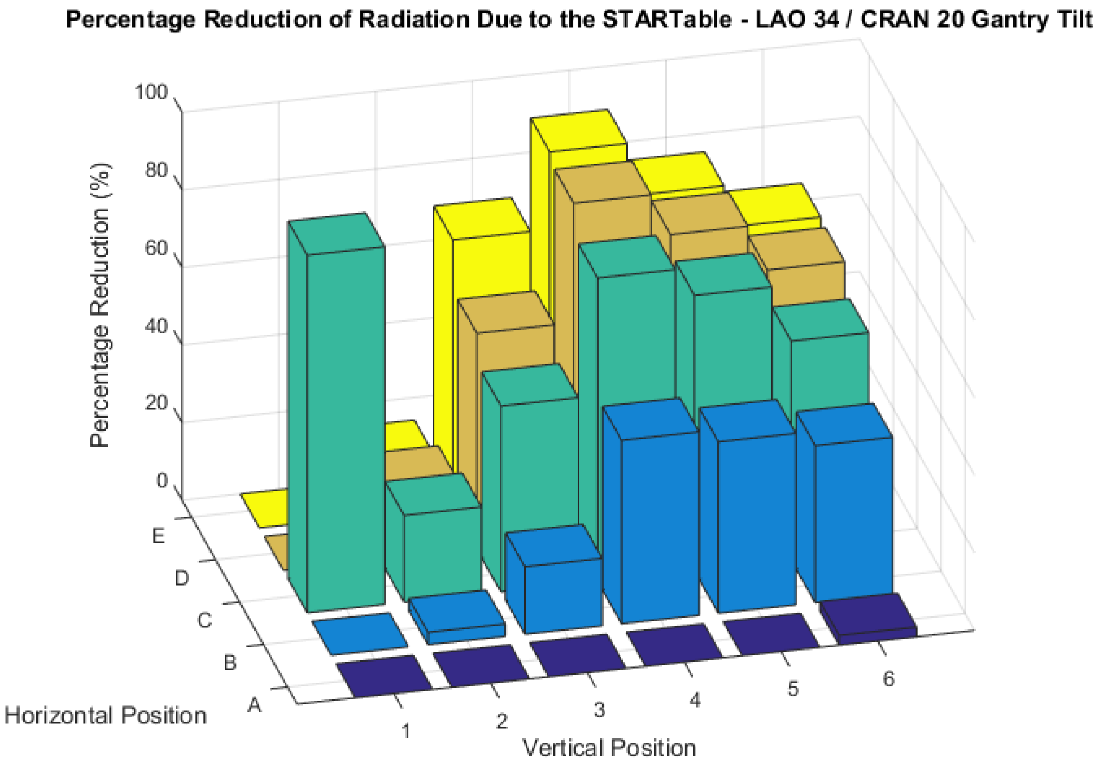

Figure 8 – Bar chart of percentage reduction of radiation at an orientation of LAO 34 / CRAN 20

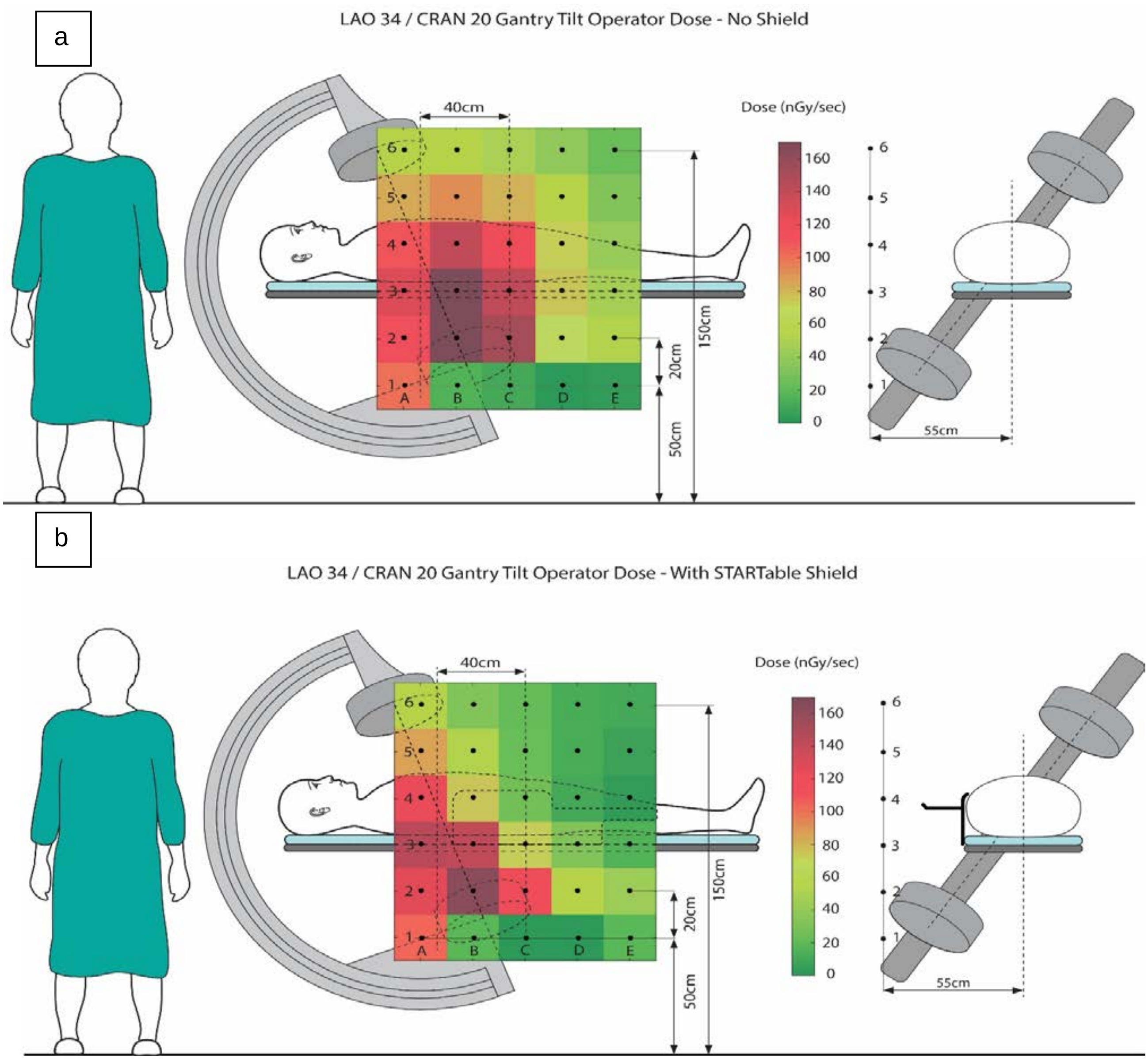

Figure 9 - Colourmaps of the absolute values with (a) and without (b) the STARTable

Comparing the figures of this section display the effectiveness of the shield at a position of extreme angulation. Although Figure 8 looks rather similar to its companion graph at no tilt, the comparison of Figure 9 shows a massive decrease in the raw radiation values at these same locations. This is very important to providing protection to clinicians when they are using this orientation, which emits a higher baseline radiation level.

Although the percentage values at the higher tilt are much the same as those in the zero-tilt situation, the reductions in the radiation at extreme angulation have greater magnitude reductions in attenuation than those at zero / zero orientation. This is displayed when comparing Table 6 and Table 14. The largest value of the zero-tilt (174 nGy/sec) is approximately one quarter of the largest value of the extreme angulation (718 nGy/sec). This reinforces the need for high attenuation in the case of extreme angulation.

6 Conclusion:

The vertical leaded portion of the STARTable product is proven to provide reasonable amounts of attenuation throughout both angles of the C-Arm operations, and specifically helps to reduce radiation in the extreme angled case. Though it provides little protection under the table, the STARTable provides moderate protection and may be used with other radiation protection equipment to help reduce radiation to a safe level. For all the tests, the beam quality was approximately 80 kVp. The attenuation a clinician receives is calculated with the assumption that they stand slightly caudal to the radial entry point.

At gantry tilt 0º

- The maximum percentage scatter radiation reduction throughout the grid is 90%.
- At 110 cm (waist height – 4D correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical STARTable is 77%.
- At 150 cm (neck height – 6D correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical STARTable is 65%.
- At the cranial end of the STARTable, the scatter radiation reduction is negligible.
- At the caudal end of the STARTable, the scatter radiation reduction is 79%.

At LAO 34 / CRAN 20

- The maximum percentage scatter radiation reduction throughout the grid is 89%.
- At 110 cm (waist height – 4D correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical STARTable is 87%.
- At 150 cm (neck height – 6D correlating to usual clinician position during procedure), the scatter radiation reduction with use of Adept Medical STARTable is 64%.
- At the cranial end of the STARTable, the scatter radiation reduction is negligible.
- At the caudal end of the STARTable, the scatter radiation reduction is 89%.

Though these figures give a general idea of the amount of attenuation received, it would be interesting to perform further experimentation with multiple measurements at each point, hence determining the nature of those values and gaining a more accurate representation of the percentage changes to the clinician's radiation dose.

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