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Dose to patients from X-ray imaging in Radiotherapy

An update from the IPEM working party

CT planning Scans

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Overview

- Introduction
  - The aims of the working party
  - Who are we?
  - The ‘grand plan’
- Planning CT data
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  - Reference dose and scan length values
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- CBCT audit – update on progress
- Summary

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Introduction

The aims of the working party

- To undertake an audit of typical imaging doses for the full range of X-ray imaging procedures undertaken in Radiotherapy departments
  - This includes planning CT scans, on treatment CBCT imaging, and also may consider other modalities such as planar X-ray and fluoroscopy
- To publish a range of typical ‘doses’ for common procedures
  - Like PHE do with national reference doses in diagnostic imaging
  - If data is good enough, this should allow adoption as national ‘DRLs’ for RT imaging
- Make data available to the UK Radiotherapy community that will enable better optimisation of imaging
  - This may also identify best practice that will ultimately benefit patients

Who are we?

- The core members of the working party are;
  - **Tim Wood** (Chair) – DR Physicist, Hull and East Yorkshire Hospitals NHS Trust
  - **Matthew Williams** (Secretary) – DR/RT Physicist, Velindre Cancer Centre
  - **Anne Davis** – DR Physicist, Portsmouth Hospitals NHS Trust
  - **Becky Lindsay** – RT Physicist, Leeds Teaching Hospitals NHS Trust
  - **Rosy Plaistow** – RT Physicist, Cambridge University Hospitals NHS Foundation Trust
- Feeding back to IPEM DR and RT Special Interest Groups
- Consulting with Radiotherapy Board
  - A collaboration between RCR, SCoR, and IPEM
- Also observers from PHE

The ‘grand plan’

- Aim for at least two peer-reviewed publications in a relevant journal (likely PMB or similar)
  - **Planning CT doses**
  - **CBCT doses**
- Want to include a simple evaluation of **image quality** to go alongside the assessment of doses
- Look at **other imaging modalities**, if time
- May also extend to **paediatrics**,
  - Will need to be a more targeted exercise as relatively few centres do these
- Aim to engage as many departments as possible – both **NHS** and **private sector**

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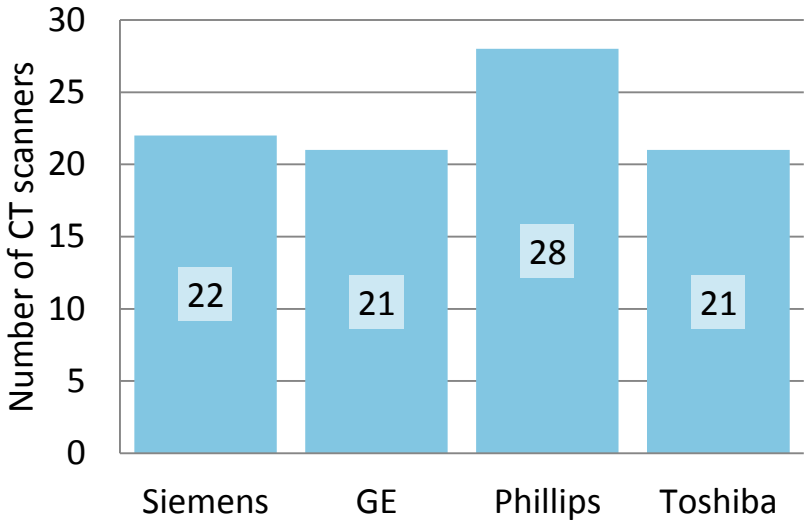
The pre-data collection questionnaire

Pre-data collection questionnaire

- Pre-data collection questionnaire distributed early 2017
- Aimed to collect some basic information on the systems used in hospitals, common imaging protocols, etc.
- Overall response rate was excellent – 59 out of 73 UK centres submitted a response (80.8%)
  - **Includes private providers**
- A high proportion of these centres (88%) have dedicated person for imaging in place
  - For some centres, this includes DR support
  - Some centres have lead Radiographers
  - Others RT physicsits
- Information gathered on CBCT equipment and protocols
  - Not the subject of todays talk

Pre-data collection questionnaire

- With regards to **CT planning scan equipment and protocols**;
  - In the 59 UK centres to submit data, there are a total of 92 CT scanners currently 'in use'
  - Fairly evenly split between four vendors
  - The seven proposed 'clinical protocols' were used by the majority of centres
  - There was no common 'other' protocol suggested for audit
  - *Note*, no nodes was selected for audit due to more standardised protocols (scan lengths) being used



CT Protocol	N	% of centres
Breast (no nodes)	57	96.6
Prostate (no nodes)	56	94.9
Gynae (no nodes)	46	78.0
Lung 3D	53	89.8
Lung 4D	48	81.4
Brain	44	74.6
Head and neck	54	91.5

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CT planning scans

Method & data processing

CT planning scans

- Launched data collection in February 2017, and closed after one month extension on 31st May 2017
- Asked for protocol info and up to 30 patients for each scan protocol/scanner combination
  - Many datasets are smaller than this
- Data received from 68 CT scanners in 57 RT centres (78% of UK centres)
  - Last data set arrived in September…
  - Some small data sets in the sample
  - Largest data sets, in terms of number of scanners, are prostate (64 scanners) and breast (62), as expected from the questionnaire data

Data processing

- Data was checked thoroughly before adding to a master database
  - Checked for typos, inconsistencies, misplaced decimal points, etc
  - Queries/errors were followed up with the relevant centres, where appropriate
- A MATLAB tool was used to process the data for each clinical indication
  - Adapted from that used in the IPEM Hybrid Imaging audit
  - Calculates mean, median, 2×SEM, 95% confidence intervals, min and max $CTDI_{vol}$, DLP, scan length and weight (where provided) on each scanner
- Data saved to Excel for further processing and checking
  - Final checks of ‘data quality’

Data analysis

- **Third quartile** ('national reference') and **median** ('achievable') of the **scanner average data** were calculated in Excel
- For this study, **median** from each scanner was used to define scanner average $CTDI_{vol}$, DLP, scan length (not mean)
  - More robust against outliers e.g. very obese patients
  - In accordance with draft guidance from the ICRP on '*Diagnostic Reference Levels in Medical Imaging*' and is also a widely used technique in many centres
  - For data plots, error bars are the 95% confidence intervals

Scanner median & patient weight

- A limited number of centres provided weight information, but these demonstrated large variations
  - e.g. prostate data had a range from around 40 kg up to 180 kg
- We deliberately chose not to specify weight as an exclusion criteria for this study
  - Information not always readily available
  - It was anticipated that datasets would already be relatively small given the specific clinical indications requested
  - The nature of the clinical indications often means patients are at extremes of weight classification e.g. many very obese, but also others with significant weight loss due to their condition
- **Use of median for scanner average is a robust method for dealing with lack of weight information**
  - *Centres comparing to our reference values should determine average doses in the same way*

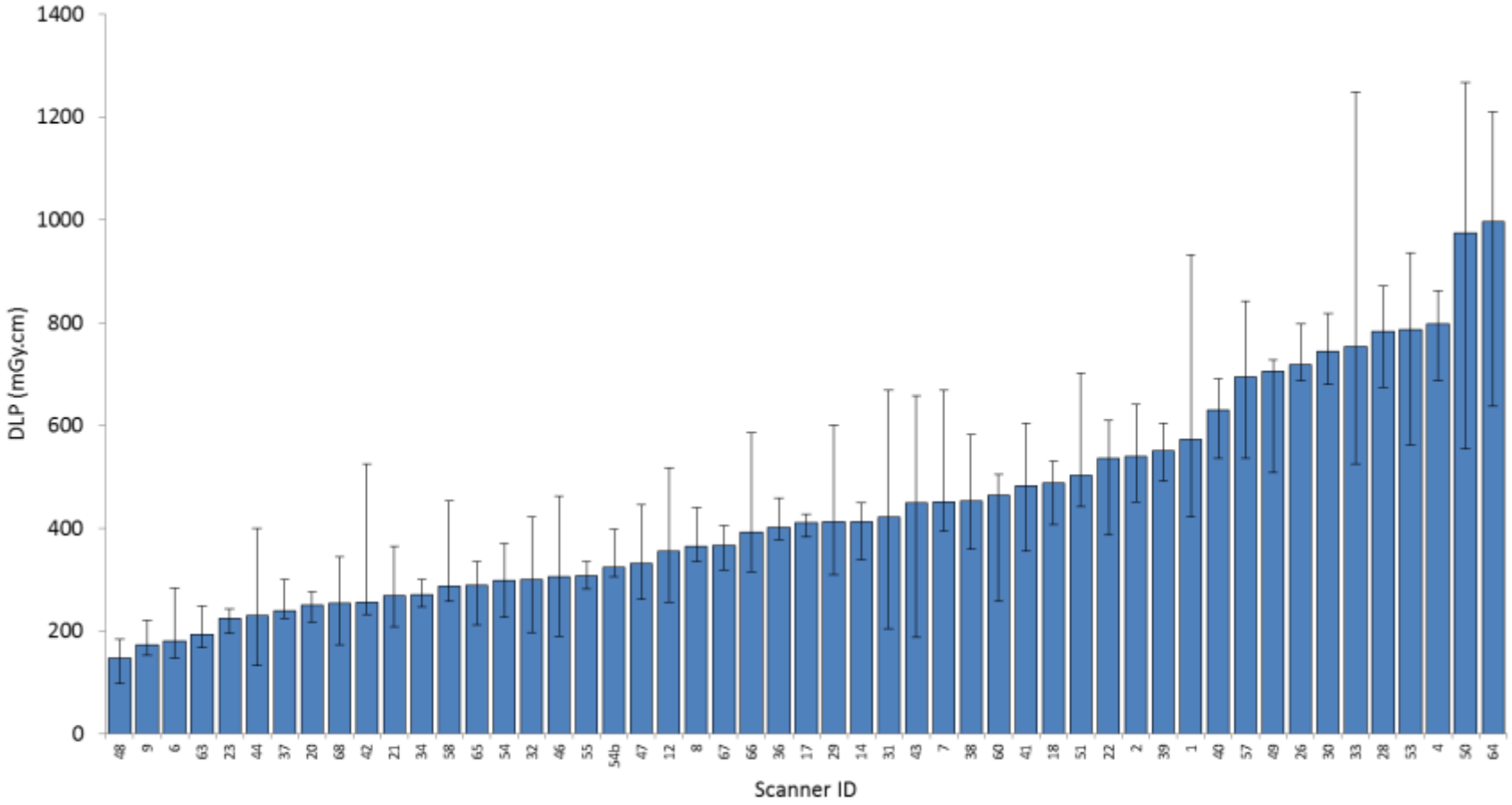
CTDI phantom size

- CTDI phantom size is of obvious importance to the dose metrics shown by the scanner
- Following on from experience of IPEM hybrid dose WP and PHE with C-spine data collection, phantom size was requested for all protocols
- **Most RT planning scans are done on the body phantom**
- However, for **head & neck** and **brain scans**, both head and body phantom datasets were submitted
- Data for the different phantom sizes were analysed separately, and also as a single data set with AAPM SSDE correction factors applied to convert 32 cm data to 16 cm
  - A conversion factor of 2.06 was used

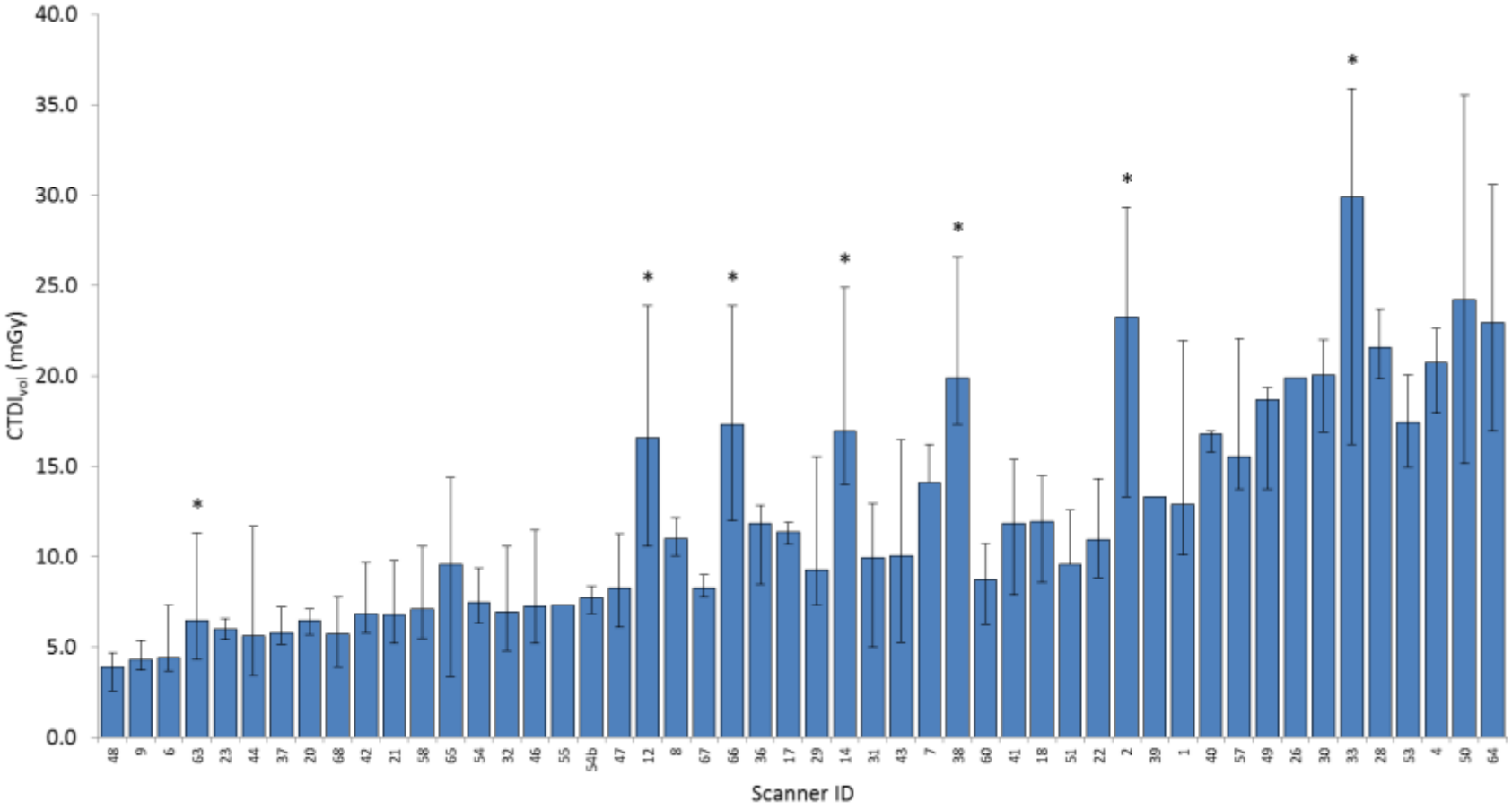
Toshiba $CTDI_{vol}$

- For software version 4.63 or earlier, Toshiba scanners display maximum $CTDI_{vol}$, not average like all other vendors
  - *Typically* corresponds to scanners from before 2013
  - Scanners on later versions of software give average value
- For protocols **that use the AEC system** this will result in overestimation of the dose and may skew the national reference values for $CTDI_{vol}$
  - Does not affect DLP (based on average $CTDI_{vol}$)
- All centres with Toshiba scanners installed prior to 2013 were asked to confirm the software version of their scanner
- If the data was from v4.63 or earlier;
  - The average $CTDI_{vol}$ was excluding from the calculation of national reference values (DLP and scan length were left in)
  - $CTDI_{vol}$ still included in plots for further discussion

Lung 3D median DLP



Lung 3D median $CTDI_{vol}$



* = max $CTDI_{vol}$ value

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CT planning scans

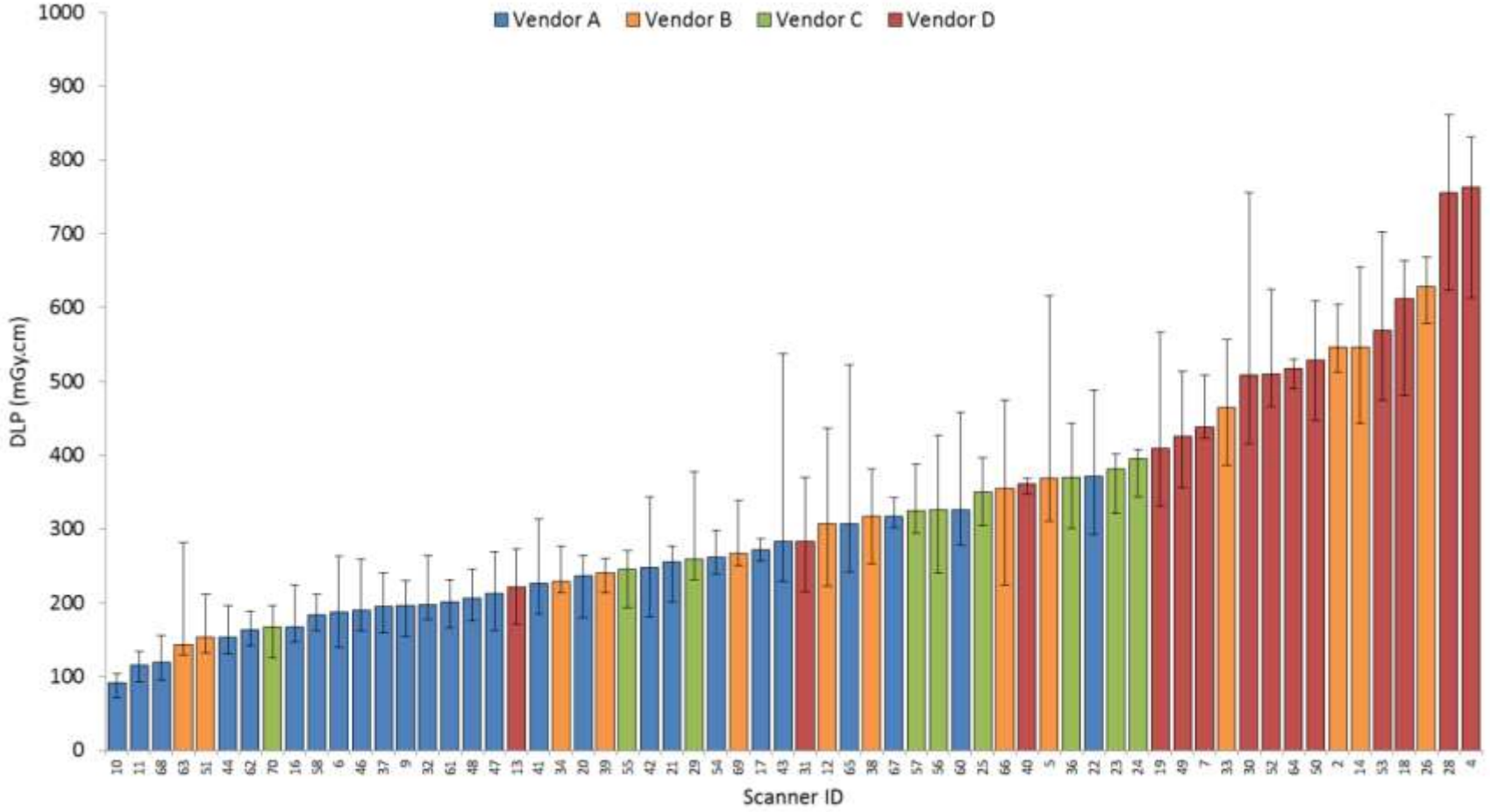
Chest based planning…

Note, all plots have scanner ID organised in ascending DLP order

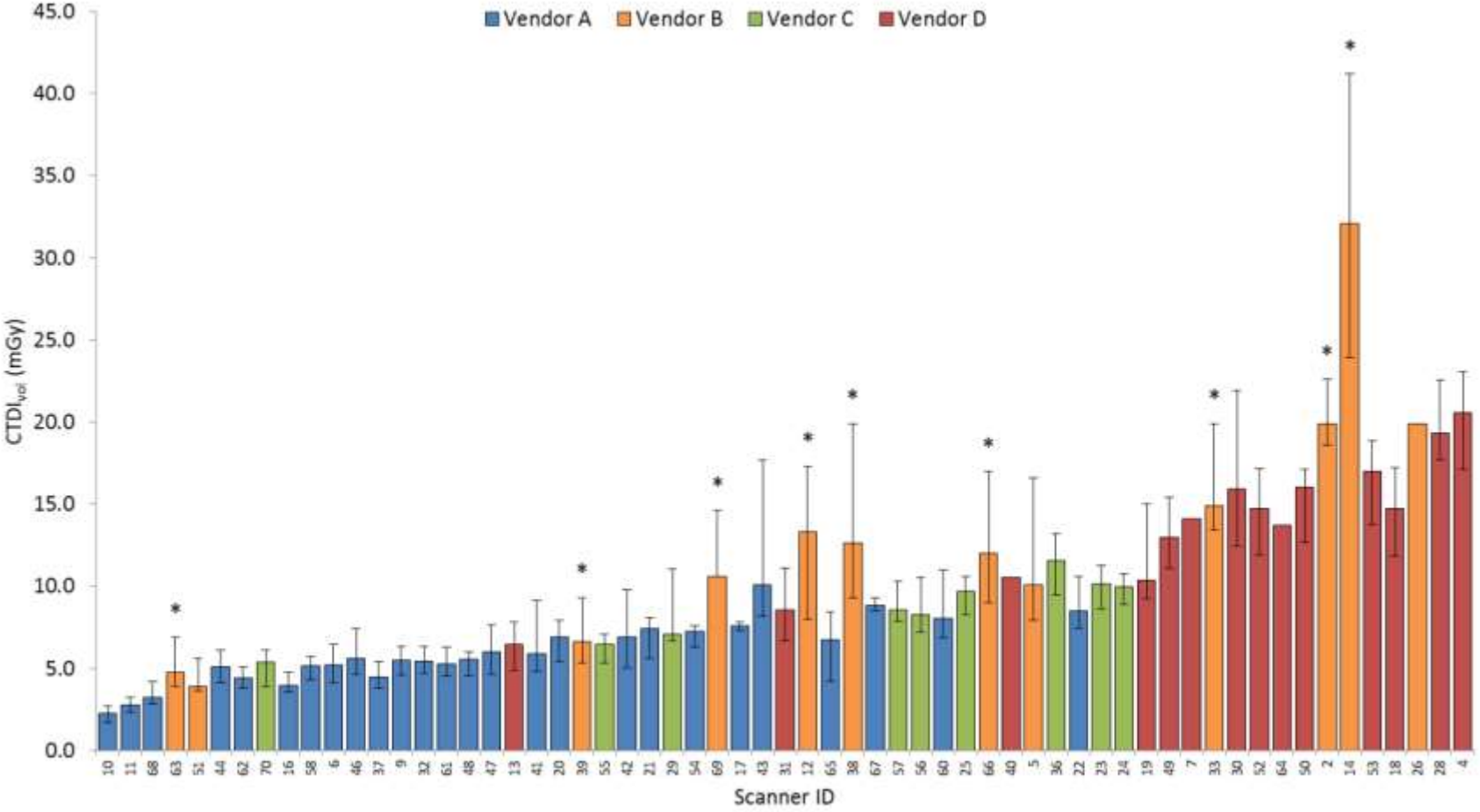
Breast

- One of the largest data sets
  - 62 DLP scanner median values
  - 61 CTDIvol scanner median values (52 when max CTDI scanners removed)
  - 58 scan length scanner median values
- Wide range of doses. Ratio of maximum to minimum scanner doses;
  - DLP = 8.3
  - CTDIvol = 9.0
- Scan lengths relatively consistent across scanners
  - Ratio of max to min = 1.6
- Clustering of vendors?
  - Are a number of centres running manufacturer default protocols without further optimisation?

Breast – DLP

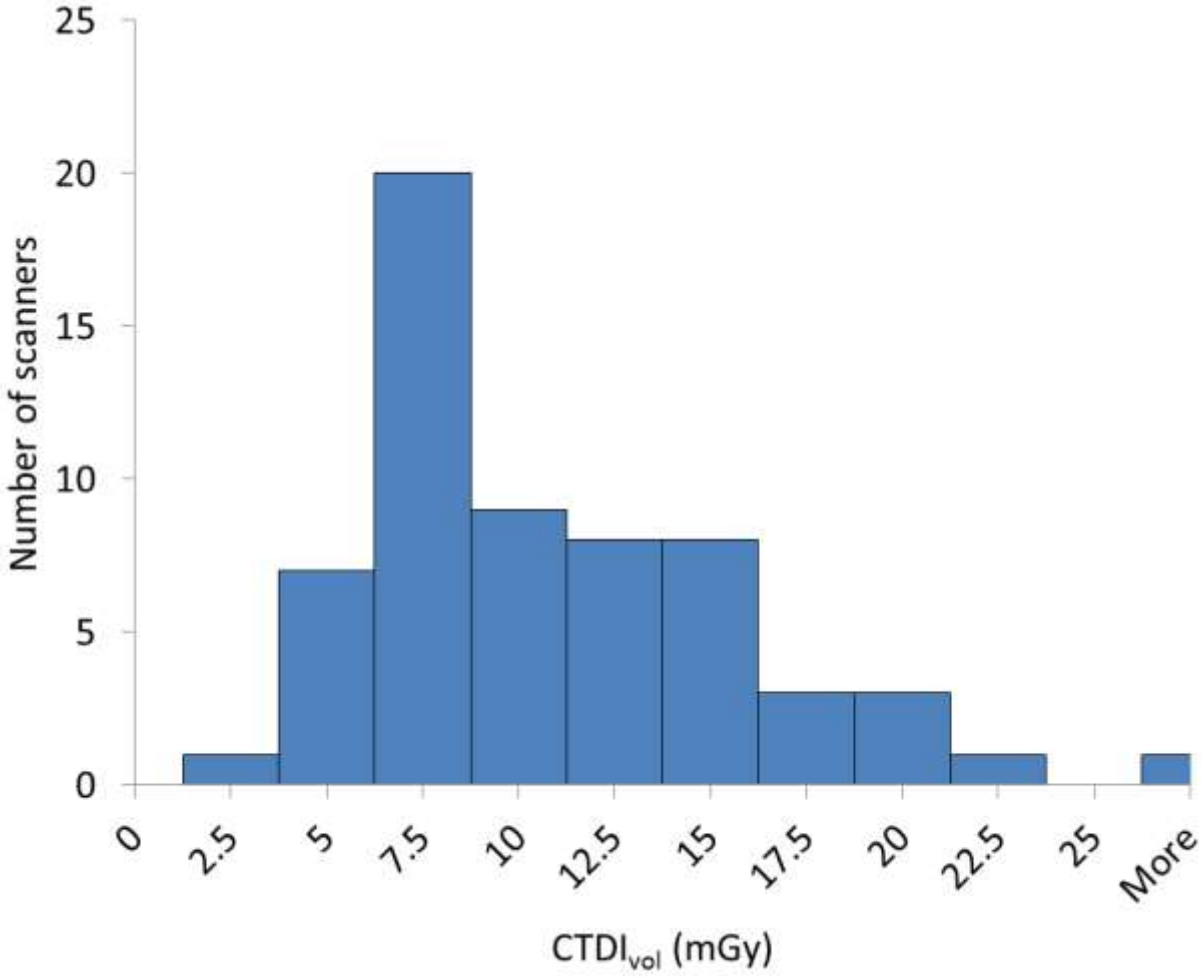

Vendor A
Vendor B
Vendor C
Vendor D
DLP (mGy.cm)
1000
900
800
700
600
500
400
300
200
100
0
10 11 68 63 51 44 62 70 16 58 6 46 37 9 32 61 48 47 13 41 34 20 39 55 42 21 29 54 69 17 43 31 12 65 38 67 57 56 60 25 66 40 5 36 22 23 24 19 49 7 33 30 52 64 50 2 14 53 18 26 28 4
Scanner ID

Breast - $CTDI_{vol}$

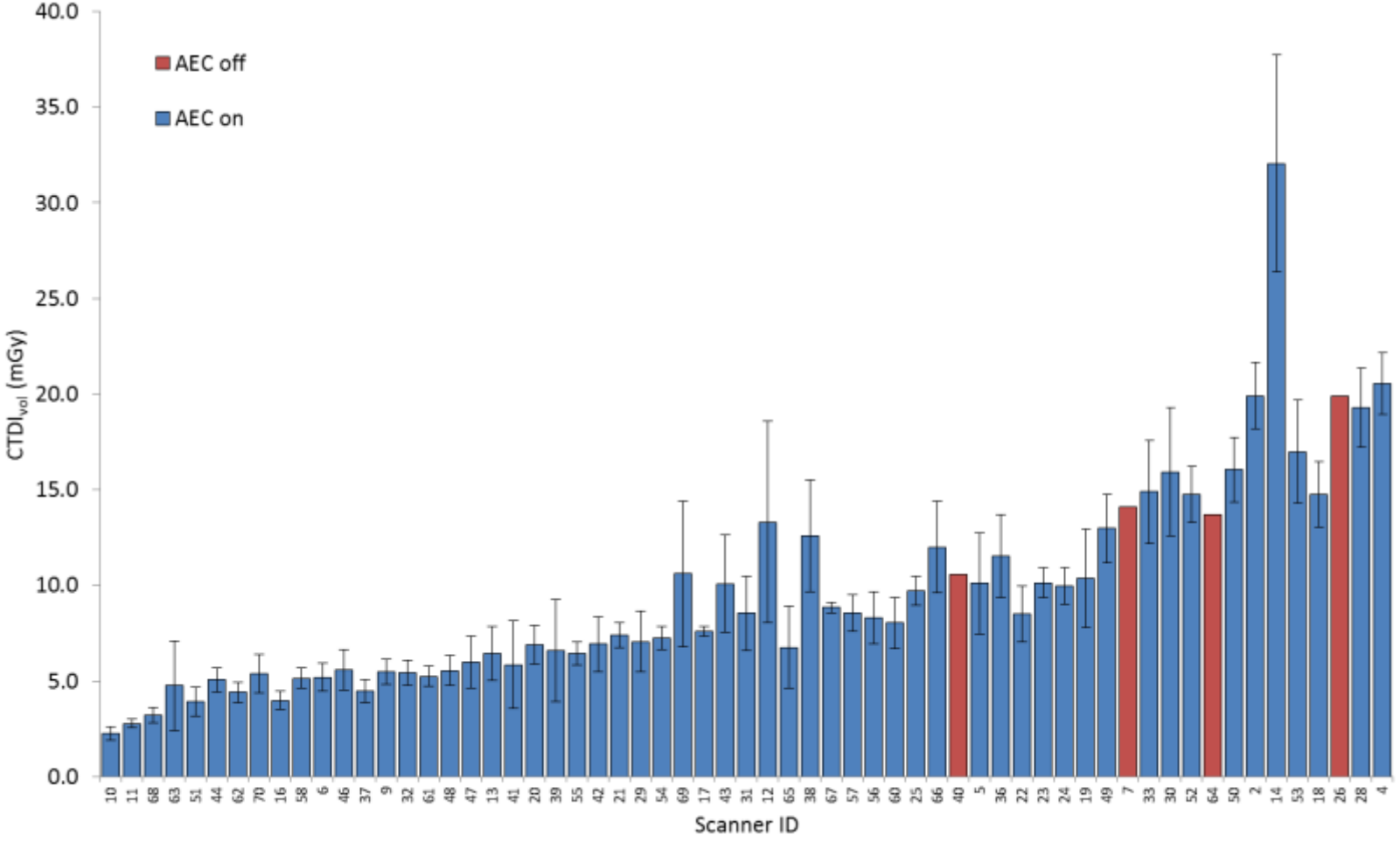


* = max $CTDI_{vol}$ value

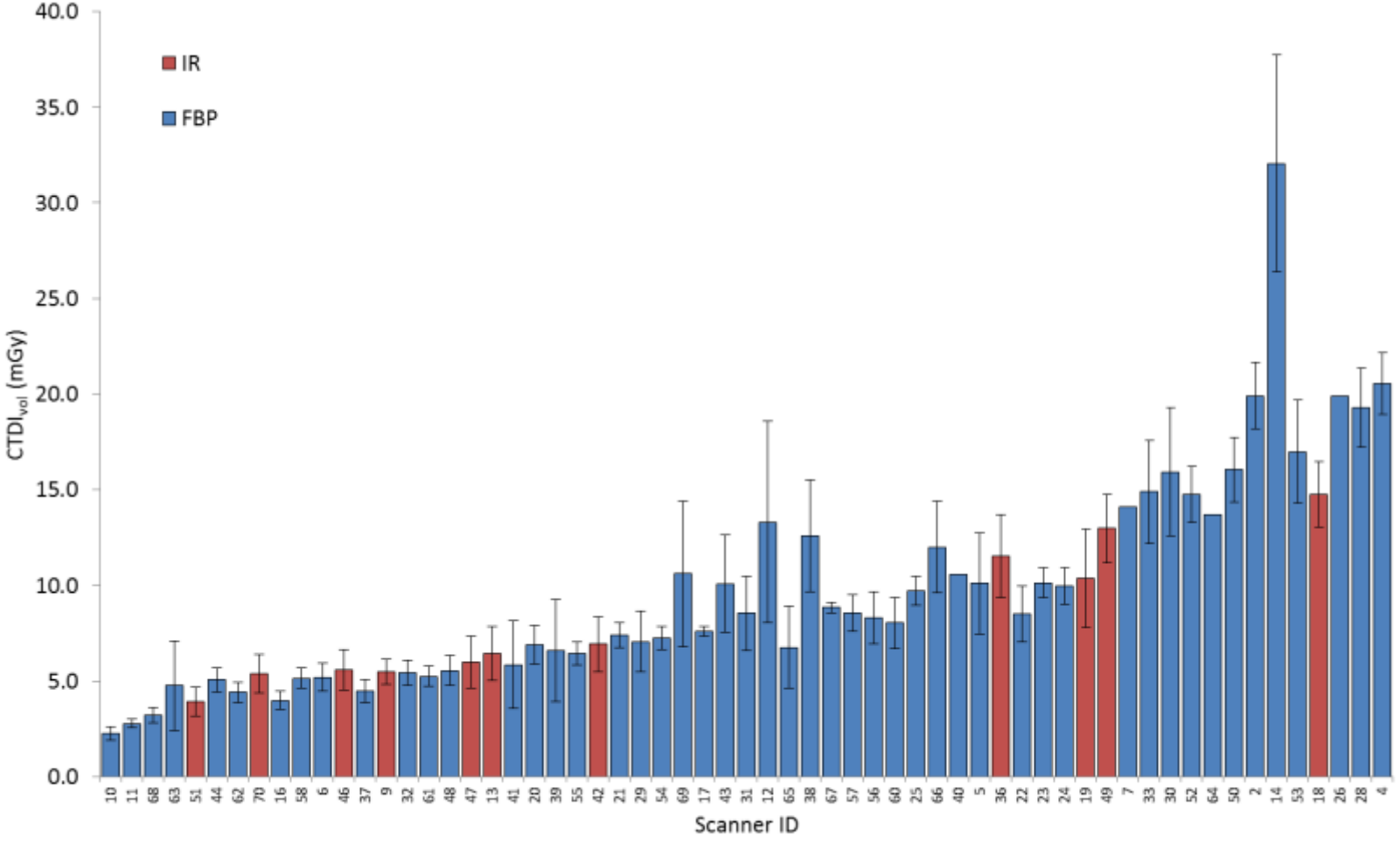
Breast - $CTDI_{vol}$



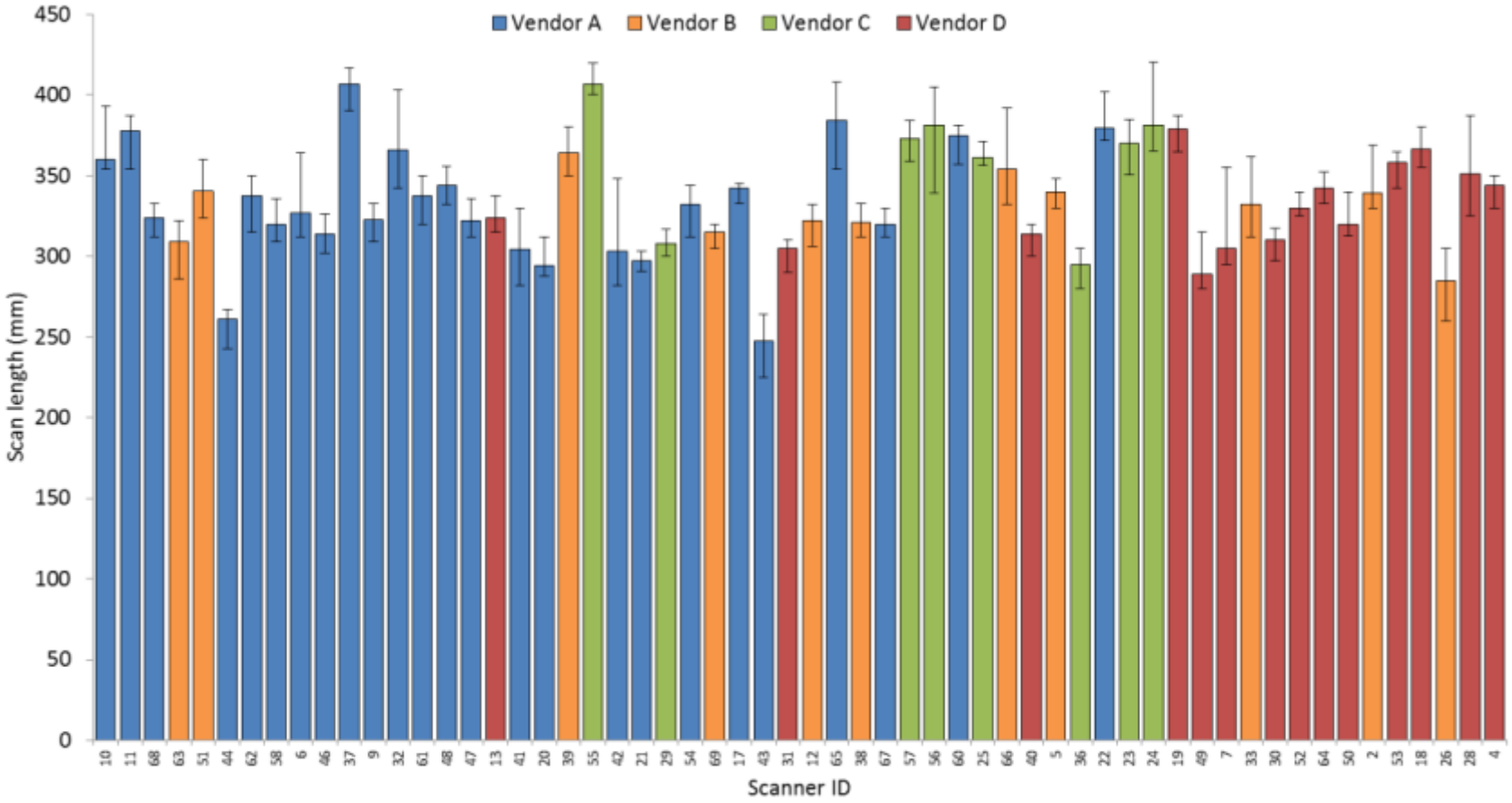
Breast – AEC vs fixed mAs



Breast – FBP vs iterative



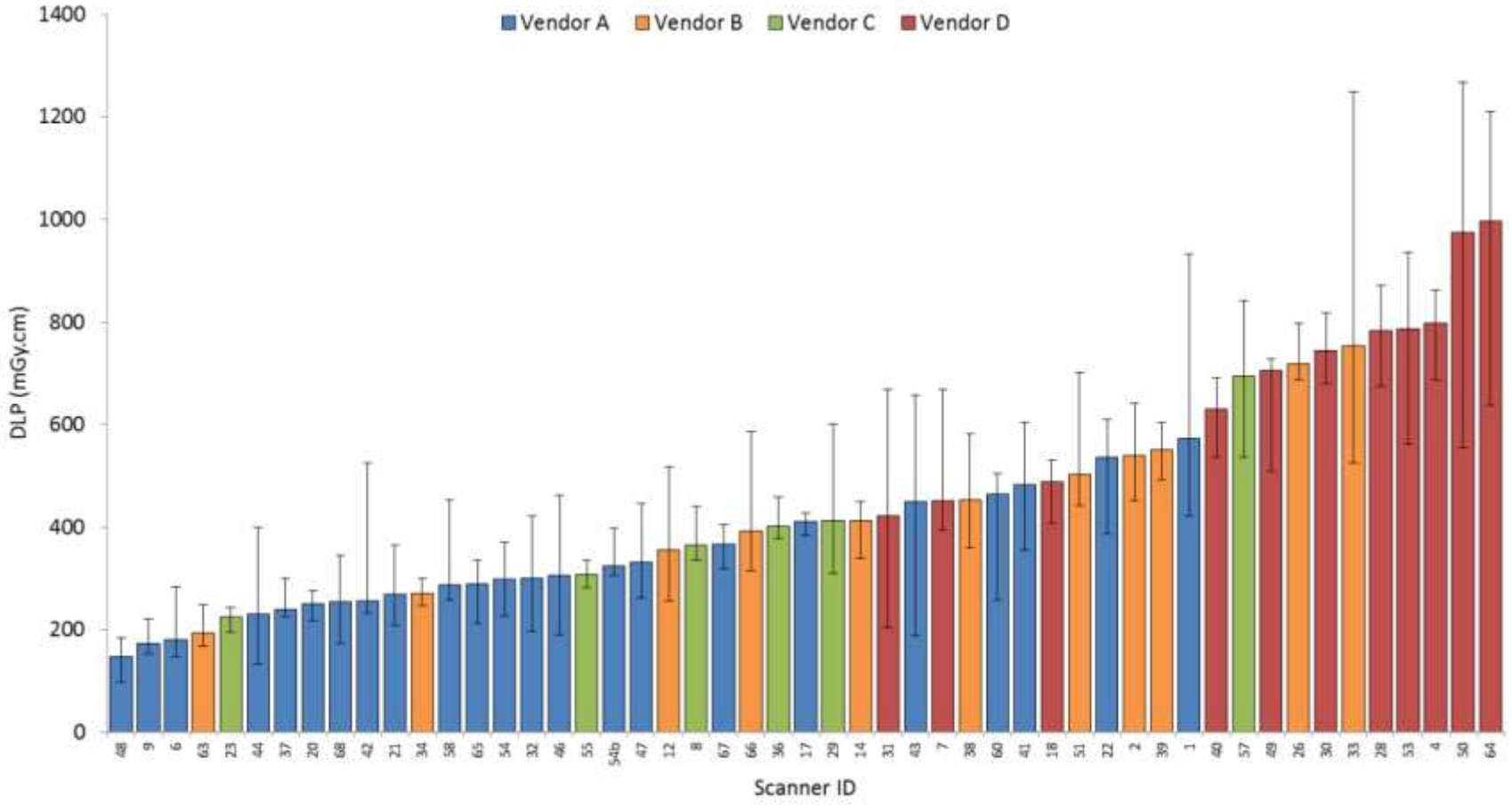
Breast – Scan length



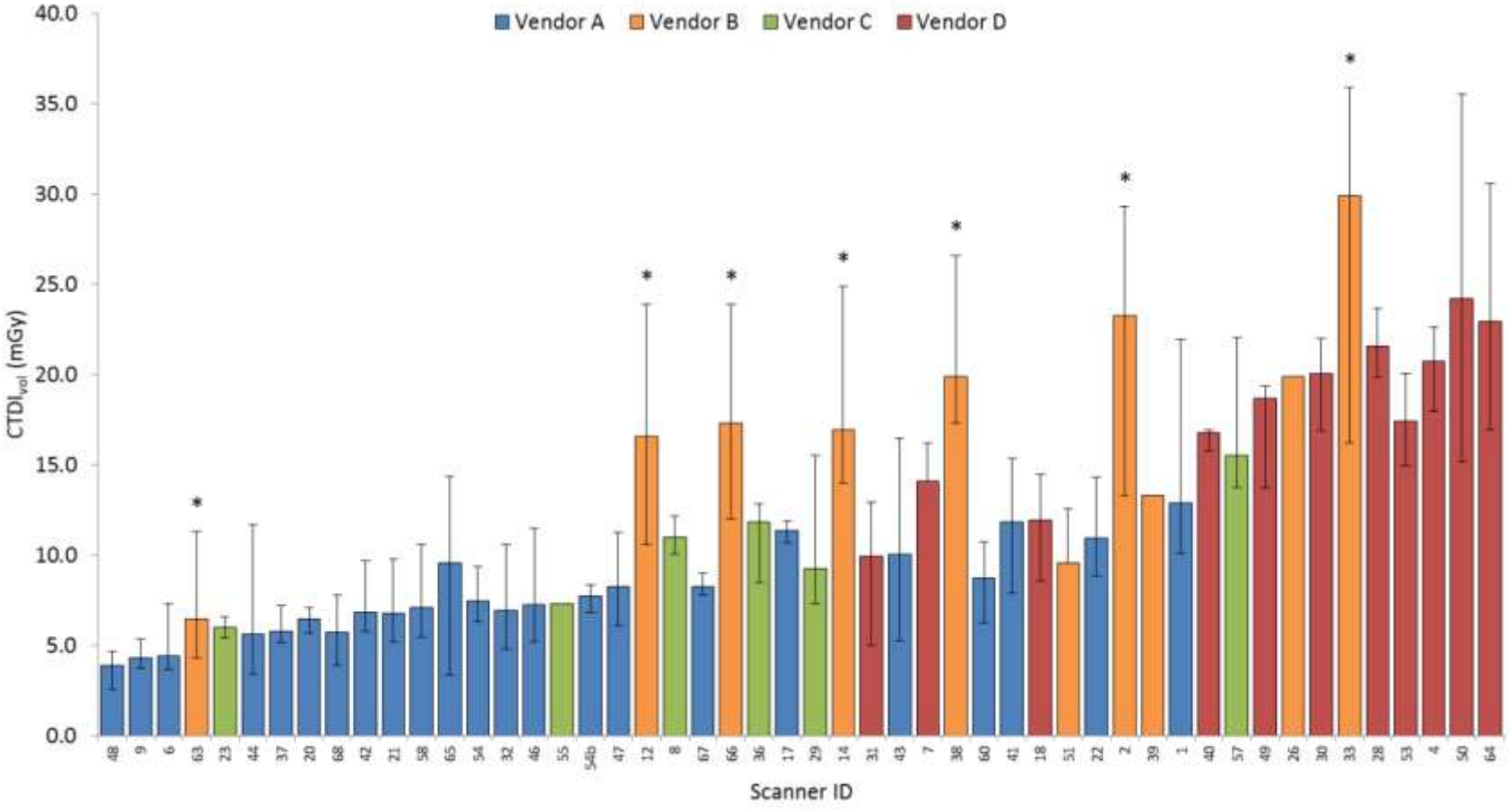
Lung 3D

- Good size data set;
  - 51 DLP scanner medians
  - 50 $CTDI_{vol}$ scanner medians (42 excluding max CTDI values)
  - 49 scan length medians
- Again, wide range of doses
  - Max-to-min ratios of 6.7 and 6.2 for DLP and $CTDI_{vol}$, respectively
- Relatively consistent scan lengths
  - Max-to-min ratio of 1.5
- Clustering of vendors again?

Lung 3D – DLP

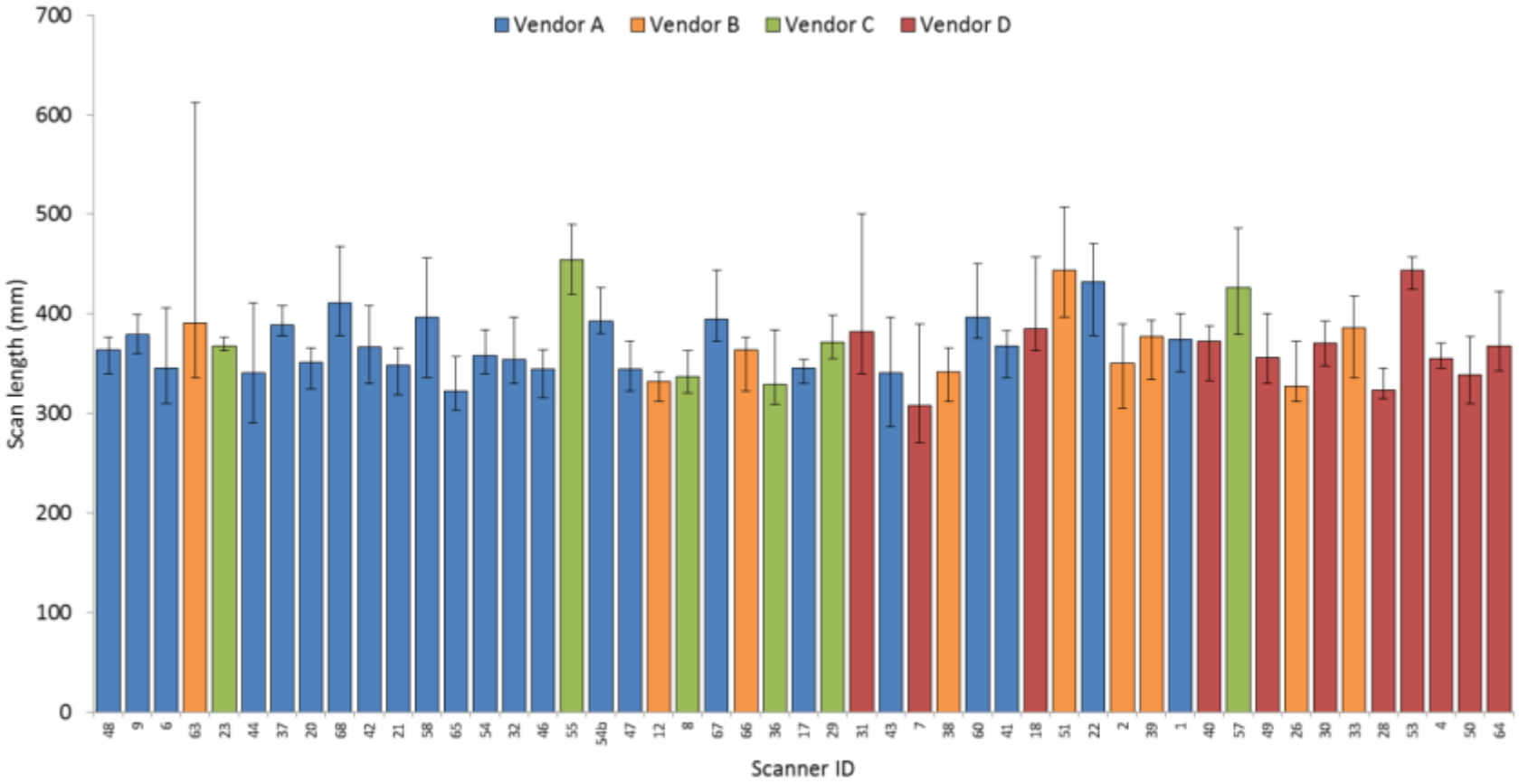

Vendor A
Vendor B
Vendor C
Vendor D
DLP (mGy.cm)
1400
1200
1000
800
600
400
200
0
48 9 6 63 23 44 37 20 68 42 21 34 58 65 54 32 46 55 54b 47 12 8 67 66 36 17 29 14 31 43 7 38 60 41 18 51 22 2 39 1 40 57 49 26 30 33 28 53 4 50 64
Scanner ID

Lung 3D - $CTDI_{vol}$



* = max $CTDI_{vol}$ value

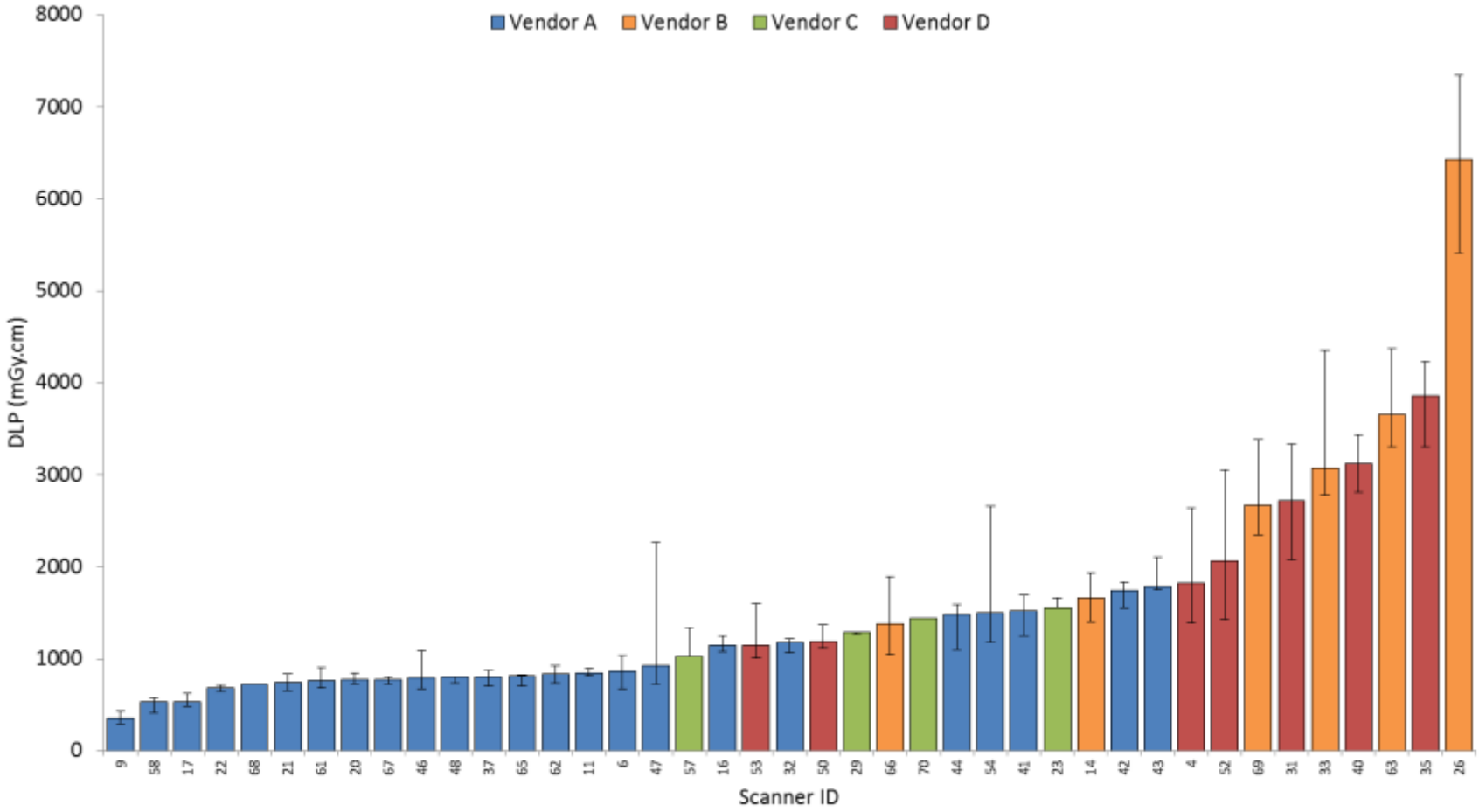
Lung 3D – Scan length



Lung 4D

- Relatively small data set
  - 41 DLP scanner medians
  - 40 $CTDI_{vol}$ scanner medians (39 excluding max CTDI systems)
  - 36 scan length medians
- Very wide range of doses
  - Factor of 18.6 between min and max DLP
  - Factor of 16.7 between min and max $CTDI_{vol}$
- Very strong vendor dependence
  - Different approaches to 4D CT data acquisition and processing?

Lung 4D – DLP


Vendor A
Vendor B
Vendor C
Vendor D
DLP (mGy.cm)
8000
7000
6000
5000
4000
3000
2000
1000
0
Scanner ID
9
58
17
22
68
21
61
20
67
46
48
37
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62
11
6
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16
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32
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66
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44
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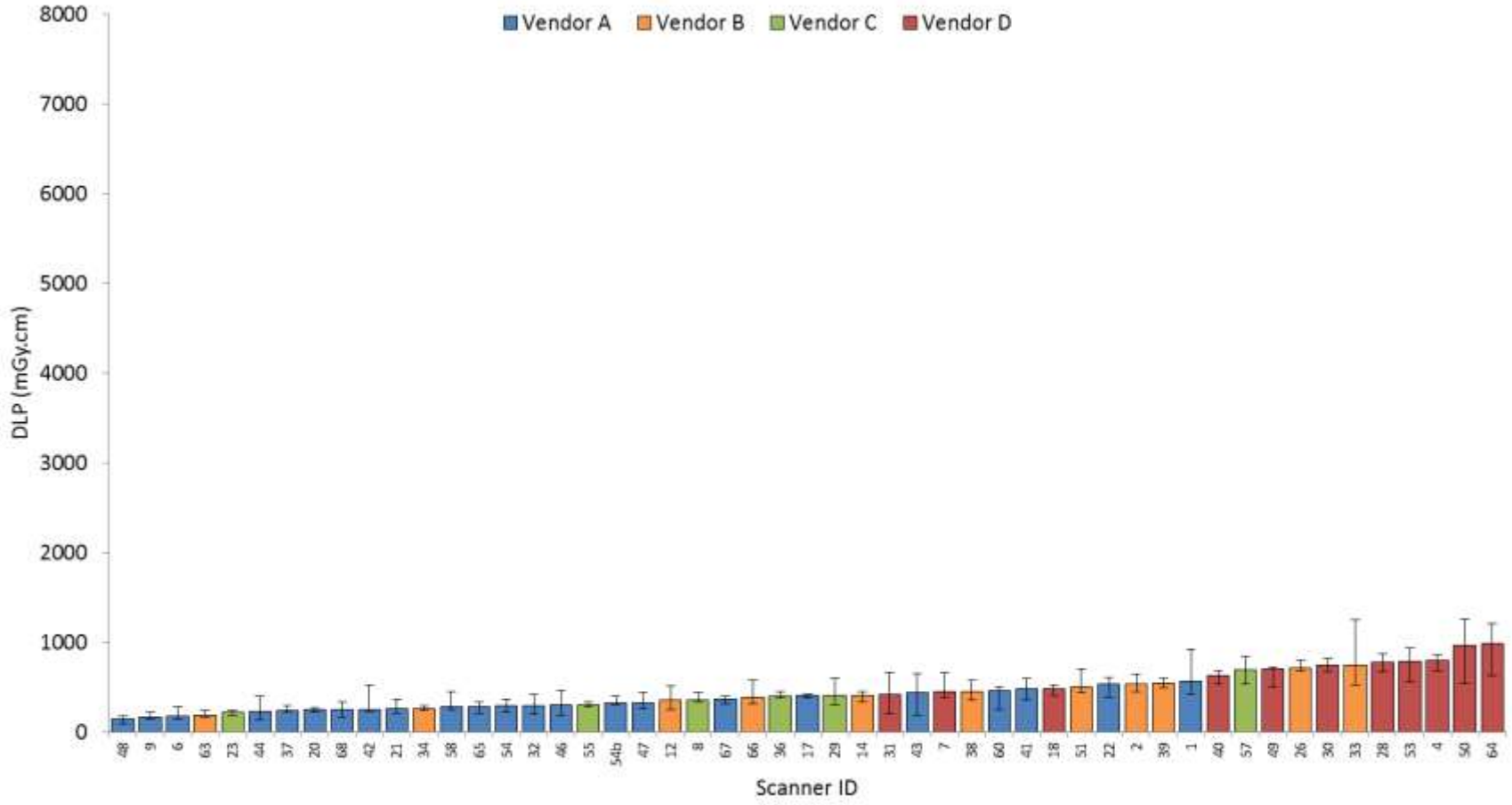
41
23
14
42
43
4
52
69
31
33
40
63
35
26

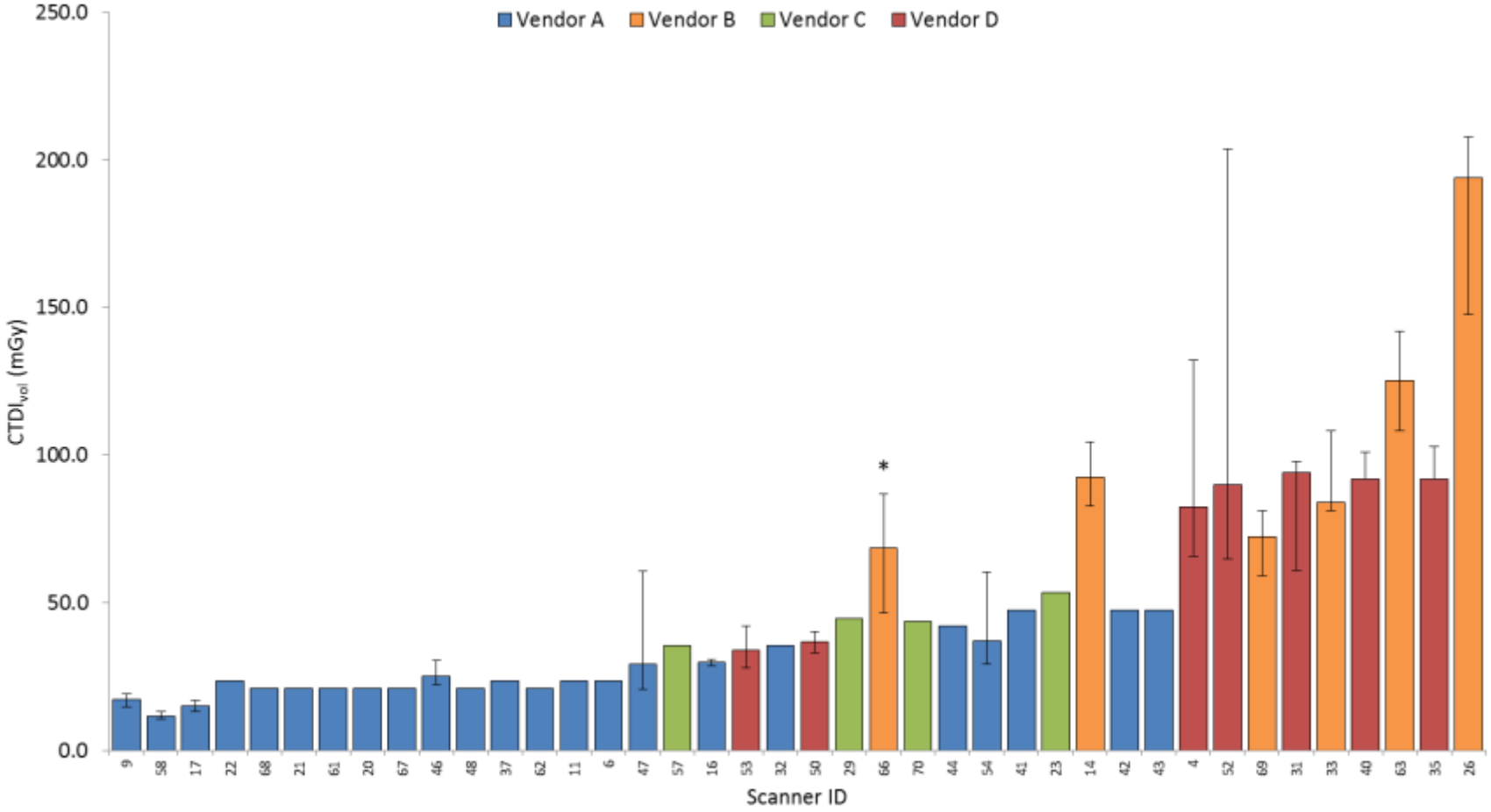
Compared with 3D scans…

(on same axis)

Lung 3D - DLP


Vendor A
Vendor B
Vendor C
Vendor D
DLP (mGy.cm)
8000
7000
6000
5000
4000
3000
2000
1000
0
48 9 6 63 23 44 37 20 68 42 21 34 58 65 54 32 46 55 54b 47 12 8 67 66 36 17 29 14 31 43 7 38 60 41 18 51 22 2 39 1 40 57 49 26 30 33 28 53 4 50 64
Scanner ID

Lung 4D - $CTDI_{vol}$

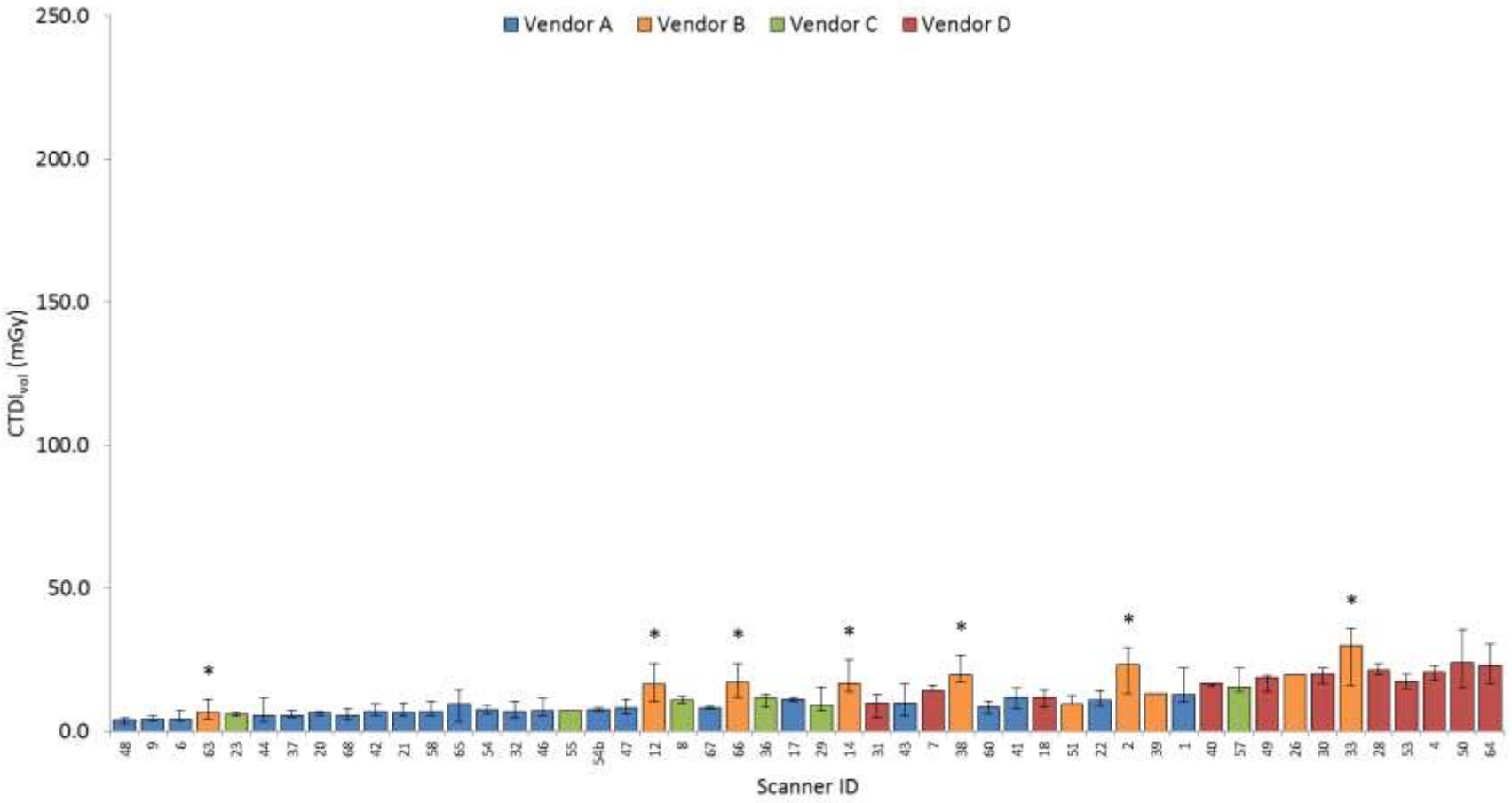


* = max $CTDI_{vol}$ value

Compared with 3D scans…

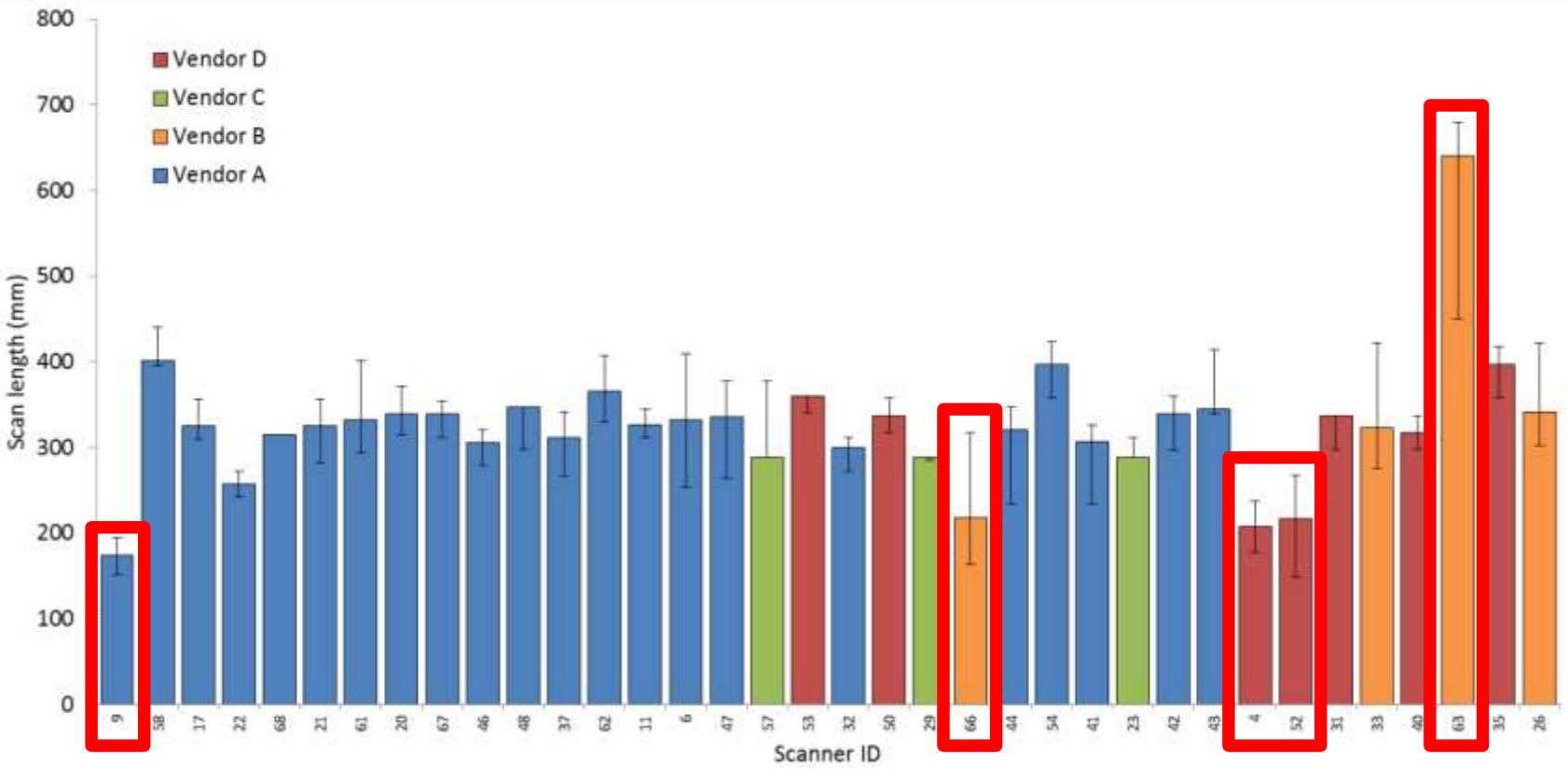
(on same axis)

Lung 3D - $CTDI_{vol}$



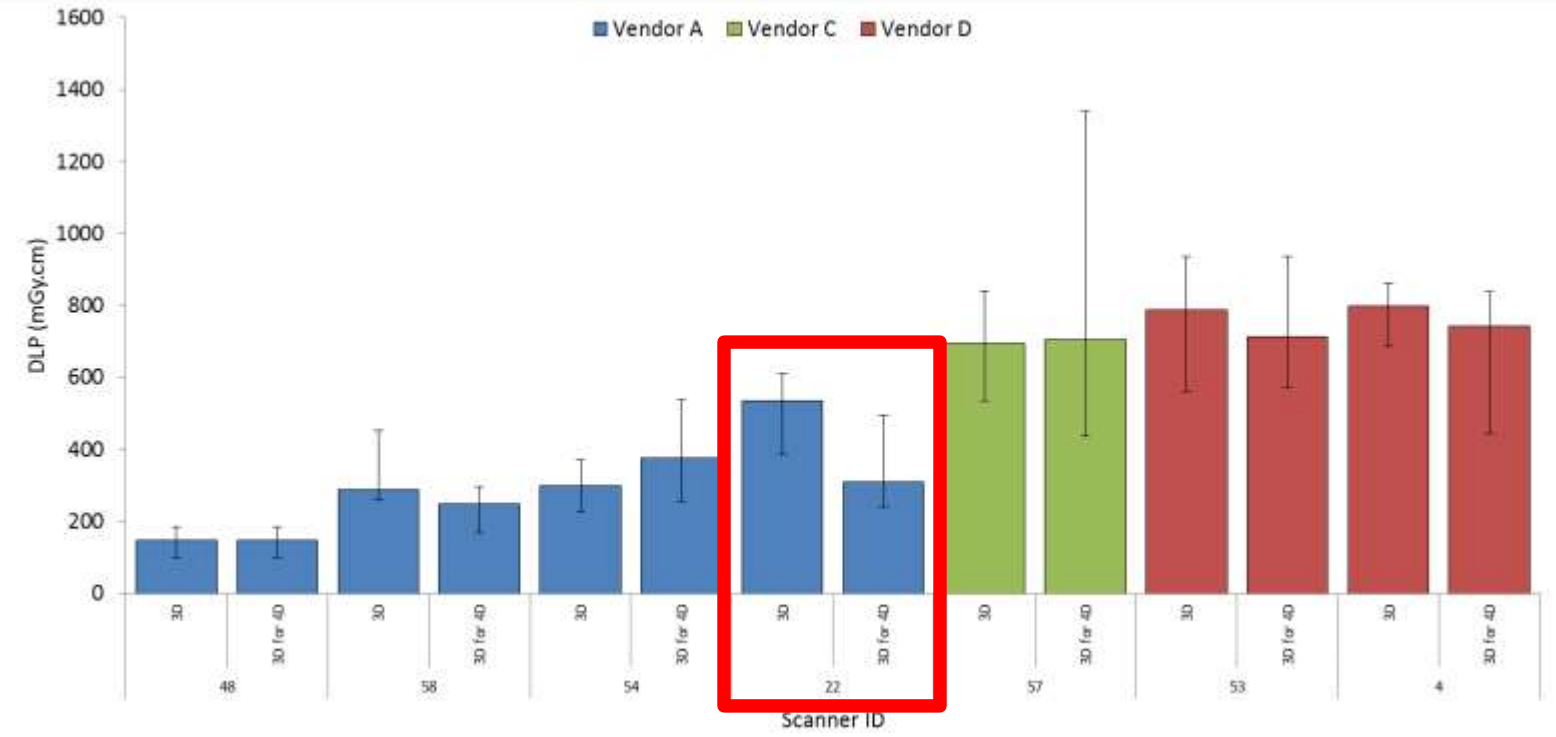
* = max $CTDI_{vol}$ value

Lung 4D – Scan length

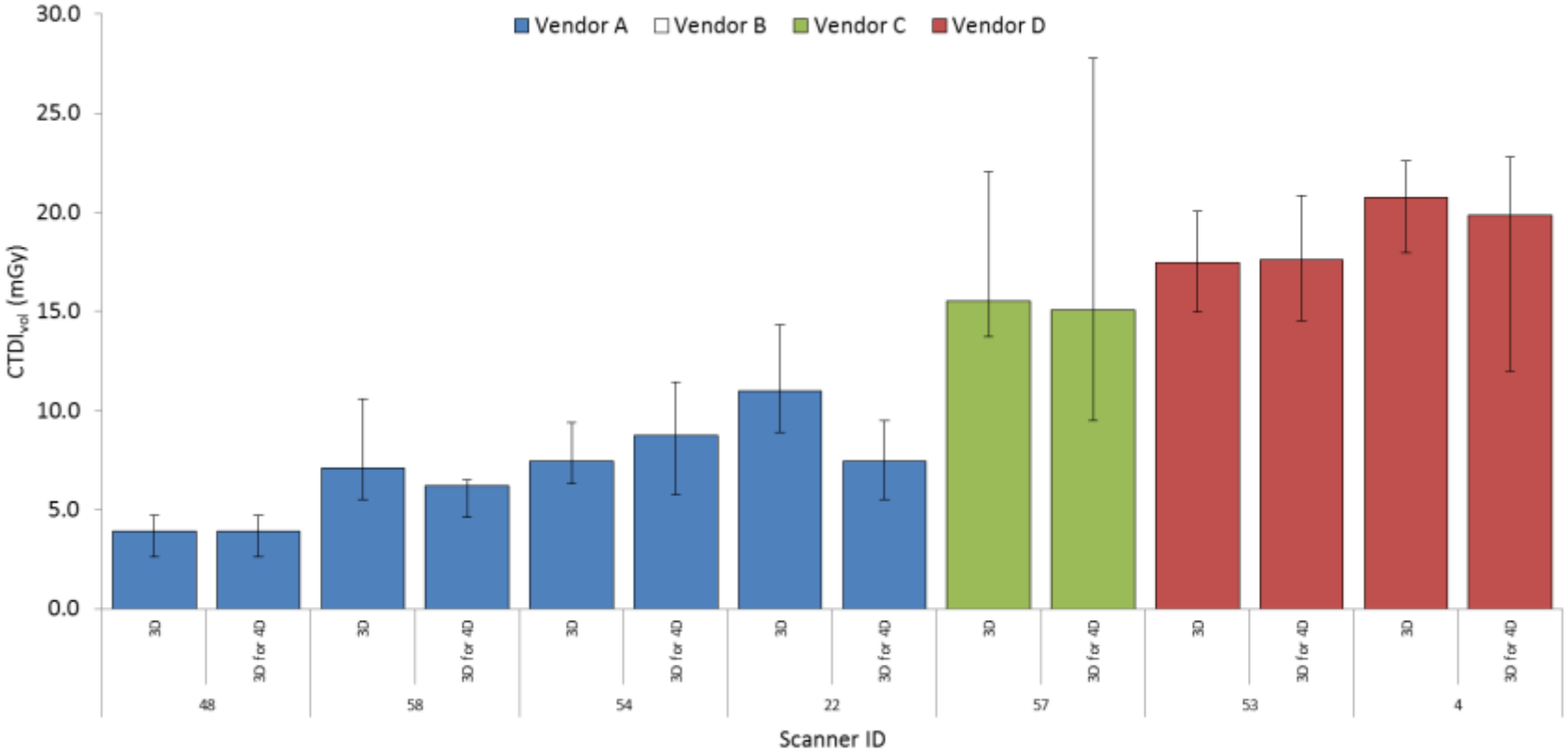


Lung 3D **as part of** 4D

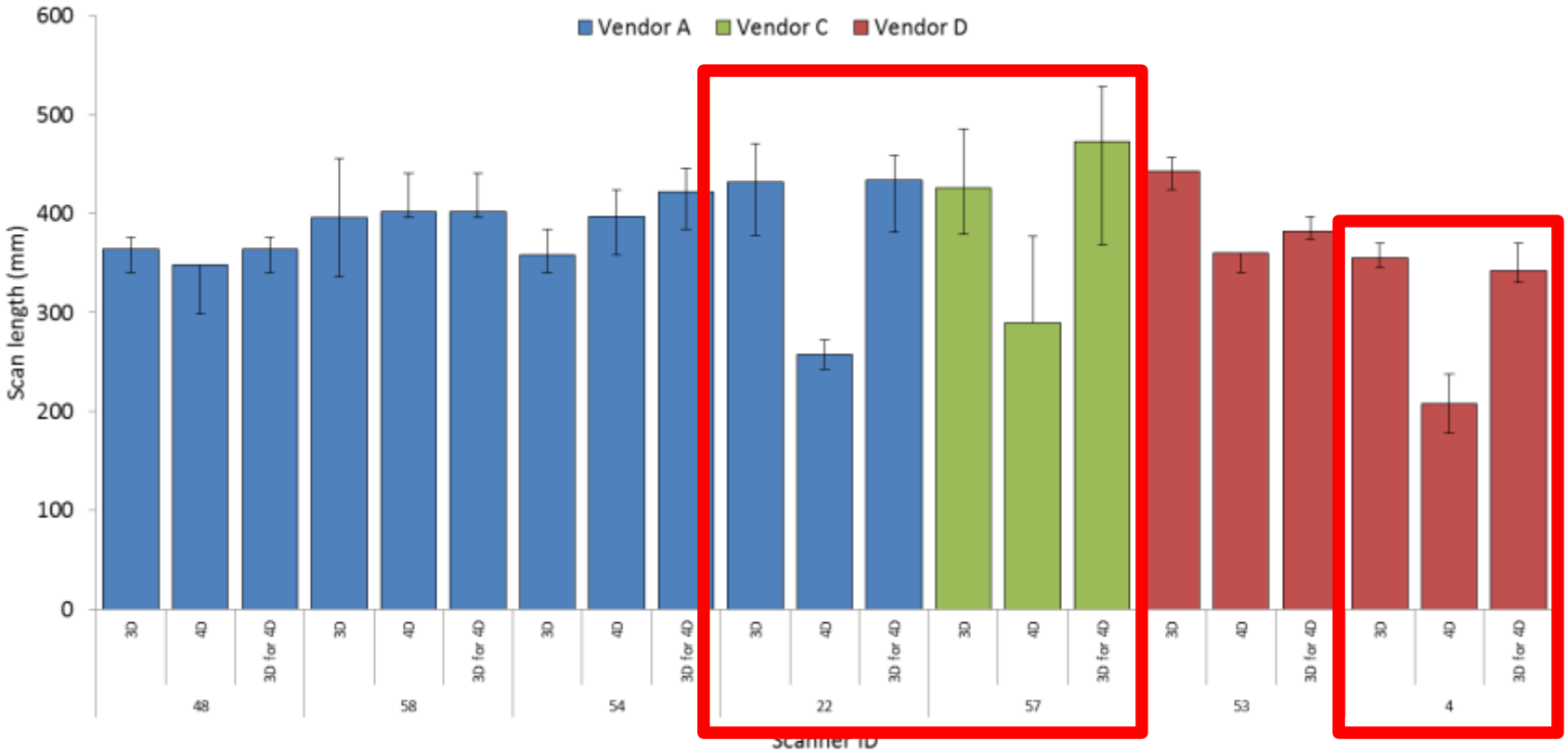
- Some centres are performing exclusive 4D CT imaging
- Some centres perform a 3D scan combined with a 4D scan
  - 7 centres provided enough data on both aspects for a comparison to be made…



Lung 3D **as part of** 4D – $CTDI_{vol}$



Lung 3D **as part of** 4D – scan length



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CT planning scans

Proposed reference doses

CT planning scans

Please note, these values have not yet been finalised, so please use with caution!

However, they are unlikely to change by much (if at all)

The final paper should be used as the definitive values when published

CT Planning scans – $CTDI_{vol}$

Examination	Phantom diameter (cm)	N	$CTDI_{vol}$ (mGy)			
			Median (Achievable)	Third quartile (Reference dose)	Minimum	Maximum
Breast	32	52	7.5	10.4	2.3	20.6
Gynaecological	32	27	13.1	15.2	7.2	30.3
Lung 3D	32	42	9.6	13.8	3.9	24.2
Lung 4D	32	39	35.6	62.9	11.6	194.0
Prostate	32	64	12.9	16.4	7.0	33.8
Brain	16	41	39.8	-	19.1	91.3
	32	11	26.7	-	14.4	45.8
All brain data	16	52	41.6	50.2	19.1	94.4
Head and Neck	16	13	21.5	-	7.8	84.8
	32	39	13.2	-	4.6	69.5
All H&N data	16	52	25.5	49.3	7.8	143.0

CT Planning scans – DLP

Examination	Phantom diameter (cm)	N	DLP (mGy.cm)			
			Median (Achievable)	Third quartile (Reference dose)	Minimum	Maximum
Breast	32	62	283	392	92	763
Gynaecological	32	36	510	612	207	1431
Lung 3D	32	51	410	546	149	996
Lung 4D	32	41	1174	1746	346	6426
Prostate	32	64	419	565	280	1319
Brain	16	41	1043	-	179	2888
	32	11	785	-	102	1336
All brain data	16	52	1107	1499	179	2888
Head and Neck	16	13	990	-	302	3291
	32	39	525	-	166	2470
All H&N data	16	52	1077	2153	302	5088

CT Planning scans – scan length

Examination	Phantom diameter (cm)	N	Scan length (mm)			
			Median (Achievable)	Third quartile (Reference length)	Minimum	Maximum
Breast	32	58	332	361	248	407
Gynaecological	32	33	377	401	303	474
Lung 3D	32	49	367	386	308	454
Lung 4D	32	36	326	340	174	640
Prostate	32	64	305	340	160	523
Brain	16	41	250	-	186	420
	32	11	248	-	214	422
All brain data	16	52	248	290	186	422
Head and Neck	16	13	383	-	312	534
	32	39	400	-	290	585
All H&N data	16	52	398	420	290	585

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CBCT scans

CBCT scans

- Need to consider use of manufacturer defaults/size-specific protocols, lack of 'dose display' on some systems, differences between Varian and Elekta, etc.?
- Currently working on a data collection spreadsheet for CBCT
  - Aim to launch in autumn/winter 2017/18
- The ***provisional*** plan is to give typical doses as **standard** $CTDI_w$ values (i.e. not wide beam dosimetry)
- ***Rationale;***
  - Will give an indication of how the dose is distributed in a phantom (take into account the spectrum)
  - Wide beam dosimetry more 'correct', but also time consuming and prone to errors depending on measurement technique
  - **Easy** to measure with readily available equipment
- ***Limitations;***
  - Values will not be appropriate for estimating patient dose

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Summary

Summary

- The first phase of the IPEM 'Dose to patients from X-ray imaging in Radiotherapy' Working Party is drawing to a close!
- Questionnaire data is in and shows how imaging is used across the majority of UK radiotherapy centres
- CT planning dose audit has now closed, and UK reference quantities ($CTDI_{vol}$, DLP and scan length) have been determined for a range of 'standard' examinations
  - Results indicate **wide variation in practice** across UK
  - An indication that dose quantities tend to have some manufacturer dependence
  - Aim to publish results and detailed analysis by the end of 2017 (or at least submitted to relevant journal)
- Launch **CBCT audit in autumn/winter 2017/18**
  - Data collection spreadsheet still under development

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Thanks to all who have submitted data, and thanks for listening

Any questions?

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