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Non-contrast computed tomography versus cinefluoroscopy for the assessment of mechanical prosthetic valve leaflet motion

Ahmed Mohamed Diab
Cardiology Department, Al-Azhar University, Cairo, Egypt
Corresponding author email: m.abdelghani.nl@gmail.com

Mohammad Abdelghani
Cardiology Department, Al-Azhar University, Cairo, Egypt and Cardiology Department, Amsterdam University Medical Center, University of Amsterdam

Mohamed Abdelfattah
Radiology Department, Al-Azhar University, Cairo, Egypt

Hamada Elsheikh
Cardiology Department, Al-Azhar University, Cairo, Egypt

Mohy E. Mansour Elabbady
Cardiology Department, Al-Azhar University, Cairo, Egypt

***Abstract*---**Introduction: valve replacement remains the definitive treatment of most cases with severe valvular heart disease. Mechanical prosthetic valves remain the main option in younger patients. Objective: evaluation of mechanical prosthetic valve function by comparing the feasibility of leaflet motion assessment by cinefluoroscopy vs. CT. Materials and methods: Leaflet motion was assessed in 30 bileaflet mechanical prostheses (21 mitral and 9 aortic) by cinefluoroscopy and non-contrast CT. Assessment was considered feasible when the 'in profile' projection (with the radiographic beam parallel to both the valve ring plane and the tilting axis of discs) could be achieved. Results: Overall feasibility of fluoroscopic assessment was 74% (mitral, 66% vs. aortic, 93%; p=0.071), while feasibility of CT assessment was 100% (p=0.003). Among prostheses with unfeasible fluoroscopic assessment, CT suggested an extreme C-arm angulation to achieve the "in profile" projection (RAO: 76.0±5.8°, LAO: 122.7±32.5°, CRA: 51.4±16.0°, CAU: 57.0±18.2°). Among prostheses with feasible assessment by both techniques, fluoroscopy and CT yielded similar opening and closing angles (intraclass correlation coefficient, 0.959 - 0.998) with lower irradiation with CT as compared

with fluoroscopy (26.2[21.1-29.3] vs. 289[179-358] mGy, p<0.001). While CT scan took 8.7±0.5 seconds, fluoroscopy required 2.64±1.56 minutes to achieve and record the “in profile” projection. Conclusions: Non-contrast CT provides a higher feasibility and a quicker evaluation of mechanical prosthetic valve leaflet motion with less irradiation than fluoroscopy, suggesting that CT scan can serve as a first line tool for leaflet motion evaluation after echocardiography.

***Keywords*---**Prosthetic valve, computed tomography, fluoroscopy, motion, leaflet motion.

Introduction

Valve replacement remains the definitive treatment of most cases with severe valvular heart disease. To date, about four million prosthetic valve replacements have been performed, and the annual number of valve replacements is projected to reach 850 000 per year by 2050(Lancellotti et al., 2016).While many older patients requiring valve replacement are offered bioprosthetic heart valves, mechanical prosthetic valves (MPVs) remain the main option in younger patients. Prosthetic valve dysfunction is a serious -potentially- life-threatening condition, that often requires multimodality imaging for proper evaluation (Lancellotti et al., 2016).

While echocardiography is the primary tool to evaluate prosthetic valve hemodynamics, assessment of MPV leaflet motion is an echocardiographic challenge; limited by the special probe angulation required to display the leaflets in many cases and the acoustic shadowing by prosthetic material(Lancellotti et al., 2016). Indeed, transthoracic echocardiography can accurately capture MPV leaflet motion in 77% of mitral prostheses and only 13-40% of aortic prostheses (Muratori et al., 2006).

Fluoroscopy is an easy and readily available technique for evaluating MPV leaflet mobility and is particularly superior to echocardiography in the aortic position (Muratori et al., 2013). However, proper fluoroscopic evaluation of MPV (in a plane where X-ray beam is parallel to both the valve ring and the tilting axis of the leaflets) is influenced by the in-situ orientation of the prosthesis. Achieving this ideal projection can be time-consuming requiring more irradiation and is frequently difficult considering limitation of C-arm motion and patient’s physical characteristics, and-in some patients -the appropriate assessment of leaflet motion is not feasible (Montorsi et al., 1996).

More recently, cardiac computed tomography (CT) has been shown to provide incremental information on valve mobility (Habets et al., 2011), with a similar (Suchá et al., 2014) or higher (Symersky, Budde, de Mol, & Prokop, 2009) sensitivity than fluoroscopy in detecting leaflet motion restriction. Unlike fluoroscopy (where the imaging plane is dependent on the in-situ orientation of the prosthesis), CT images can be reconstructed in any imaginary cross-sectional plane, and -like fluoroscopy- the dynamic assessment of radiopaque MPVs does not require contrast.

We sought to compare the feasibility, time-consumption, and radiation exposure of non-contrast CT as compared with cinefluoroscopy in the assessment of MPV leaflet motion.

Materials and Methods

The study included 30 patients with bileaflet MPV (30 valves; 21 mitral, and 9 aortic) presenting to the echocardiography unit of Al-Husain Hospital, Al-Azhar University, Cairo, Egypt between August 2021and February 2022.Exclusion criteria included pregnancy and extreme obesity. Data collection was approved by the local ethics committee and conforms to the Declaration of Helsinki. The data underlying this article will be shared on reasonable request to the corresponding author.

All patients were subjected to systematic evaluation of the MPV by echocardiography, cinefluoroscopy, and computed tomography. As recommended by practice guidelines, prosthetic valve leaflet motion was assessed in the 'in profile' or "tilting disk" projection; defined as the projection with the radiographic beam parallel to both the valve ring plane and the tilting axis of discs(Lancellotti et al., 2016). While practice guidelines(Lancellotti et al., 2016) describe two different (complementary rather than equal) methods of leaflet motion angle measurement on cinefluoroscopy vs. CT (the angle between discs in the fully open and closed positions for the former; and leaflet angles relative to the plane of the orifice ring for the latter), we applied both methods to both techniques to facilitate comparison.

Cinefluoroscopy: With the patient in the supine position, cinefluoroscopy using an Allura Xper FD 10/10 (Philips Medical Systems, Best, The Netherlands) machine was used to view the MPV in the postero-anterior and lateral projections to identify the 'in situ' orientation of the valve. Afterwards, deliberate lateral and cranio-caudal angulations were utilized to view the MPV in the 'in profile' projection (Lancellotti et al., 2016). Evaluation was considered feasible when the "in profile" projection could be obtained allowing accurate calculation of the opening angle (OA) and the closing angle (CA). Short cine loops (3−10 beats) at 15-30 frames/s were recorded. OA and CA were defined as the angle between discs in the fully open and closed positions, respectively. Additionally (similar to standard CT measurements), opening and closure angles relative to the plane of the prosthetic valve ring were measured for each leaflet individually (Lancellotti et al., 2016) (Figure 1).The time from start of the first fluoroscopic run to the end of the final cine loop was considered the "acquisition time".

Computed tomography: In the absence of contraindications, patients with a heart rate > 65 beats/min received an oral bolus of a beta-blocker one hour before the examination. CT scans were performed with 160 multidetector CT scanner (Aquilion PRIME, Toshiba Medical Systems, Ohtawara, Japan). Non-contrast, retrospective ECG-triggered scans were acquired at a slice thickness of 0.5 mm and images were reconstructed at 10% increments of the RR-interval through the full cardiac cycle. Images were analyzed offline on a dedicated workstation using multiplanar reformatting in cine mode. Imaging planes were set to obtain the "in

profile" view allowing measurement of the opening and closing angles (similar to those measured on cinefluoroscopy).

Prediction of the fluoroscopic "in profile" view was conducted on Synapse Workstation (FUJIFILM Medical Systems USA, Inc., Stamford, CT), and fluoroscopic C-arm angulation was considered out of practical range if lateral (RAO/LAO) angle was >120° or craniocaudal angle was >45°. Transthoracic echocardiography: Comprehensive TTE evaluation was performed using commercially available equipment (iE33 system, Philips Medical Systems, Andover, MA, USA; and Vivid E95, GE Healthcare, Horten, Norway). Color Doppler was used for evaluating intra and/or paraprosthetic regurgitation. Doppler parameters included: peak transprosthetic velocity, transprosthetic velocity time integral, peak and mean transprosthetic gradient, Doppler velocity index, pressure half time (in mitral position), and ejection time (in aortic position)(Lancellotti et al., 2016).

Statistical methods: Statistical analysis was performed using SPSS v. 26.0 (SPSS Inc., Chicago, Illinois, USA). Continuous variables were summarized as mean±SD, while categorical variables were summarized as frequency and percentage. A p-value <0.05 was considered significant. The relationship between leaflet motion angles measured by fluoroscopy and CT was evaluated by the two-way mixed intraclass correlation coefficient (ICC; presented with its 95% confidence interval; CI). Paired numerical data were compared using paired t-test (or Wilcoxon signed-rank test), while paired nominal data were compared using McNemar's test.

Results

The study included 30 bileaflet MPVs (21 mitral and 9 aortic) from 30 patients. Table 1 summarizes the clinical and echocardiographic data of the study population.

Feasibility of fluoroscopic assessment of MPV leaflet motion:
Feasibility of fluoroscopic assessment (i.e., the "in profile" view) was lower in mitral (66%) than in aortic prostheses (93%; p=0.071). The "in profile" view of the mitral prosthesis was most often (74%) achieved in RAO/CRA projection (average: 46.4°/27.9°). On the other hand, the "in profile" view of aortic prostheses was achieved with similar frequency in LAO/CRA (39%), RAO/CRA (31%), and RAO/CAU (31%). No prosthesis was best visualized in the LAO/CAU projections.
Among MPVs with unfeasible fluoroscopic assessment, CT suggested an extreme C-arm projection in all cases (RAO: 76.0±5.8°, LAO: 122.7±32.5°, CRA: 51.4±16.0°, CAU: 57.0±18.2°).

Comparison of fluoroscopic vs. CT assessment of MPV leaflet motion:
Fluoroscopy and CT data are summarized in Table 2. CT could provide an analyzable "in profile" view of all prostheses (100% vs. 74.4% for fluoroscopy, p=0.003). Among MPVs with feasible assessment by both techniques, fluoroscopy and CT yielded similar opening and closing angles (Tables 3 and 4). However, radiation exposure was significantly lower with CT than with fluoroscopy (26.2[21.1-29.3] vs. 289[179-358] mGy, Wilcoxon signed-rank test p<0.001).

While CT scan took 8.7±0.5 seconds, fluoroscopic acquisition required 2.64±1.56 minutes to achieve and record the optimal “in profile” projection.

Discussions

The assessment of MPV function is based on echocardiography, but adequate assessment of leaflet motion is limited by acoustic shadowing. Cinefluoroscopy has been considered the standard method to assess leaflet motion, while CT is considered as an alternative option. In the present study we compared fluoroscopy and CT for MPV leaflet motion assessment and found that: 1) achieving an “in profile” view of the prosthesis was feasible in 74% of cases by fluoroscopy and 100% by CT, 2) feasibility of fluoroscopic assessment was higher in aortic than in mitral position, 3) in prosthesis with feasible assessment by both techniques, fluoroscopy and CT yielded similar measurements, but CT scans required shorter time and lower irradiation for acquisition.

Cinefluoroscopy and CT in MPV leaflet motion assessment; what we know and what this study adds:
Fluoroscopy is an easy and readily available non-invasive technique for evaluating MPV, providing a more reliable evaluation of leaflet mobility-especially in the aortic position- than echocardiography (Cianciulli et al., 2005; Muratori et al., 2013). Leaflet motion should be viewed in the ‘in profile’ projection, allowing calculation of opening and closing angles (Lancellotti et al., 2016). Due to variability in surgical prosthesis orientation, deliberate use of lateral and cranio-caudal angulation is often required to achieve such a projection. Montorsi et al.(Montorsi et al., 1996) evaluated the influence of different intraoperative valve orientation on feasibility of fluoroscopic evaluation of bileaflet MPVs (in mitral, aortic, and tricuspid positions). In prostheses oriented perpendicular to the ventricular septum, the prosthesis' "in profile" projection was rapidly (15 +/- 5 seconds) achieved in all patients. In prostheses oriented parallel to the ventricular septum, a proper fluoroscopic evaluation was impossible to obtain in40%-95%of patients. In the remaining prostheses (with intermediate orientations), extremely angulated, uneasy projection was often required to achieve an appropriate fluoroscopic image.

Acknowledging these challenges of fluoroscopy, cardiac CT emerged as a tool that can provide incremental information on valvular mobility with very good image quality for most bileaflet MPVs(Habets et al., 2011). In an in vitro pulsatile model, CT yielded similar closing angle measurements as fluoroscopy(Suchá et al., 2014). In pilot clinical studies, it was suggested that CT may have an even higher sensitivity than fluoroscopy in detecting leaflet motion restriction(Symersky et al., 2009).Unlike on fluoroscopy (where the imaging plane is dependent on the in-situ orientation of the prosthesis), CT images can be reconstructed in any imaginary cross-sectional plane, making the desired “in profile” view achievable in virtually all scenarios.

In the present study, we found that achieving an ideal “in profile” view on fluoroscopy is challenging, especially in mitral prostheses. Although most mitral prostheses were optimally visualized in an RAO/CRA projection, the exact angulation was variable, and several mitral prostheses were better visualized in

other C-arm quadrants (than RAO/CRA). This leads to a relatively prolonged session, with “trial-and-error” strategy until the desired view is reached, and eventually a significant incremental irradiation exposure. Moreover, an “in profile” view was impossible to achieve in one third of mitral prostheses. Feasibility of fluoroscopic assessment of aortic prostheses was much better, requiring less acquisition trials and -eventually- less irradiation. However, the overall feasibility of achieving an “in profile” view on fluoroscopy was 74% and CT prediction of the fluoroscopic projection confirmed that achieving such a projection would require an extreme C-arm angulation.

Like fluoroscopy, CT scan required no contrast, and -superior to fluoroscopy- the scan was consistently short with predictable relatively small irradiation exposure, yielding a reliable measurement in 100% of cases (as opposed to the above mentioned 74%). These findings collectively suggest that CT scan is a more robust tool to assess MPV leaflet motion, and that it can serve as a first line tool after echocardiographic assessment. The advantages of CT over fluoroscopy are more relevant when a quicker scan is required, a lower irradiation is imperative (such as during pregnancy), and in mitral position. CT also seems to be a more suitable tool -than fluoroscopy- for serial and follow up assessments. Notwithstanding, CT is not without limitations. Availability -although much improved- remains an issue, and heart rate control and respiratory training remain prerequisites to improve image quality.

Conclusions

Non-contrast CT provides a higher feasibility and a quicker evaluation of mechanical prosthetic valve leaflet motion with less irradiation than fluoroscopy, suggesting that CT scan can serve as a first line tool for leaflet motion evaluation after initial echocardiographic assessment.

Acknowledgements: Nil

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Tables

Table (I): Clinical and echocardiographic data

	Mitral Prostheses (n=21)	Aortic Prostheses (n=9)
Age (yr)	47.6±7.9	44.1±9.3
Female	18 (62.1%)	8 (57.1%)
Weight (kg)	79.9±11.4	83.6±15.9
Body mass index	30.0±6.5	30.1±7.6
Body surface area (m^2)	1.91±0.14	1.97±0.17
Atrial fibrillation	15 (51.7%)	6 (42.9%)
Echocardiography data	(n=20)	(n=8)
Vmax (m/s)	1.75±0.36	3.0±0.9
Mean PG (mmHg)	5.6±2.1	22.9±14.6
Peak PG (mmHg)	12.8±5.0	38.2±22.9
EOA (cm^2)	2.1±0.9	1.66±1.04
Presentation	**Number**	**Percentage**
Dyspnea	25	62.5%
Cough	20	50%
Fever	15	37%
Hoarseness of voice	12	30%
Hemoptysis	12	30%
Pain	10	25%
Weight loss	9	22.5%
Pressure manifestation	5	12%
Asymptomatic [incidentally discovered]	1	2.5%

Data presented as mean ± SD or frequency (%).

Table (II) Fluoroscopy and computed tomography data

	Mitral Prostheses (n=21)	Aortic Prostheses (n=9)
Fluoroscopy feasible*	19 (65.5%)	13 (92.9%)
Fluoroscopic projection:		
RAO/CRA	14 (73.7%)	4 (30.8%)
RAO/CAU	2 (10.5%)	4 (30.8%)
LAO/CRA	3 (15.8%)	5 (38.5%)
LAO/CAU	-	-
Fluoroscopy data	(n=11)	(n=8)
Opening angle	17.2±5.5	18.9±8.4
1st. Occluder angle	81.5±2.8	80.7±4.1
2nd. Occluder angle	81.2±3.0	80.6±4.1
Closing angle	132.4±3.3	125.5±5.5
1st. Occluder angle	23.6±2.1	26.4±3.3
2nd. Occluder angle	23.8±1.9	27.0±2.7
Radiation dose (mGy)	509±600	293±180
Acquisition time** (min)	3.0±1.8	2.1±1.0

Computed tomography data	(n=21)	(n=9)
Opening angle	20.6±12.0	19.7±8.6
1st. Occluder angle	78.9±10.1	80.3±4.3
2nd. Occluder angle	78.8±8.4	80.2±4.3
Closing angle	131.4±4.2	126.1±5.9
1st. Occluder angle	23.8±2.1	26.3±3.4
2nd. Occluder angle	24.4±3.2	27.1±2.6
Radiation dose (mGy)	25.1±4.5	24.9±4.4
Acquisition time (s)	8.7±0.5	8.9±0.5

*p=0.071, **p=0.068

Table (III): Comparison between fluoroscopic (Fl) and CT data in 19 valves with paired data

	Fluoroscopy	CT	Difference, median (IQR)	p-value*
Opening angle (OA)°	17.9±6.8	18.3±6.8	0.10 (-0.2-0.2)	0.325
1st Occluder angle OA°	81.2±3.4	81.0±3.3	0.00 (-0.20-0.10)	0.395
2nd Occluder angle OA°	80.9±3.4	80.7±3.5	0.10 (-0.18-0.20)	0.390
Closing angle (CA)°	129.6±5.4	129.6±5.5	-0.10 (-0.28-0.10)	0.883
1st Occluder angle CA°	24.7±2.9	24.8±3.0	0.00 (-0.10-0.28)	0.345
2nd Occluder angle CA°	25.1±2.7	25.2±2.8	0.00 (-0.28-0.28)	0.450

*Paired sample t-test

Table (IV): Intraclass correlation (ICC) coefficient of disk motion assessment by fluoroscopy (Fl) and CT in 19 valves with paired data

	ICC Coefficient*	95% Confidence Interval	
		Lower bound	Upper bound
Opening angle (OA)	0.972	0.944	0.986
1st. Occluder angle OA	0.959	0.916	0.980
2nd. Occluder angle OA	0.960	0.918	0.980
Closing angle (CA)	0.998	0.996	0.999
1st. Occluder angle CA	0.998	0.995	0.999
2nd. Occluder angle CA	0.981	0.962	0.991

*p-value for all<0.001

FIGURE LEGENDS

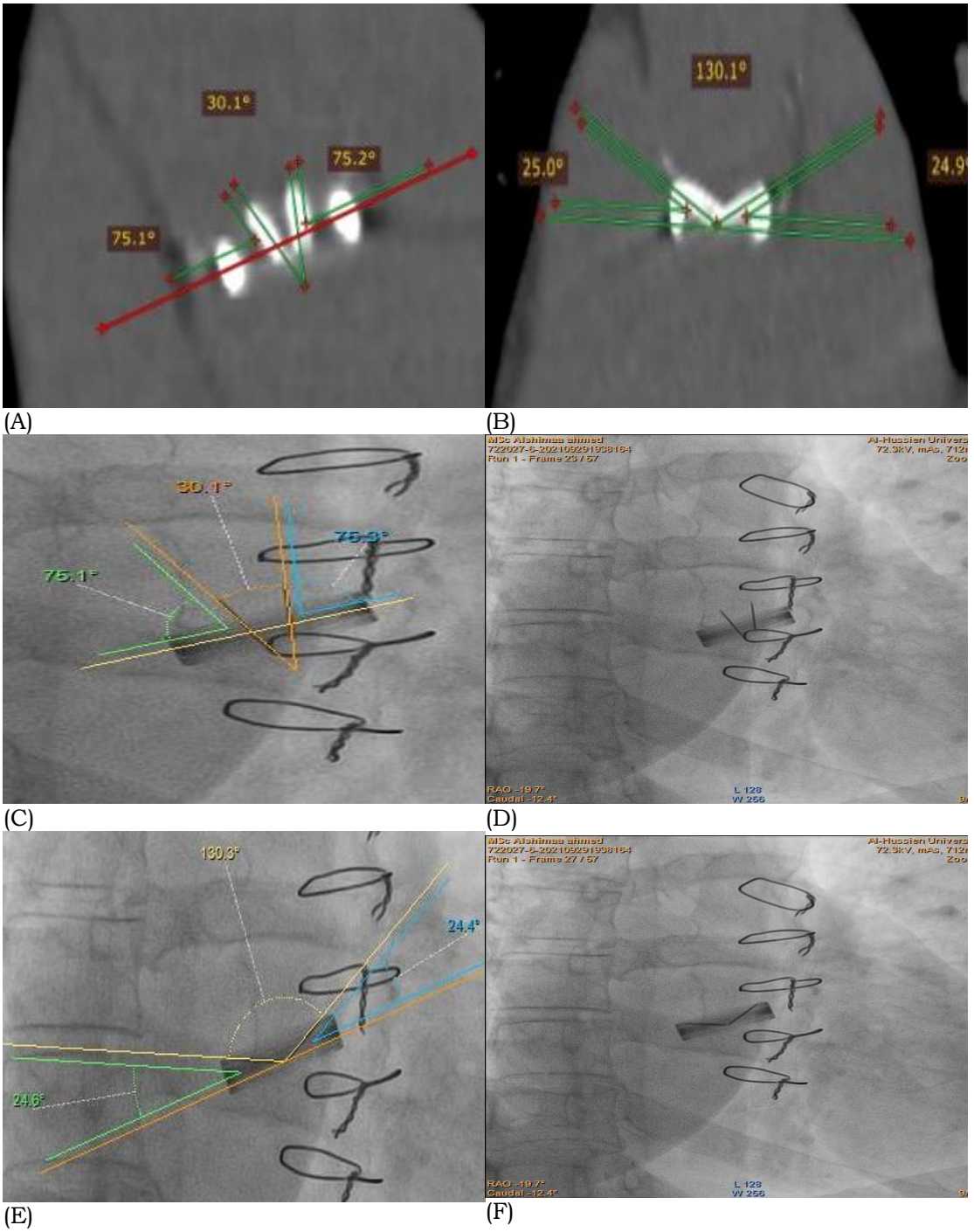
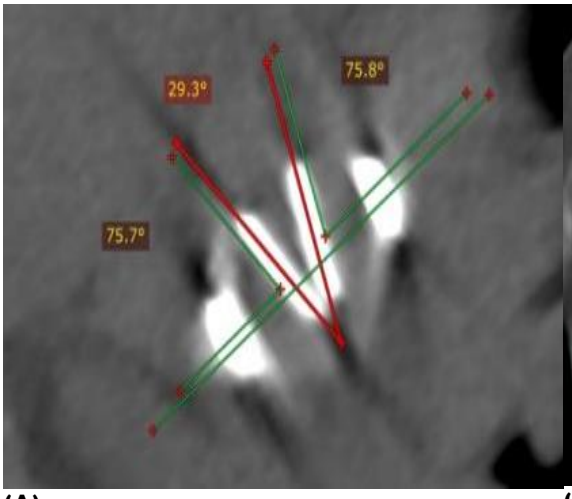
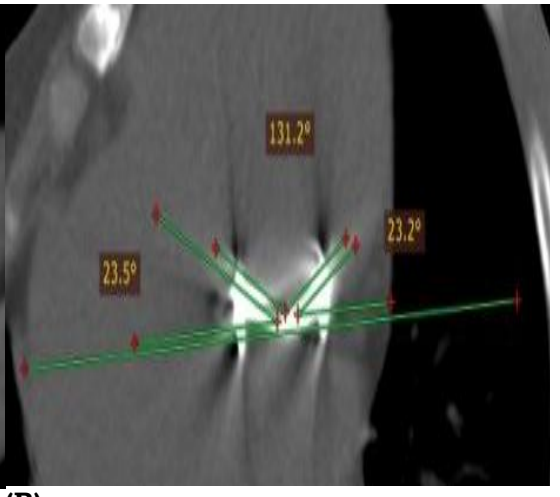


Figure (I): (A, B) CT measurement of prosthetic aortic valve for a selected study case (Opening angle (OA)°, 1st Occluder angle OA° and 2nd Occluder angle OA° (Lt. panel). Closing angle (CA) °, 1st [7] angle CA° and 2nd Occluder angle CA° (Rt.

Panel). (C, D) Fluoroscopic measurement of prosthetic aortic valve for a selected study case, Opening angle (OA)°,1st Occluder angle OA° and 2nd Occluder angle OA° (Lt. panel). (E, F) Fluoroscopic measurement of prosthetic aortic valve for a selected study case, Closing angle (CA) °,1st Occluder angle CA° and 2nd Occluder angle CA° (Rt. Panel).



(A)



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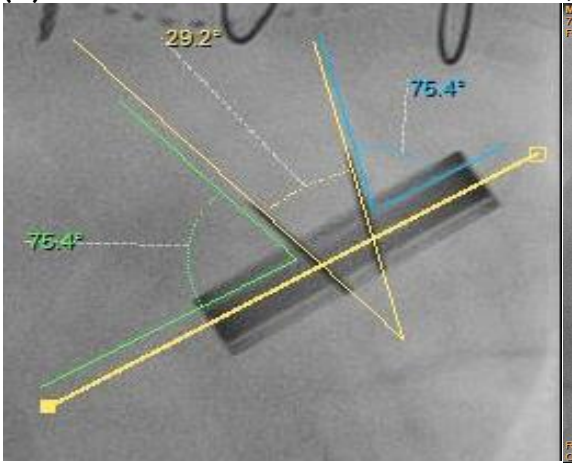
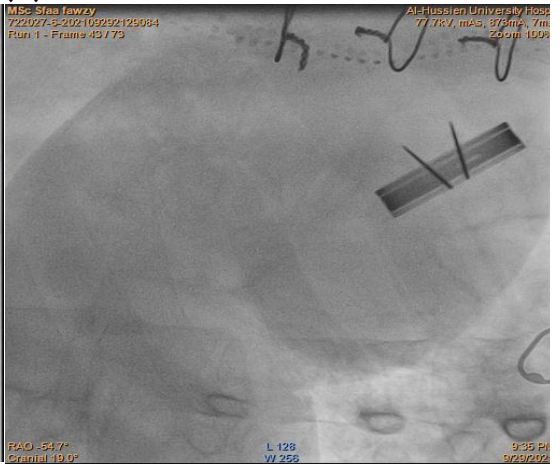


(C)



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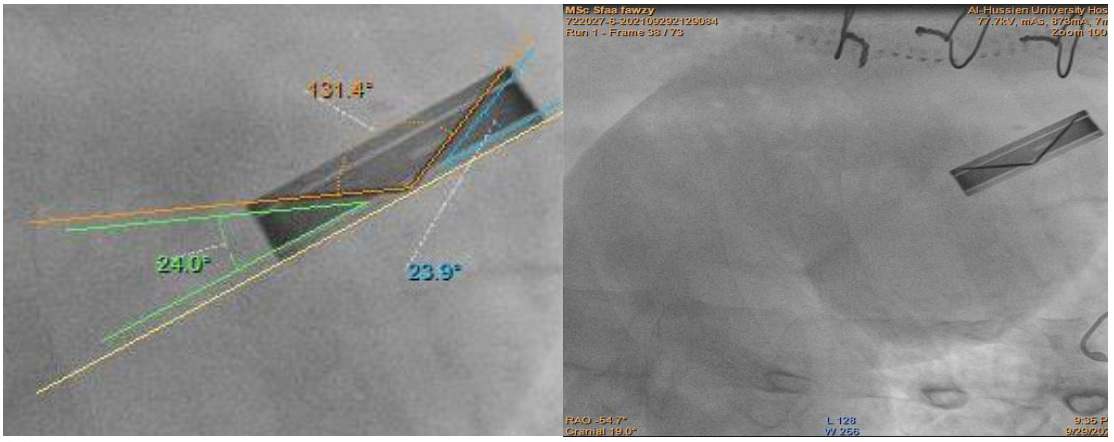

(E) (F)

Figure (II): (A, B) CT measurement of prosthetic mitral valve for a selected study case opening angle (OA)°,1st Occluder angle OA° and 2nd Occluder angle OA° (Lt. panel). Closing angle (CA) °,1st Occluder angle CA° and 2nd Occluder angle CA° (Rt. Panel). (C, D) Fluoroscopic measurement of prosthetic mitral valve for a selected study case, Opening angle (OA)°, 1st Occluder angle OA° and 2nd Occluder angle OA° (Lt. panel). (E, F) Fluoroscopic measurement of prosthetic mitral valve for a selected study case, Closing angle (CA) °, 1st Occluder angle CA° and 2nd Occluder angle CA° (Rt. Panel).