Four-dimensional Digital Tomosynthesis based on Visual Respiratory Guidance

Dong-Su Kim[1,2], Siyong Kim[3] and Tae Suk Suh[1]

[1] Department of Biomedical Engineering & Research Institute of Biomedical Engineering College of Medicine, The Catholic University of Korea, Seoul, Korea

[2] Korea Atomic Energy Research Institute (KAERI), Daejeon, Korea

[3] Department of Radiation Oncology, Virginia Commonwealth University, VA, USA

INTRODUCTION

4D Digital Tomosynthesis (DTS) acquisition methods

Slow gantry rotation

- ✓ Constant frame rate & rotation speed → single scanning motion
- ✓ Shorter acquisition time
- ✓ Easier implementation

Step-and-shoot

- ✓ Acquiring projections at each of fixed locations
- ✓ Regular projection angle intervals in phase bins
- ✓ Difficult to implement

Purpose of this study

Constant (from Machine): Gantry rotation speed & projection frequency

Fundamental

Breathing control with Visual Guiding — Virtually Constant: Period & amplitude in patient's breathing

Slow gantry rotation
<Pros.>
- ✓ Easy to implement

<Cons.>
- ✓ Critical to sort respiratory phase bin correctly (necessary to homogeneous angle distribution)

Techniques

Respiratory guidance
<Pros.>
- ✓ Improving the regularity of breathing motion
- ✓ Enhancement of image quality

Implementation of respiratory-guided 4D DTS based on slow gantry rotation technique

MATERIALS & METHODS

<Slow gantry rotation technique in 4D DTS> [Maurer *et al*, *Med Phys*. 2010]

$$FR_{min} = \frac{100\%}{PW \times RC_0}, \quad AI_{100} = GRS \times \left(1 + \frac{PW}{100}\right) RC_{100}, \quad GRS = \frac{AI_{100}}{\left(1 + \frac{PW}{100}\right) RC_{100}}.$$

$$AT = \frac{SA[deg]}{GRS[deg/s]} = \frac{SA \times RC_{100} \times \left[1 + \frac{PW}{100}\right]}{AI_{100}}, \quad NPA = FR[s^{-1}] \times AT[s] = \frac{100 \times SA \times RC_{100} \times \left[1 + \frac{PW}{100}\right]}{PW \times RC_0 \times AI_{100}}.$$

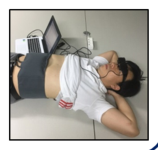
< Projection Acquisition Parameters >

FR	frame rate	from Machine
AI_{100}	maximum angular interval	from Machine
GRS	gantry rotation speed	from Machine
PW	phase windows	from Machine
SA	scan angle	from Machine
RC_0	shortest respiratory cycle	from Patient
RC_{100}	longest respiratory cycle	from Patient
AT	acquisition time	→ Time (shorter)
NPA	number of projection acquired	→ Dose (lower)

Breathing Control by Visual Guiding → Lower $RC_{100}/RC_0 \approx 1$

Guiding system

- ✓ Visual biofeedback for 10 volunteers
- ✓ In-house cuff type air pressure sensor (Kim et al. (1998) *Phys Med Biol.* 63: 055014)
- ✓ Guiding wave form (sine wave)
  - period: 4s / maximum amplitude: ±1 cm



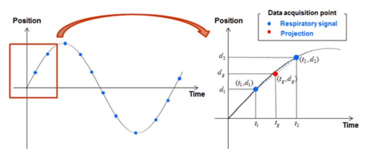


Fig 1. Schematic illustrations of linear interpolation process using relationship between respiratory signal and projection data acquisition frequency.

Scenarios

- ✓ Acquisition DTS images based on …
  - 10 phases sorting
  - (1) The planned breathing data (**SuRB**)
  - (2) The breathing data from volunteers with (**SwG**) or without guidance (**SuFB**)
- ✓ Modified Shepp-Logan phantom (mSL)
- ✓ 4D XCAT phantom (Duke Univ.)
  - 100 kVp, 0.05 mAs per proj / AP, LR / 2cm lesion

DTS Imaging

- ✓ Simulated Varian On-Board Imager®
  - SDD/SID: 150/100 cm / Scan angle: 40 deg
  - Detector: 512 x 384 pixels / 0.776 x 0.776 mm²
  - Voxel: 512x512x320 / 0.5x0.5x0.5 mm³(4D XCAT) 300x300x61 / 0.5x0.5x2.5 mm³ (mSL)
- ✓ FBP with slice-thickness filtering (G Lauritsch et al. (1998) Proc. Of the SPIE conf. 3338: 1127-1137)
- ✓ Image Quality Evaluation: SSIM / NRMSE

RESULTS

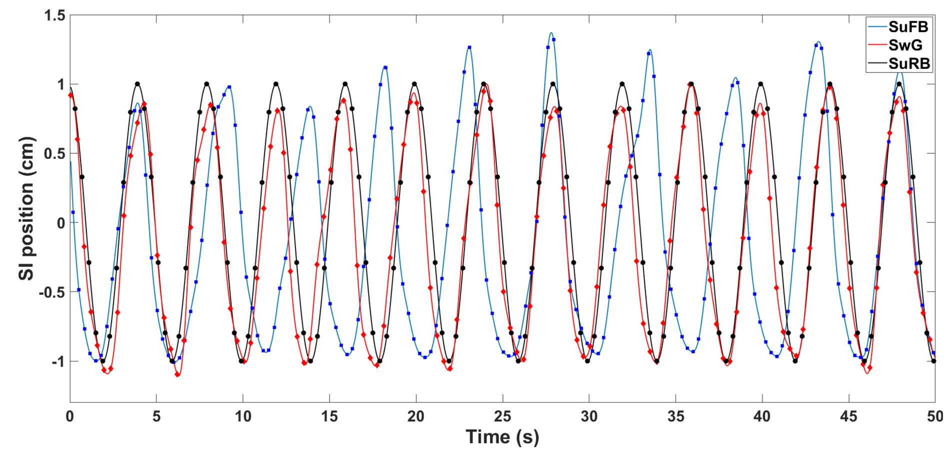


Fig 2. An example of respiratory signals for one of volunteers. Blue, red and black lines indicate SuFB, SwG and SuRB, respectively. Each marker indicates SI position at the time of each projection. Note that the minimum and maximum positions of guiding wave form (i.e., SuRB) are -1 and +1 cm.

Volunteer		RP_{min}(s)	RP_{max}(s)	FR(s)	GRS(deg/s)	AT(s)	NPA	NPA_{SwG}/NPA_{SuFB}
	SuRB	4.00	4.00	2.5	0.77	51.76	129	-
1	SwG	3.60	4.40	2.7	0.71	56.94	153	0.62
	SuFB	3.85	7.60	2.5	0.41	98.35	245	
2	SwG	3.80	4.35	2.6	0.71	56.29	146	0.63
	SuFB	2.25	4.10	4.4	0.75	53.06	233	
3	SwG	3.65	4.20	2.7	0.74	54.35	146	0.85
	SuFB	3.15	4.30	3.1	0.72	55.65	172	
4	SwG	3.55	4.30	2.8	0.72	55.65	155	0.82
	SuFB	4.70	6.95	2.1	0.44	89.94	188	
5	SwG	3.70	4.35	2.7	0.71	56.29	151	0.51
	SuFB	3.00	6.90	3.3	0.45	89.29	294	
6	SwG	3.30	4.60	3.0	0.67	59.53	178	0.89
	SuFB	2.85	4.40	3.5	0.70	56.94	199	
7	SwG	3.75	4.20	2.6	0.74	54.35	141	0.62
	SuFB	3.20	5.70	3.1	0.54	73.76	228	
8	SwG	3.55	4.45	2.8	0.69	57.59	161	0.92
	SuFB	3.45	4.85	2.8	0.64	62.76	175	
9	SwG	3.60	4.35	2.7	0.71	56.29	151	0.47
	SuFB	1.45	3.65	6.8	0.85	47.24	321	
10	SwG	3.60	4.50	2.7	0.69	58.24	157	0.70
	SuFB	2.25	3.95	4.4	0.78	51.12	224	

Abbreviations
RP_{min} = minimum respiratory period, RP_{max} = maximum respiratory period, ***FR*** = frame rate, ***GRS*** = gantry rotation speed, ***AT*** = acquisition time, ***SA*** = scan angle, ***NPA*** = number of projections acquired

Tab 1. Projection acquisition parameters from respiratory signals for each volunteer

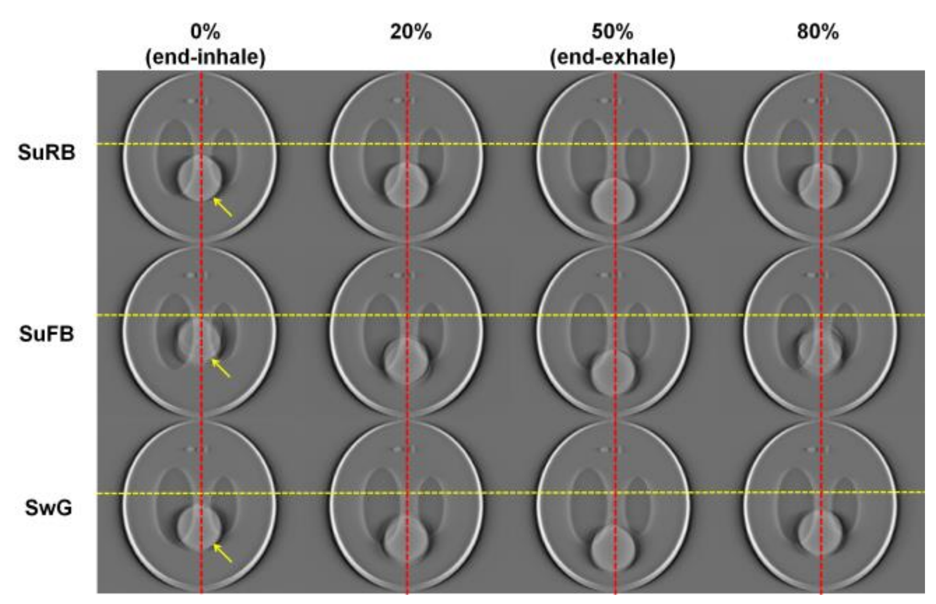


Fig 3. mSL image reconstruction at 0% (end-inhale), 20%, 50% (end-exhale), and 80% for one of volunteers. Note that the mSL consists of a moving part and a static part. Arrows indicate moving sphere according to respiratory signal acquired.

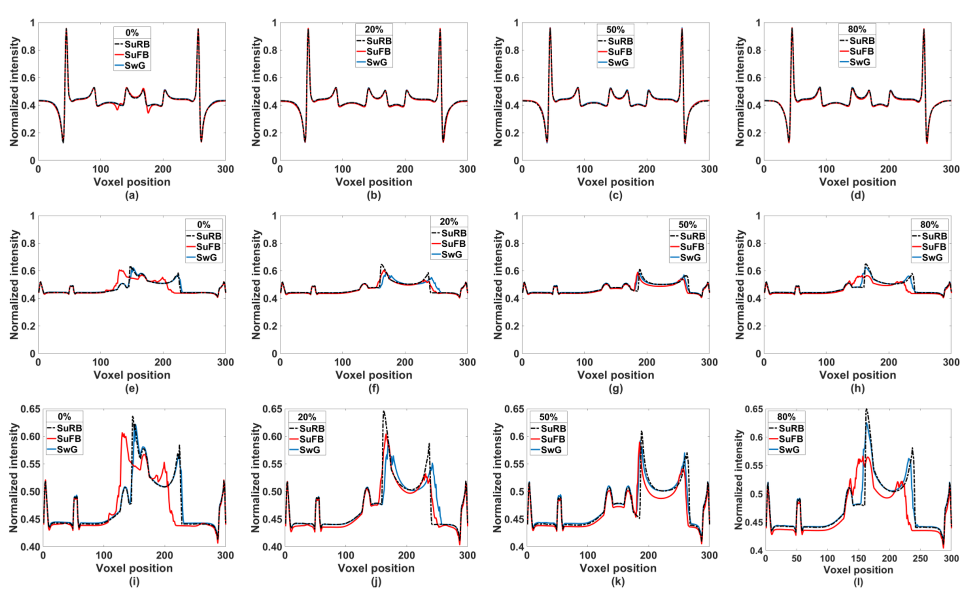


Fig 4. Line profiles for yellow and red dash lines for each phase image in figure 3; (a)-(d) yellow, (e)-(h) red lines at 0%, 20%, 50%, and 80%, and (i)-(l) profiles of rescaled normalized intensity from 0.40 to 0.65 in (e)-(h), respectively.

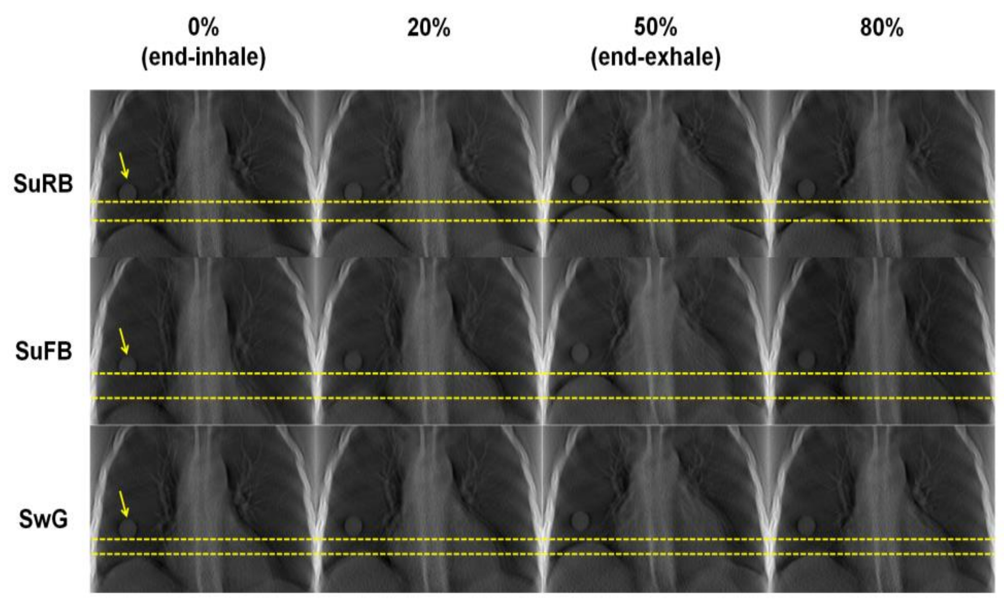


Fig 5. Reconstruction images of AP direction (i.e., coronal) using the 4D XCAT phantom. Yellow dash lines mean the apex of the diaphragm at its lowest and highest. Arrows indicate 2 cm lesion.

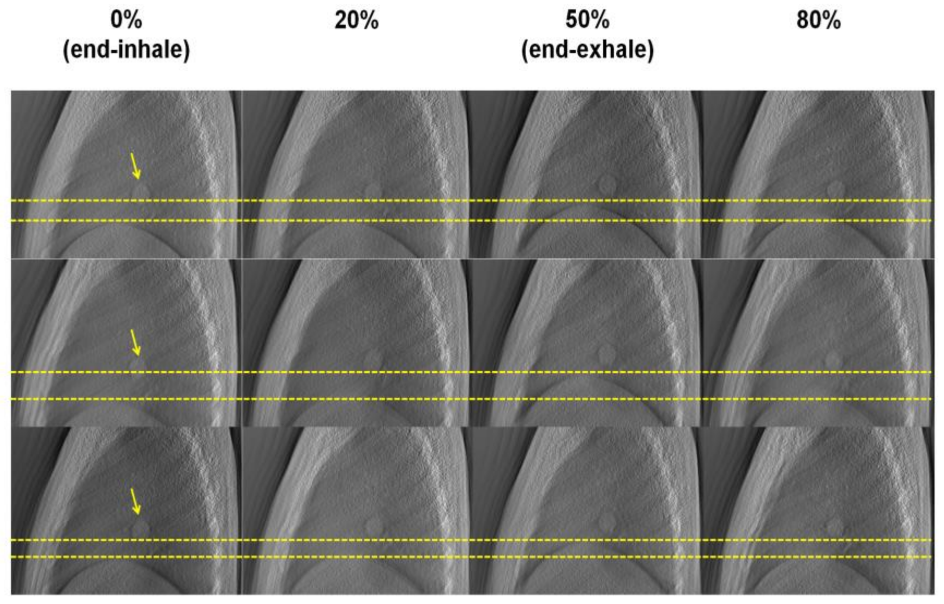


Fig 6. Reconstruction images of LR direction (i.e., sagittal) using the 4D XCAT phantom. Yellow dash lines mean the apex of the diaphragm at its lowest and highest. Arrows indicate 2 cm lesion.

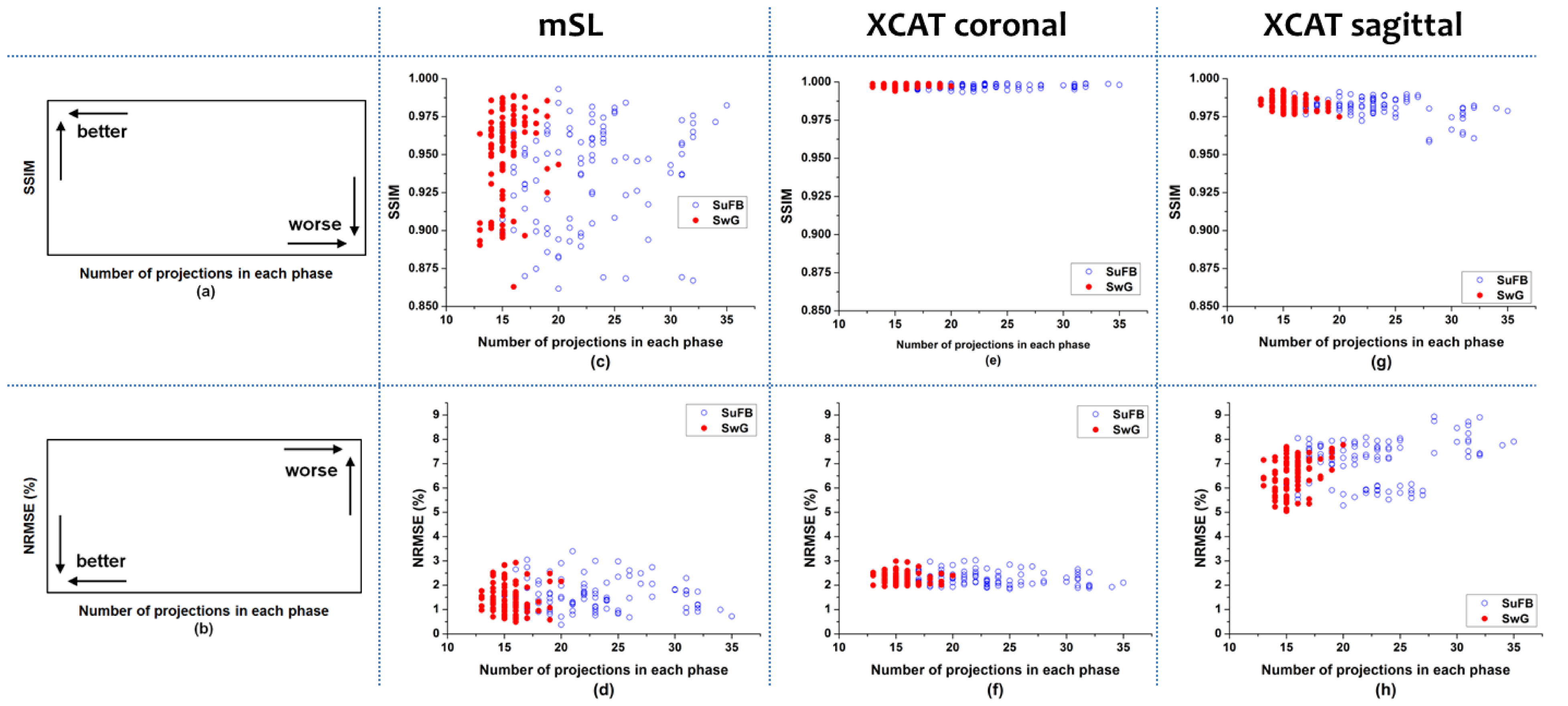


Fig 7. Scatter plots of relationship between the number of projections in each phase with regard to SSIM (left side) and RMSE (right side) values. Note that (a) and (b) are to remind that the closer to the top left for SSIM and to the bottom left for NRMSE, the better the results, respectively. (c)-(d) are for mSL, (e)-(f) coronal XCAT, and (g)-(h) sagittal XCAT.

DISCUSSION & CONCLUSION

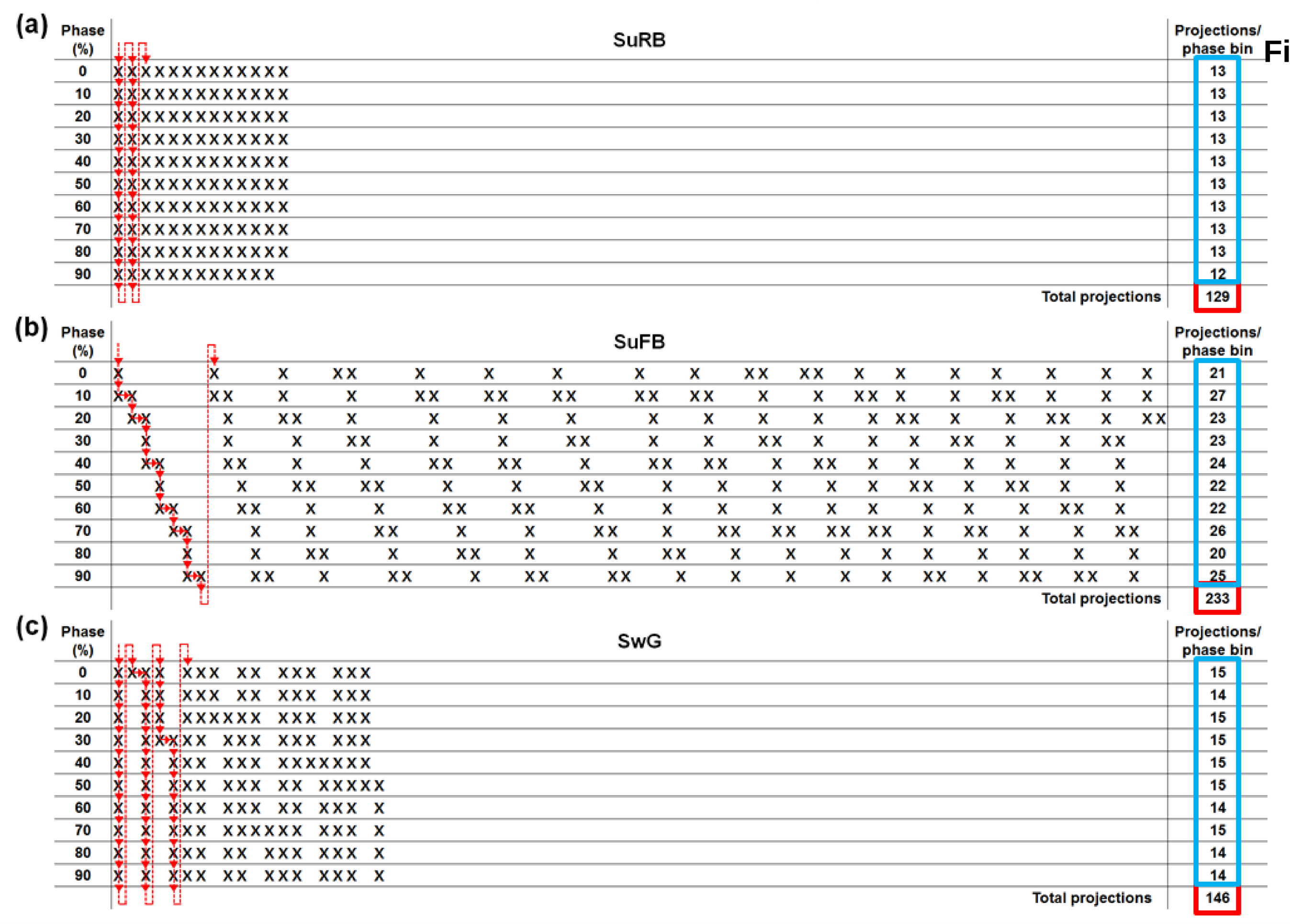


Fig 8. Projection acquisition sequences with regard to phase sorting and acquisition time for one of volunteers; (a) SuRB, (b) SuFB, and (c) SwG, respectively. The red dash lines and arrows indicate the order in which the projections were obtained. The rightmost column shows both projections per each bin and the total..

- ✓ **Introduction to 4D DTS based on respiratory guidance**
- ✓ **A respiratory-guided 4D DTS: improved image quality using lower imaging-dose**

REFERENCES

- Maurer J et al., "Slow gantry rotation acquisition technique for on-board four-dimensional digital tomosynthesis," Med. Phys. 37, 921-33 (2010).

DSK: dsk@catholic.ac.kr / TSS: suhsanta@catholic.ac.kr