Ejection Fraction Evaluation With FAC: How reliable it is?

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Abstract

Evaluation of ejection fraction (EF) is one of the core arts in both quick ultrasound exam of the heart (FATE, POCUS, etc.) and comprehensive cardiological ultrasound study. There are many methods of qualitative and quantitative assessment of EF and this paper is focused on application of the Fractional Area Change (FAC) method. In a study based on comparative analysis of Teichholz/FC method and FAC method, it is demonstrated that the FAC measurement and calculation needs to be revised in light of the new results. Also, it enables application of FAC method in improvised POCUS heart exam with a convex probe in absence of cardiological measuring and calculations software.

1. INTRODUCTION

This study was inspired by common necessity of getting the best possible results with limited resources: using software poor-equipped ultrasound machines during POCUS (Point-Od-Care-UltraSound) exams in such a way to compensate their technical limitations. For over a decade I am engaged as a sonographer both in my private medical office and in other medical facilities. I am using various probes and software options on a daily base, in order to perform not just "quick" POCUS exams, but also "comprehensive" specialized echosonography studies, such as detailed echocardiography, breast exam, carotid Doppler, abdominal ultrasound etc. During all that time I have developed particular interest in comparing some procedures and finding ways to get certain insight and result in the easiest and fastest way.

This means: if there is a complex procedure or calculation that is required to give us some information about certain anatomical or dynamic function of an organ, lets try making it simpler or using other ways to get to the same goal. Of course, being "innovative" in the area with enormous literature and online resources is rather hard and risky - frequently it ends up with "inventing" something that already exists. Or creating something that "hair-splitters" immediately "put on a cross" as an "unnecessary simplification". (Some radiologists and cardiologists in particular have highly critical stand regarding the entire POCUS concept, calling it "overrated gadgetry" or "laymen playful pretending"...)

As an example of how the POCUS can be usefully performed even without "default" hardware and software, I like to mention the ejection fraction (EF), one of the core information gained through both FOCUS and FATE (FOCUS=Focused Ultrasound, quick partial exam; FATE=Focused assessed transthoracic echocardiography, meaning the same: quick ultrasound evaluation of heart) and "comprehensive" cardiological echocardiography (a.k.a. "Study").

EF is defined as the percentage of blood ejected during systole out of all the blood volume that was present in the left ventricle prior to the systole. (Note: There is also right ventricle EF, and most of the things said for the left ventricle EF, or LVEF, also apply to RVEF; however, this paper is focused on the LVEF). It is perceptual relation between the so called end-dyastolic volume of the left chamber (EDV) and the stroke volume (SV) of the heart. EF is calculated with next formula: EF= (SV/EDV) x 100

There are several "normal" ranges of satisfying EF, and I like to use the one where normal EF is 65% plus/minus 10. Reduced EF means reduced systolic function. The less EF is, the worst are the symptoms of heart failure. It can be easily concluded that EF is a numerical evaluation of cardiac insufficiency. We all know the New York Heart Association NYHA stages of heart insufficiency - the four grades that closely correlate with the EF. And the EF can be also described in four levels: normal (above 55%), mildly decreased (~40-55%), moderately decreased (~30-40%) and severely decreased (under 30%).

There are several ways of measuring EF. We use them accordingly to the equipment we have, or depending on the needs we have. If we use ultrasound just to get the basic info about the condition of the heart, we might be satisfied with "eyeballing" and simple qualitative description of EF (EF good, mildly reduced, etc.). This rough estimation of the LV contractility is frequently sufficient for physician in the ER, ICU or in a GP office. However, quantitative evaluation of EF is frequently proffered, and there are several main methods of calculation:

1. Modified Simpson method - measuring LV volumes
2. Modified Quinones method - linear measurements
3. Teichholz formula based on LV diameter (including Fractional Shortening method, FS)
4. E-point septal separation (EPSS) method
5. Mitral annual plane systolic excursion (MAPSE) method
6. Fractional Areal Change (FAC)
7. Volumetric calculations with MRI

Description of all these methods goes beyond the aims of this paper and is available in numerous other resources. Some of it is a part of the Family Medicine POCUS Curriculum, designed by the International POCUS Organization, IPO, to which I belong. In my regular work I mostly use either a quick qualitative POCUS/FATE method combined with EPSS and MAPSE evaluation, or quantitative Teichholz /FS method based on measuring the internal diameter of LV, the EDD (end-dyastolic diameter) and the ESD (end-systolic diameter). I usually work on Toshiba PowerVision 6000 and Nemio platforms, or on GE Vivid and Logic systems. All of them have cardyological software with measuring and calculations based on fore mentioned formulas.

I have rarely tried the Fractional Area Change (FAC) method until recently, and it came out that this method is surprisingly underrated. This is particularly visible once we try to apply FAC in improvised conditions, such as using the curvilinear probe (convex or "abdominal" probe) and using it not only in standard parasternal short axis position (PSAX), but also in modified subxyphoid position.

Now, before I move on to description of the FAC method and the conclusions I came to, I must once more explain why would we "improvise" with non-cardiac probes in POCUS/FOCUS/FATE.

Most of the currently available handheld (portable) ultrasound systems do not offer full set of specialised measurements. Frequently there are no such options like automatic calculation of EF. Some recent AI-based machines calculate EF according to EPSS, (eg. Clarius wireless probes), but mostly manufacturers of handheld systems claim that POCUS is "not a comprehensive exam" and therefore eyeballing and qualitative evaluation of myocardial function should be sufficient. I tend to disagree with both parts of this position: first, POCUS is NOT necessarily a "quick focused exam", it is simply as it says: Point-Of-Care Ultrasound. So, if one has the time, knowledge and equipment to perform a full comprehensive ultrasound exam at the bedside, it is also POCUS. Secondly, simple eyeballing and qualitative evaluation of LV contractility may be sufficient if we are in a hurry, or when there are obstacles to additionally calculate the EF. But The FAC (as it will be described in the remaining of the paper) is rather quick and easy procedure and requires very basic ultrasound equipment and software.

In addition to portable systems with relatively poor measurements and calculations software (including all of them: Butterfly, V-Scan, Philips Lumify, EagleView, Clarius etc.), there is another problem which pushes us to "improvise" as POCUS diagnosticians. Being POCUS instructor who runs workshops in various public medical facilities, I have realized that phased-array probes (sector probes used for echocardiography) are often missing from the most of the departments except cardiology. So, what is available to colleagues are convex ("abdominal") probes and linear probes, with standard measuring and calculating software lacking LV study options.

Special POCUS curriculum that I have designed for GP/FM/ER/ICU physicians is strongly based on these premises:

1. POCUS in primary health care settings shall be performed most often either with a handheld probe or with convex or linear probe, in absence of cardiological probe and software.

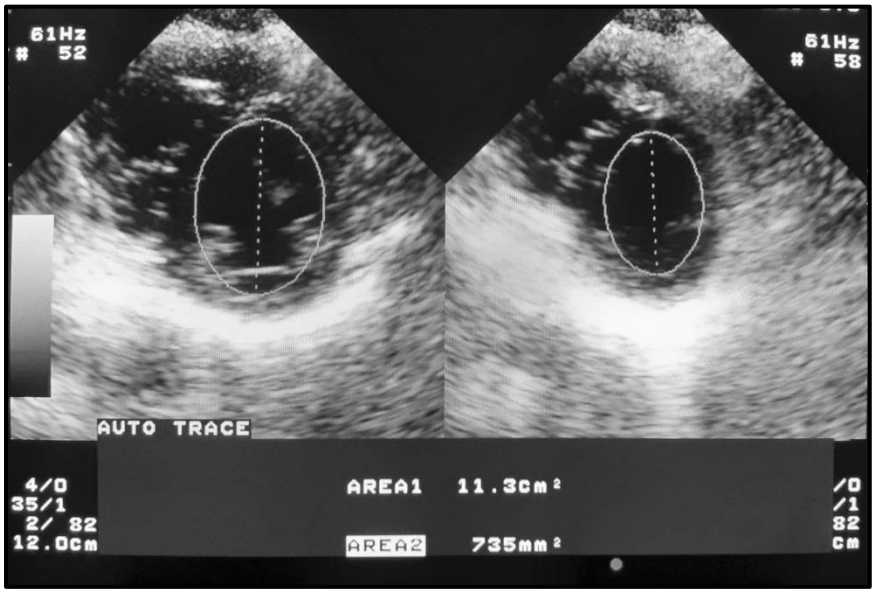
2. There will be only basic common options available to sonographer:

- B-mode grayscale imaging
- Classical measurements: distance, volume, area
- M-mode with distance measurement
- Color Doppler (CD) and Pulse Wave Doppler (PW), allowing measuring of Vmax (PSV) and resistance index.

3. Interpretation of POCUS findings in context of clinical exam will enable physician to draw correct conclusions even with less information from ultrasound scaning.

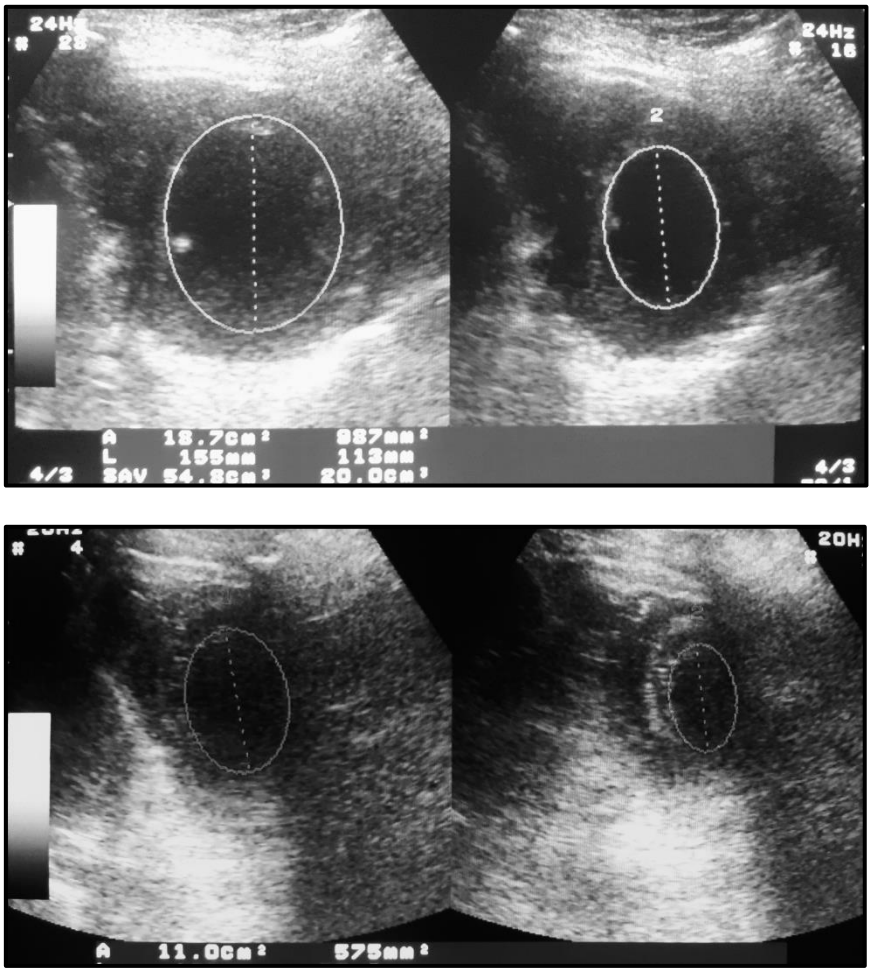
Having all this in mind, I tried to apply FAC method using convex probe.

Fractional area changes (FAC) is difference between transverse section of LV during systole and diastole. Using simple area tool, available in practically any B-mode preset, we can measure end-diastolic area (EDA) of LV, and end-systolic area (ESA). Measuring is done in standard parasternal short axis position (PSAX), at the level of papillary muscles.



Picture 1: PLAX LV transverse section, EDA and ESA

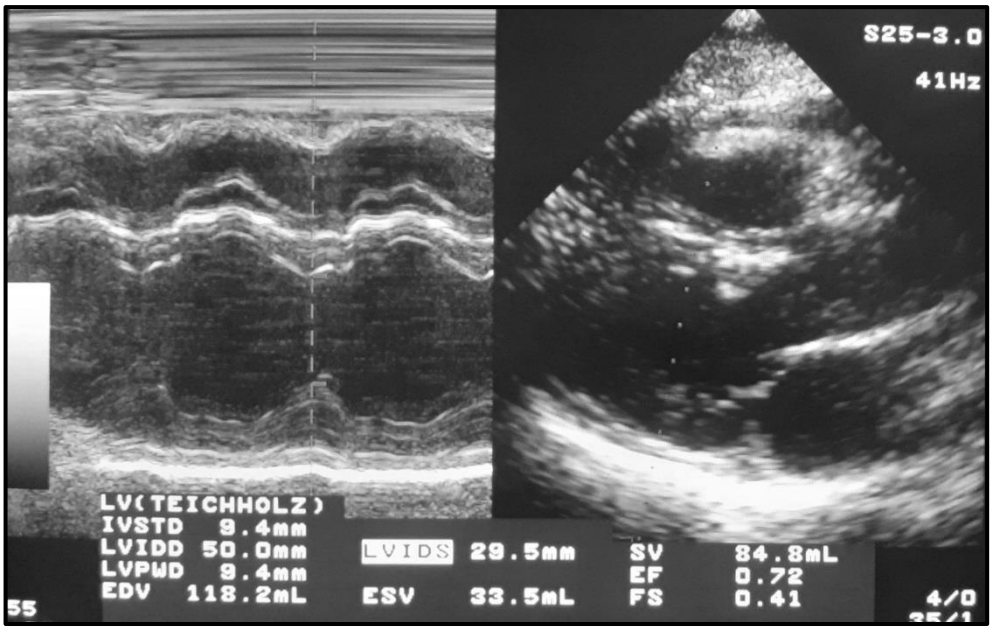
It can be also done in other transverse sections of LV, and one of them corellating to PLAX is modified subxyphoid position:



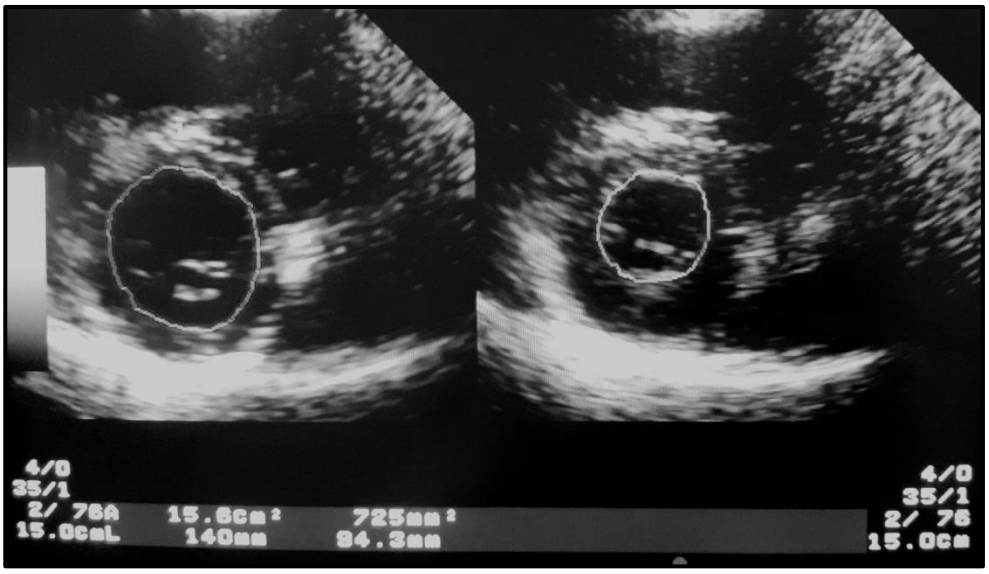
Picture 2 and 3: Same heart, FAC from PLAX and subxyphoid position:
Relation of EDA/ESA is almost the same, at around 47%

FAC is calculated by following formula:

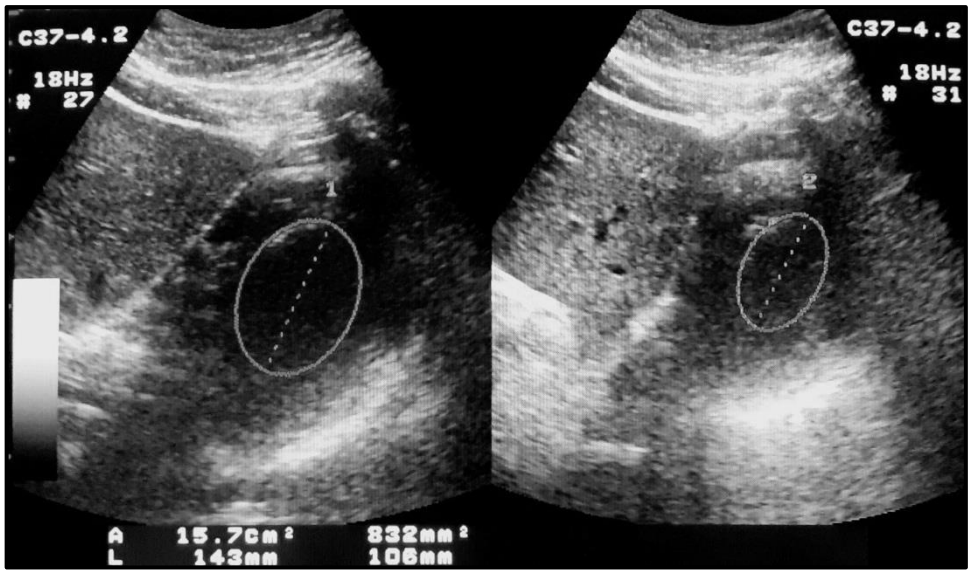
FAC = (EDA - ESA)/EDA



Picture 4: LV in PLAX position, standard EF calculation with Teichholz/FS method.
EF for this patient is 72%



Picture 5: LV in PSAX position, measuring EDA and ESA
Please note: This is the same patient's heart from previous image. Using EDD and standard formula, we get the value of 17,7cm². Also, using ESD and standard formula, we get the value of 6,6cm². Obviously, these values differ from the measured values (15,6cm² and 7,2cm²). Using PLAX calculated values we get the FAC of 63%. Using PSAX measured values we get FAC of 53%. It is significant difference.



Picture 6: Same heart, EDA and ESA measured in modified subxyphoid position. According to these values, FAC is 47%. This new FAC is even more different from the PLAX-calculated FAC. So, what is the real EF? What is the correct relation of FAC and EF? And where and how to measure EDA and ESA in order to calculate FAC?

FAC	Ejection Fraction
60%	75%
50%	66%
40%	54%
30%	42%
20%	29%
10%	15%

Picture 7: Recommended relationship between FAC and EF available in literature

Goals of this study are, therefore:

1) to check the accuracy of relationship between EF and FAC.
2) to check if convex probe and areal measurments of LV in subxyphoid position can be used in the evaluation of EF

2. METHOD

I used the reports from my clinic, which contained echocardiography results, including EF calculated by the Teichholz/FS method. This method is based on foollowing formula:

$$FS=(EDD-ESD)/EDD$$
$$EF\sim 2FS$$

All patients whose reports were included in the study were examed on Toshiba PowerVision 6000 platform with authomatic software for EF calculation. In one of my previous papers I have demonstrated on a series of measurments that the more precise relation of FS and EF can be presented with following formula:

$$EF=0,9x2FS$$

This correction is not included in this study, because I used authomaticaly generated results from Toshiba ultrasound platform.

It is demonstrated by further calculations that the FAC/EF relation is DIFFERENT from what is currently proposed in available resources. Using all EDD and ESD values for each patient, I calculated the FAC by the standard formula. From their EDD and ESD I calculated EDA and ESA first, using formula:

$$EDA=3,14x(0,5xEDD)^2 \quad \text{and} \quad ESA=3,14x(0,5xESD)^2$$

Results are given in the separate table.

In the second phase, I performed exams on 10 new patients: first with a sector-probe and Teichholz/FS calculation, and then with a convex probe and FAC method. Results confirm that current recommended correlation between FAC and EF should be revised.

3. RESULTS

From the archive of patients I randomly selected 30 reports with performed "comprehensive" echocardiography and measured EDD, ESD and EF. Calculation of EF is done by Toshiba PowerVision 9000 software, according to Teichholz/FS formula. From measured EDD and ESD I calculated EDA and ESA. Using these values, I calculated the FAC for each of the previously measured EF. Here are the results (FAC is given in rounded numbers):

	EDD	ESD	**EF**	EDA	ESA	**FAC**
1	48	28	71	18,0	6,15	66
2	54	30	76	22,89	7,06	69
3	51	36	53	20,41	10,17	50
4	60	37	68	28,26	10,75	62
5	49	26	79	18,84	5,31	72
6	45	31	56	15,89	7,54	52
7	71	55	45	39,57	23,75	40
8	64	44	59	32,15	15,20	53
9	61	45	52	29,21	15,89	46
10	52	38	51	21,22	11,33	47
11	67	50	50	35,24	19,62	44
12	58	50	30	26,41	19,62	26
13	76	64	33	45,34	32,15	29
14	67	58	30	35,24	26,41	25
15	62	50	41	30,17	19,62	35
16	70	52	49	38,46	21,22	45
17	52	40	46	21,22	12,56	41
18	59	46	42	27,32	16,61	39
19	56	44	39	24,62	15,20	38
20	48	29	70	18,08	6,60	63
21	64	56	26	32,15	24,62	23
22	56	36	64	24,62	10,17	59
23	67	49	51	35,24	18,84	46
24	65	57	24	33,17	25,50	23
25	80	61	46	50,24	29,21	42
26	76	59	43	45,34	27,32	40
27	70	53	44	38,46	22,05	43
28	48	31	64	18,08	7,54	58
29	41	23	76	13,19	4,15	68
30	51	38	48	20,41	11,33	44

Table 1: Calculation of FAC from previously measured EDD and ESD

In order to better analyze accuired data, I listed all EF/FAC results from smaller to largest:

FAC	EF	+
23	24	1
23	26	3
25	30	5
26	30	4
29	33	4
35	39	4
38	41	3
39	42	3
40	43	4
40	44	4
41	45	4
42	46	4
43	46	3
44	48	4
44	49	5
45	50	5
46	51	5
46	51	5
47	52	5
50	53	7
52	56	4
53	59	6
58	64	6
59	64	5
62	68	6
63	70	7
66	71	5
68	76	8
69	76	7
72	79	7

Table 2: EF and FAC values on the same patients and the correction numbers

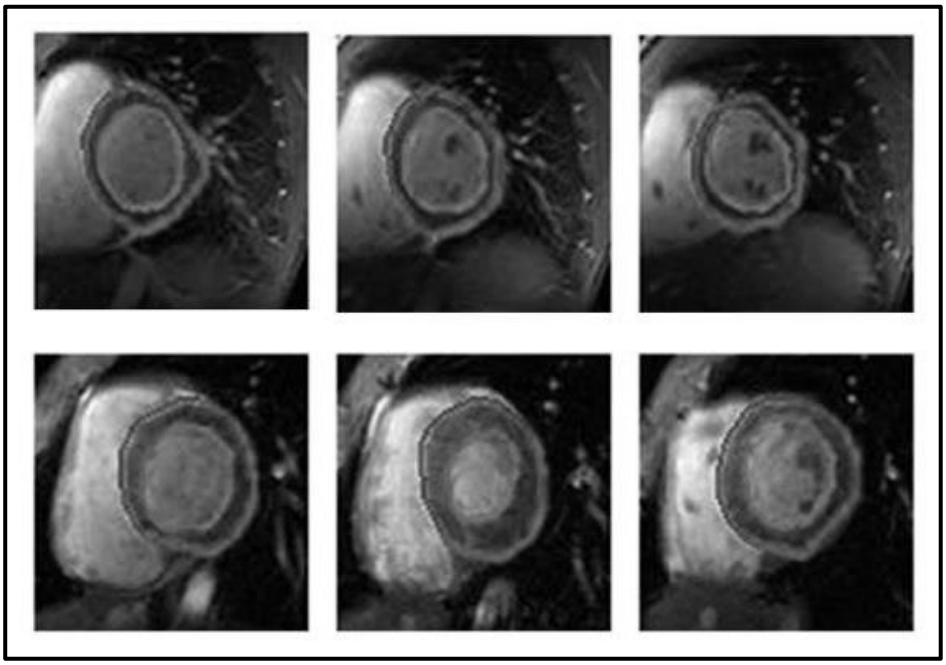
I examed 10 patients first with a sector probe (and used the softvare to calculate EF), then I examed same patients with convex probe and calculated their EF through FAC (EDA and ESA). Here are the results:

Sector probe, EF from PLAX			Convex probe, FAC from subxyphoid view		
EDD	**ESD**	**EF**	**EDA**	**ESA**	**FAC**
46	29	66	14,5	5,6	61
53	33	67	15,5	6,4	59
52	31	70	22,1	10,5	52
44	26	71	18,7	9,9	47
56	36	64	21,8	12,2	44
61	52	36	28,2	19,4	31
76	60	30	46,6	27,1	42
51	29	73	16,4	8,2	50
67	53	40	34,2	21,5	37
54	33	75	22,0	7,3	66

Table 3: Comparation of EF calculated from PLAX position and Teichholz/FS formula measured by sector probe, and FAC calculated from EDA and ESA measurment by convex probe in subxyphoid position

4. DISCUSSION

Calculation of EDA and ESA from EDD and ESD by using simple formula for circle surface πr^2 is based on a presumption that the PLAX measured EDD and ESD are exact/correct diameters of the LV, where LV is presumed to be perfectly cylindrical. However, this is not the case. Since transverse section of LV is not a perfect circle, EDD and ESD measured in PLAX position may significantly differ from real diameters. Let's see this on a transverse section of LV acquired from MRI of the heart:



Picture 8: MRI automatc segmentation of the short axis LV, the blue contour is epicardium, and the red contour is the endocardium.

It is obvious that position/angle of the probe greatly affects measurement of EDD and ESD. Not to mention that EDD and ESD may significantly depend on the contractility of the particular portion of septal or posterior wall. If we measure EDD in M-mode in a such maner that we "cut" through a hypokinetic part of previously inflicted myocard, we shall get the smallest movements of the wall, smaller the difference between EDD and ESD, and eventually, smaller EF. Same goes for measurements of EDA and ESA. We must find the portion of the LV where we have the biggest difference between EDA and ESA. Only in this way we shall have exact representative FAC and representative clinically valuable EF.

If we calculate FAC from EDD and ESD by simple transforming them into EDA and ESA, what we get is is a series of numbers that are rather similar to corresponding EF values. This is obvious in Tables 1 and 2. Seems that the lesser is the EF, smaller is the difference between EF and FAC.

From Table 2 one can even conclude that following (approximate) correction should be made to FAC in order to get an approximate EF:

Approximate FAC	Average correction	Approximate EF
< 20	no correction	<20
20-55	+ 5	25-60 (±2)
55-65	+ 6	60-70 (±2)
65-70	+ 7	70-80 (±2)
> 70	no correction	>80 (±5)

Table 4: Suggested corrections to determine an approximate EF from FAC

Obviously, this table is significantly different from numbers corruently propesed (see Picture 7)

But if we look at the figures in the Table 3, things get a bit complicated. Something is wrong, because FAC even corrected as suggested in Table 3 do not give expected and correct EF. And we must presume that the EF values in the Table 3 are correct, because these are result of well established Teichholz/FS formula. So where is the error? Once more, "Errare human um est!". Or, to be precise: be careful and find proper section of the LV. Ask your patient to take a deap breath, so that the heart and LV get lower as the diaphragm goes down. And in that moment, just rotate a bit your probe and you will get that modified subxyphoid view, useful for LV transverse section area measurement. Even with convex probe.

So, to answer that question from the introduction: YES, convex probe and areal measurement of LV in subxyphoid position can be used in the evaluation of EF. The EDA/EDS ratio is pretty mach the same, no matter if it's measured with a convex probe in subxyphoid position, or with a sector probe in PSAX position. And it is all about that ratio. It is all about finding the section where this EDA/EDS ratio is the biggest. It often means repeated measurements in several planes. In addition, just a quick observation of MAPSE (should be above 10mm) and EPSS (should be under 8mm), and we already know that the EF must be somewhere at around 55% or above. And that means that the ratio between EDA and EDS should be approximately 2:1 or higher. (See Table 1).

5. CONCLUSION

FAC is a solid tool for approximate quantitative evaluation of EF. It should be used in combination with MAPSE and EPSS. It can be calculated from EDA and ESA by a simple formula, and these two values can be relatively easy obtained even with a convex probe in a modified subxyphoid position. Roughly estimation is that when MAPSE is above 10 mm, EPSS is above 8 mm and ratio between EDA and ESA is at least 2:1, the EF shall be normal, at 55% or higher. More precise evaluation of EF can be done by correction of FAC as given in the Table 4 od this study. Current recommended relation between FAC and EF is in certain aspects similar to our results, but this new method offers more accurate determination of EF.

6. References

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